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Alternative Power: The Politics of Denmark's Renewable Energy Transition

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ALTERNATIVE POWER:
THE POLITICS OF DENMARK'S RENEWABLE ENERGY TRANSITION

A Dissertation Presented

by

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ABSTRACT

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Global climate change is one of the defining political challenges and opportunities of the current era. Experts widely agree that technical means already exist for making the necessary transition from fossil fuels to renewable energy; the obstacles to doing so are primarily political. Careful observers also recognize that this period of transition creates an opening for political innovation and development. How can the political will be generated to take action to prevent climate catastrophe? And what will the process of transitioning mean for the political systems that have been built on cheap and abundant oil? Political scientists have largely ignored technological development as a lever for political development, or feared that technology could only be a force of domination. Yet renewable energy enthusiasts have often seen democratizing potential in these technologies. What can be accomplished politically by building a wind turbine? As countries like Denmark accumulate decades of experience with renewable energy, it is becoming possible to give such questions close empirical consideration. Denmark generates more of its electricity from renewable sources, and has been doing so longer, than any other industrialized nation, making it a uniquely valuable case for studying an advanced renewable energy transition in progress. This dissertation draws on novel qualitative and quantitative data to present the first comprehensive history of Denmark's energy transition from its roots in the 1970s until the present, aiming to explain how this tiny nation emerged as the world's leading wind power producer, and assess whether this process has yielded any democratic dividends. The multi-method analysis sheds new light on internal dynamics of Denmark's energy transition, and, more generally, on late-stage evolutionary processes in mature technological systems. Many studies have shown an interest in the Danish case, which is usually presented as a relatively unqualified success story, but few have provided the empirical resolution to identify these complicating factors. This dissertation employs an explanatory strategy adapted from the ecological sciences to construct a more holistic and integrative portrait, resulting in a more thorough and accurate account of how Denmark jumped out to such a significant lead in the energy transition, and why that momentum might be flagging today, with implications for other countries hoping to chart a path toward a sustainable future.

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INTRODUCTION: RENEWABLE POWER DEVELOPS IN DENMARK

1.1 Navigating the Crises of Modernity

The twentieth century is remembered as a period of innovation and upheaval at an unprecedented pace and scale—as the Age of Oil, which made possible the industrialization of everyday life and the globalization of capitalism; as the century of the Pax Americana and the successive triumphs of liberal democracy over fascism and totalitarian communism; as the dawning of the Anthropocene, when the stunning progress of science and technology launched humanity into outer space and cyberspace.

In that same century, Western societies developed and deployed Zyklon B and Uranium-235, towering monuments to the cruelty and hubris of the times, and yet only two of the more visible markers in a vast field where the heirs of the Enlightenment bury the casualties of their crimes against humanist principles. Two decades into the next century, add ISIS and CDOs and Covid-19 to the annals of unintended consequences of the end of history. Technological advancements and economic expansion have failed to deliver on utopian visions of eliminating scarcity and making labor superfluous, but have succeeded in exacerbating inequalities and refining the exploitation of people and the planet, stress testing the legitimacy and durability of the liberal democratic world order. Since the 1960s awareness has been rising that this political-economic orthodoxy, with its culture of unbridled consumption and fantasies of limitless growth, is rapidly altering planetary systems in ways that threaten the very survival of human civilizations.

For modernity, it is a decidedly uneven legacy, rife with uncertainty about the future. Nearly three decades after the first Earth Summit assessed the scope of the global threat, there is little agreement about the path forward, and even less concerted action. The sense of looming crisis seems to intensify with each news cycle. The concentration of carbon in the atmosphere marches steadily past the tipping points of climate modelers. Wars rage unabated across the resource-rich Middle East, the threat of flare ups and escalations ever present. Emboldened authoritarian regimes are challenging the postwar consensus, as are insurgent right-wing populist movements, which are themselves largely reactions to the material and spiritual immiseration of neoliberalism, the complacency and impotency of experts and elites, and, most proximately, the influxes of refugees from the military-industrial "shock therapy" and environmental devastation of late capitalism, migrations that are only expected to accelerate as climate change accelerates.

Most observers would agree that in the first generation since the impending climate crisis reached public consciousness, insufficient progress has been made in steering industrial societies away from the fast-approaching cliff's edge. Even a global pandemic that froze travel for more than a year could not slow the pace of emissions, as atmospheric carbon levels marched unabated toward 420 ppm in summer 2021, already far past the limit of 350 ppm deemed "safe" by scientific experts. (1) The visible devastation racked by worsening storms, floods, fires and droughts has already grown severe, yet the most powerful global actors—mainly nation-states and multinational corporations—have largely failed to assert leadership in responding to these threats. In the United States, a fearmongering president spent his four-year term convincing adoring mobs that wind turbines cause cancer, while the fossil fuel lobbyists he appointed to key regulatory posts worked behind the scenes to dismantle the policy achievements of the conservation and environmental movements, in the process obliterating any pretense of unbiased, scientific, rational public administration in the world's most important democracy. A rising China tries to have it all ways, simultaneously promoting clean technologies, gobbling up resources and spewing toxic pollution at record rates, all while the regime stifles democratic rumblings in its populace with an innovative model of techno-totalitarianism. The international community looks impotent and increasingly irrelevant, its cardres of technocrats jetting to a neverending series of conferences that produce little more than flimsy pledges aiming at incrementalist targets, targets that are routinely missed, by wide margins, seemingly without consequence. Oil exploration booms, drilling deeper into marginal resources and ecologically-sensitive territories, from the pine forests and permafrost of Alberta, to formerly protected national monuments and wildlife refuges in Utah and Alaska, inching inexorably toward the melting ice sheets at the North Pole.

Lest this characterization of the present predicament sound excessively gloomy, it must be added that the prospects for making the systemic changes needed to put human societies on sustainable trajectories have never been brighter. While the future of the Paris Climate Accord, sabotaged by the Americans, is murky, climate change has established primacy of place in the global political discourse, and will continue to provide a forum for international cooperation. Forward-thinking firms are racing to stake out market shares in the sustainable industries of the future. State and local governments around the U.S. are picking up the slack in the absence of federal leadership, and beginning to adopt ambitious climate plans. In many parts of the country, renewable energy is now cheaper than natural gas or coal.

This imminent potential for transformation should not be mistaken for a guarantee of its actualization. As energy sector analysts are fond of saying, there are no free lunches; no easy fixes will be found to the multi-dimensional challenges of the moment. Fantasies of providential destiny, the progressive dialectic of historical necessity, technocratic mastery, or self-regulating systems must be abandoned if the crises of modernity are to be confronted, and humanity is to grow out of an ecologically irresponsible adolescence. The distance from ideas to actions must be closed. How to traverse that space between possibility and praxis will be a major preoccupation of this work.

Humans have acquired the power to destroy the planet—or at least ourselves—but there is also reason to hope we can gain the wisdom and the will to save it. Yet the standard toolbox of solutions offered by governments, businesses, and thought leaders remains inadequate to the task. The achievements of social movements, which have at least managed to change the conversation around the climate, should not be discounted; but for the overwhelming majority of the planet's population environmental activism barely registers as a concern. Most Americans are content to assuage any guilt they may feel with curbside recycling programs of questionable efficacy and oxymoronic "green" consumerism. Around the world, citizens have largely been sidelined from efforts to build sustainable societies. Practical templates for transformative social action on the climate remain in short supply. Having seen the limits of free markets, of state-centered expertise, and of liberal internationalism, perhaps the time has come for a new expression of power to emerge.

1.2 Situating the Research

The chapters that follow will not engage in polemics against global capitalism, extractivism, or liberalism. This work is, instead, a descriptive and analytic attempt to understand the social and political mechanisms that drove the first generation of large-scale renewable energy development, through a close historical study of a paradigmatic case, in the hope that models and strategies can be identified for building more sustainable energy systems around the world.

I make no attempt to argue for the necessity of a rapid and thoroughgoing response to climate change. I will present no charts depicting skyrocketing GHG emissions or rising seas. Many more qualified voices have already sounded the alarm, and the evidence for a state of climate emergency is overwhelming. (2) I begin this study from the premise that any social system dependent on fossil fuel energy is inherently unsustainable, if for no other reasons, because the resources are finite and they are being rapidly exhausted. The ExxonMobils of the world are welcome to contest such assertions until their stock options vest, the rest of us have no time to waste on bad faith exercises in muddying the waters. Environmental economists have already demonstrated that to have any chance of limiting warming to the international target of two degrees Celsius, substantial portions of known oil, gas and coal reserves will have to be left in the ground. (McGlade and Ekins 2015) If readers remain unconvinced about the desirability of replacing fossil-fueled energy systems, they will not find these pages much occupied with making that case. I take the inevitability of such a transition for granted—indeed, it has already begun. I am interested in how sustainable energy systems are being built in practice, and with what consequences for the societies that undertake these projects.

Unlike some of the more strident environmentalist critics of capitalism (e.g., Klein 2014, Dryzek 1992, Bookchin 1982), I do not attempt to argue that the existing political economic order is irreconcilably incompatible with an ecological society. Many commentators have identified liberal, capitalist, industrial, or extractivist ideologies as root causes of environmental degradation. It is hard to deny that the environmental records of capitalist societies have been abysmal. The invisible hand has distributed environmental harms inequitably and inefficiently, in large part by externalizing many of those costs from the price of doing business. I am personally skeptical that an economic system which attempts to reduce all value and judgment to a price signal will somehow learn self-restraint and respect for considerations that cannot be monetized. That said, liberal capitalism has proven nimble and adaptable, and predictions of its impending demise have been repeatedly disappointed. The approach I take in my analysis is to remain agnostic about the possibility of "greening" capitalism, as proponents of market-based solutions to climate change advocate. (e.g., Mathews 2015) I examine a range of approaches to the expansion of renewable energy technologies, and try to present the strengths and weaknesses of these alternatives in an evenhanded manner. I leave it to readers to decide which of these pathways is compatible with their values and their circumstances. In the concluding chapter, I discuss how evolving energy technologies are creating new hybrid forms that cut across the traditional conceptual distinctions of environmental discourses, and I suggest that some version of an "all of the above" strategy on renewable energy development may be necessary, given the scope, complexity and pressing nature of the problem.

Thus I do not begin this study as a partisan for wind energy, nor do I champion any specific configuration of a non-fossil energy system. Although the empirical findings I have to report about real-world experiences with wind turbines are on the balance positive, I take care to note the failures, the conflicts and the limitations of these technologies as they have been deployed in practice. My underlying interest is not in technical infrastructures or business models, but with the prospects for democratic politics as energy networks realign, new players emerge, and new possibilities arise. Under what circumstances can this period of technological transition also sustain political innovations? Since the early days of the environmental movement, ecological thinkers have hoped that the unique characteristics of renewable technologies held potential for a democratic renewal. I plan to put this warm and fuzzy notion to the test. While I have not uncovered any necessary connection between an ecological society and a democratic one, I will detail what I see as important symbioses between the drives for deeper democracy and environmental sustainability.

As I explain in chapter 2, I treat democracy in substantive rather than procedural terms, as a form of politics dedicated to promoting freedom and equality. These two core principles, seemingly in conflict in liberal conceptions of governance, intersect when democracy is understood as nondomination, measured by the distribution of power among members of a social group. Social actions and systems that tend to disseminate power more widely and evenly—particularly those that empower ordinary citizens to exercise greater control over their social circumstances and government—are considered democratizing. I do not engage in normative theorizing about what an ideally democratic society might look like, but instead ask if renewable energy transitions in progress are yielding any democratic dividends. Are renewable energy technologies productive sites for nurturing democratic politics? How do more democratic models of energy development measure up on sustainability metrics, compared to other transition pathways? And as the pace of innovation in the energy sector accelerates, how are existing social structures and hierarchies being upset? What new modes of governance, what legal codes, what ideas of citizenship and forms of participation are advancing alongside the sustainability agenda?

These questions took me to Denmark, where a renewable energy revolution appears to have reached a tipping point. No other industrialized nation has done as much to reduce its reliance on fossil fuels. Denmark offers a particularly instructive case study of how far an energy transition can progress in a single generation. As recently as the mid-1970s, the Danes relied on imported oil for more than 90% of their energy needs. There were no wind turbines connected to the nation's patchwork of electricity grids. In the ensuing decades, those grids were transformed dramatically, largely to accommodate the exponential growth of wind power. When the national government started issuing energy plans in the wake of the Arab oil embargo, central planners argued that projecting even 10% wind power by century's end was unrealistic. Today, largely because a determined community of wind enthusiasts proved the planners wrong (and partly thanks to the discovery of North Sea oil), Denmark generates more than 90% of its energy domestically. By 2020, Denmark was breaking its own records, and supplying 47% of the nation's electricity from wind turbines. (3)

1.2.1 Case Selection: Why Denmark?

The explosion of wind energy in Denmark since the 1970s has been a remarkable success by almost any measure. According to the most recent published data from the Danish Energy Agency, electricity production from wind turbines increased a staggering 2,531% from 1990-2021. Over that same time period, production at large centralized power plants plummeted 99.4%. (Danish Energy Agency 2022) These results have not been achieved without substantial investment and effort, and some growing pains, but there have been few significant downsides for Danish society. Total energy use and greenhouse gas emissions have declined, partly a result of major investments in district heating and energy efficiency, while economic output has simultaneously expanded. The Danish government operates one of the world's most modern, efficient, and robust electric grids, consistently delivering uptimes around 99.99%, meaning the average consumer loses power for less than 40 minutes per year. (Danish Energy Agency 2016)

As shipbuilding and other heavy industries have declined, wind turbines are now one of the nation’s most important manufacturing exports. In 2020, Denmark accounted for 26.3% of global wind sector exports, second only to Germany at 30.1%. The Netherlands and Spain round out the top four wind equipment manufacturers, and those four countries combined represented more than three quarters of global exports. (IRENA 2022) Danish firms exported DKK 68.5 billion worth of wind technology and services in 2019, almost 14% of all Danish exports. The domestic wind industry directly employed more than 33,000 that year, about 2% of all private sector jobs. When associated services and multiplier effects are counted, total wind sector employment is estimated at above 96,000. (State of Green 2021)

Danes do pay high taxes for electricity, though not all sources agree (due to differences in measurement) that consumer prices are any higher than in neighboring countries. The government has strategically ramped up electricity taxes—in large part to fund renewable energy programs—in step with dips in wholesale electricity prices, so consumer bills have more or less remained constant. In a single generation the electricity system has been completely overhauled, with widespread public support.

There are many countries where exciting developments are occurring in the renewable energy sector today. The other obvious national case study would be Germany, which by the end of 2022 had installed 66 gigawatts (GW) of wind power, almost ten times the total capacity in Denmark. Of course, Germany's population of more than 80 million dwarfs Denmark's, at fewer than six million, and the German economy boasts much more heavy industry. As wind energy development booms worldwide, Denmark has fallen out of the top ten nations in total installed capacity, but remains comfortably in first in wind capacity per capita. The Germans have invested heavily in renewable energy in recent decades, and have rightly earned a reputation as a global leader. But they are still a distant second to Denmark in the share of their electricity produced from wind turbines, which totaled a 25.9% percent in 2022. The Germans have long been world leaders in the adoption of solar photovoltaics, which supplied another 11.4% of the country's electricity. A total of 48.3% of Germany's electricity came from renewable sources in 2022. In spite of these impressive results, Germany spent most of the last decade shuttering its nuclear plants after the 2011 Fukushima meltdown and growing ever more dependent on natural gas from Russia, before the invasion of Ukraine in 2022 forced a rapid rethinking of the country's energy strategy. Remarkably, the Germans successfully decoupled from Russian gas in less than a year, replacing the lost fuel with American liquified natural gas, burning more coal, and temporarily delaying the closure of the last operating nuclear plants. The war in Ukraine is also boosting ambitions and speeding the adoption of renewable energy around Europe, as evidenced by a 2022 agreement between Denmark, Germany, the Netherlands and Belgium to build 65 GW of offshore wind in the North Sea by 2030 (see Chapter 6).

Compared to Germany, Denmark was a relative latecomer to solar power, but a recent boom helped the Danes generate a record 67% of their electricity from wind and solar in the first half of 2023. After seeing a significant dip in wind power in 2021, down to 43.6% a—a drop-off blamed on bad weather, and good evidence of the significance of variability in wind resource availability over time—-unofficial estimates suggest domestic wind production recovered in 2022 to top half of the country's electricity mix for the first time. For comparison, the United States ranks second in the world in installed wind capacity (behind only China, which dominates the world in aggregate installations), but produces only 10.4% of its electricity from the wind, and 14% from the combination of wind and solar, illustrating just how much catching up the U.S. has to do to meet the Biden administration's ambitious climate pledges. (4)

In addition to achieving an unprecedented degree of grid penetration, the Danish wind sector has another advantage no other country can match—more than forty years of experience designing, manufacturing, installing, operating, servicing and exporting wind technology. While the Danes started subsidizing renewable energy development in the late 1970s, and saw rapid growth in the wind sector throughout the 1980s, the famed German *Energiewende* gained momentum a decade later, after the passage of the first national feed-in tariff in 1990. As the nation where the modern wind industry originated, Denmark has unique historical importance in the growth of wind systems globally, making it a site of special interest for understanding the embryonic developmental stages of the technology, and its emergence from a niche alternative to a mainstream, utility-scale generation source. Much of the story of wind power today can trace roots back to Denmark, and the Danes have retained substantial first mover advantages as a center of renewable energy expertise, industry and innovation.

If one only looks at aggregate statistics on installed capacity, Denmark might appear to be a bit player in the global business, and Danish wind professionals will admit as much about their home market. But the land-poor country hugely outpunches its weight in its impact on the global industry. Only one of the world's ten largest wind turbine manufacturers remains under partial Danish ownership—Vestas, which recently merged its offshore business with Mitsubishi—a significant retrenchment from the 1980s and 1990s, when Danish-made turbines were the sought-after gold standard for investors around the world. Today, turbine manufacturing has consolidated in the hands of industrial giants like General Electric, Siemens, and a slew of Chinese firms—evidence of the massive upscaling of an industry with roots in the barnyard smithies of rural Jutland. But most of the major players still conduct research and development in Denmark, where a skilled workforce and leading educational programs continue to place Danish wind professionals in leadership positions at firms around the globe. The Chinese and American wind industries, in particular, owe significant debts to Danish technology and expertise. Wind development in Spain, Portugal, the United Kingdom, Eastern Europe and many other places around the globe also bears a heavy Danish imprint. As I have detailed elsewhere, 8 of the 10 largest manufacturers in 2018 inherited at least some of their turbine technology from Danish firms. (5)

1.2.2 Why Wind Development?

Denmark undoubtedly has been and remains a global leader in wind power, but one might question limiting the scope of this investigation to a single renewable energy technology. It would certainly be unwise for any nation to rely too heavily on a single energy source—as the Danes learned the hard way during the energy crises of the 1970s. Virtually all plans for renewable energy systems envision a range of diverse generation sources. The Danes themselves are also world leaders in co-generation (or Combined Heat and Power (CHP)), as well as waste incineration and a variety of biomass technologies. After lagging behind neighbors like Germany for decades, solar power is taking off in Denmark in just the last few years, and as I discuss more in Chapter 6, may have greater potential than wind for future grassroots community and citizen participation in renewable energy development, in particular. But those chapters of Denmark's energy transition remain to be written; as a historical matter, wind technology has been the dominant force in establishing Denmark's reputation as one of the greenest countries on earth.

The technical and economic characteristics of modern wind energy systems make them particularly attractive candidates for widespread adoption, as well as for scholarly analysis of renewable energy transitions. Both wind and solar are now widely considered mature technologies, though of all existing renewable energy sources, wind is the most developed. Solar prices have fallen sharply in recent years, and in some very sunny locales solar arrays are now the cheapest available means of generating electricity. But this welcome growth in the solar market is only continuing a trend that has been apparent in the wind sector for decades. Wind was the first, and in many markets is still the best-suited, renewable source to compete with conventional fuels on price.

Wind and solar have also proven to be highly flexible technologies. While some regions are undoubtedly windier or sunnier than others, generating power from the wind and sun is still feasible in most places. Most everywhere has at least some wind and some sun. Indeed, these technologies are being adopted across the full range of Earth's ecosystems, from the tundras to the tropics. Wind resources have been extensively mapped, and the best sites for development have been identified around the world. As the technologies continue to advance—for example, with the engineering of turbines tuned to maximize performance in low winds—the map of attractive sites for development is expanding. The potential for renewable generation from these technologies is enormous, and could meet the needs of the entire planet's population many times over. In the waters off the east coast of the United States alone, according to an estimate by the U.S. National Renewable Energy Laboratory, the amount of wind power that could be generated is four times the current capacity of the nation's electric grid. (Musial and Ram 2010) Denmark already regularly generates more electricity from wind turbines than its population uses on windy days, with plans to build even more large offshore wind farms, and become the green "power plant of Europe."

The explosive growth of offshore wind over the past two decades demonstrates the rich diversity in renewable energy solutions. There are countless ways to build a wind turbine, or a solar collector. The classic sail-bladed windmills that ground flour and pumped water in centuries past remain an efficient design today. At the cutting edges of wind engineering, researchers are experimenting with giant kites on miles-long tethers, and multi-armed towers supporting three or more rotors. Numerous design modifications have been attempted, and many discarded. Today's commercial turbines range in size from those small enough to mount atop the mast of a sailboat, to offshore giants with wings longer than those on a 747 jumbo jet, components so large they must be assembled quayside because they cannot be transported by road. Both the financial and the technical aspects of offshore wind are so different from land-based development that industry insiders often think of the two applications as separate technologies. Chapter 6 will examine in depth the unique characteristics of the offshore wind sector in Denmark, and will compare this model to earlier approaches to wind development, as industry leaders and policymakers increasingly favor shifting more new development offshore. The point to emphasize for the moment is that wind turbines have been successfully adapted to serve the needs of diverse interests and actors in a wide range of settings.

Within the context of this study, the diversity of development models in the wind sector makes it possible to introduce variation into the analysis and to make comparisons among competing transition pathways. The Danes have been particularly creative in their approaches to wind development, pioneering several distinctive models for erecting turbines, notable among them neighbor cooperatives, in which anywhere from a few dozen to a few thousand lay citizens buy shares in a project (the cooperative model is discussed at length in later chapters). Although the wide spectrum of wind projects lacks clear boundaries in practice, for the purposes of analysis I have sorted Danish wind turbine developments into nine major categories. This typology of development styles is detailed in Appendix A, and each of the empirical chapters charts trends in these categories of development over time.

The emphasis on development may strike scholars of environmental, comparative and international politics as somewhat unusual. In these literatures, the term "development" is often weighted with normative significations. Comparative and international political scientists usually associate development with modernization, economic growth and democratization; thus in speaking of "developing nations," there is always an implicit ideological framing in which Western economic and political conditions provide aspirational benchmarks toward which more-or-less backward cultures are progressing.

My use of the concept of development in the chapters that follow is not meant to invoke any such ideological commitments. Rather, developments and developers are treated strictly as analytic categories, as the processes of acting on, building, and reconfiguring existing social and natural systems. These processes are certainly not politically neutral, but this research does not prejudge the desired directions or outcomes of development; instead, it aims to observe and describe the myriad effects of such interventions, from as many different points of view as feasible. In its impartial stance toward developers, the study also departs from much of the environmental literature, which has traditionally opposed development to conservation, as almost mutually exclusive categories, on the assumption that any and all human interventions represent pollutions of, and threats to, the purity, harmony and beauty of "untouched" nature. This old-fashioned conservationism has fallen out of favor among contemporary environmental thinkers, with the growing recognition that human beings, and in fact all living creatures, have always modified their environments, and with rising skepticism about the value of treating nature as a separate, independent realm distinct from human affairs. Challenging the dated (yet still deeply influential) human/nature dichotomy will be a central plank in the ecological approach to political analysis expounded in Chapter 2. But with respect to the analysis of Danish wind development, the study does not attempt to evaluate the impacts of this activity on nonhuman nature, beyond how those impacts are understood by participants.

The actors involved in these development projects supply the analysis with motives, values, needs and abilities—that is, with means and ends. Letting my research subjects explain their projects and purposes in their own terms allows me to avoid some nettlesome tasks, such as defining "sustainability," which I view as an essentially contested concept. Instead of devoting effort to defending a specific conception of sustainability, I ask how actors in the Danish wind sector frame their sustainability goals, and how these visions translate into their actions building the wind power network. Individual developers come to the wind energy community from a wide range of backgrounds, with distinct and sometimes conflicting competencies, worldviews, and intentions for their projects. This diversity of perspectives and ends helps the analyst view potential black boxes like "wind technology" or "energy policy" from a variety of standpoints, and to watch how the ambitions of these various actors are either supported or frustrated in interactions with other system actors, structures and forces, as time passes and circumstances change.

So the concept of “development” is used in this study with two primary valences. The allusion to evolutionary biology is intentional, as processes of growth and change, in tracking both the life cycles of individual turbine projects and the stages expansion of the aggregate network, are central concerns of this dissertation. Developers are the key actors in these processes of network formation and maintenance. For the purposes of empirical analysis, I construe the category of “developer” broadly, as anyone who invests in a wind project—anyone with a direct role in building, owning or operating a turbine. Developers bridge the gaps between agency and structure, the ideal and the material, motivation and implementation, imbuing the network with concrete interests, preferences, and political and economic principles. It is a historical fact that Denmark’s earliest wind turbine builders embarked on their projects with explicitly political agendas—agendas that ranged from resisting the Nazis, to promoting rural education and self-sufficiency, to realizing an eco-socialist utopia (those wind power pioneers are described in chapters 2-4). Thus developments can be understood as sites of construction and contestation of political, economic and material forms. By following these developers and developments closely, it is possible to trace how their visions are put into practice, how these actors build support and form alliances, and where they encounter stumbling blocks and resistance.

I am fascinated by developers in this sense of being visionaries—of imagining new possible worlds and traversing the distance between the idea and its realization. Development is fundamentally a creative act, a process of bringing forth new forms. It is also necessarily an intentional act. And what is technology, in the most general sense, but intentional action to alter the circumstances of human existence? I follow philosophers like Joseph C. Pitt in thinking of technology broadly as "humanity at work" (Pitt 2000)—at work, I would add, toward some purpose, some function, some end. In treating technology as a general category of social action, I reject approaches that reduce technology to techniques, or to technical apparatuses, or to instrumental rationality (see Chapter 2). Such theoretical assumptions capture only one form or dimension of technology, and in doing so miss many of its properties and expressions, and much of its larger relevance in human affairs.

1.2.3 Scope of Analysis

While the current conceptual vocabulary for talking about the social dimensions of technology remains frustratingly awkward, the most adequate theories available for describing the structure and function of large-scale contemporary technologies take their objects of analysis to be complex, hybrid, "sociotechnical systems." (6) As the name indicates, these theories conceive of technologies as composed of human, discursive, and material components. They include not only the technological artifacts—the system components usually referred to in conversational usage—but also support infrastructures, policies, procedures, expert and lay knowledges, beliefs, norms, cultures, social groups, institutions, and even elements of nonhuman nature. Understood in these terms, technological development is always inherently social and political development.

It is this political salience of technological change that piques my interest in the subject of energy transitions. In scientific terms, the expenditure of energy is an underlying condition for the possibility of all life, and certainly all human endeavors. (7) I am drawn to the topic out of a desire to better understand how human societies adapt specific forms of harnessing energy as means of organizing social life and pursuing their political projects.

The sociotechnical systems literature has long recognized that energy technologies are foundational elements of all civilizations, fulfilling basic social functions. As such, they have been the subjects of frequent investigation. They are exemplary large technological systems—built of myriad components, and embedded in countless social structures and activities of daily life. The essential nature of energy systems makes them matters of perpetual concern to policymakers and engineers, and control of their design and operation a substantial source of political power.

Because energy systems are so large and multidimensional, with tendrils stretching in every direction, and intermingling with other systems, they can only be captured in partial perspective in writing. Analysts must choose how to slice the seamless web of experience. Scholars of energy systems have often emphasized the dimensions of design, management and function. And although they are closely coupled in practice, a distinction is often made in both industry and scholarship between energy generation and consumption. Modern industrial societies have managed to put more distance between the sites of production and consumption, and public consciousness of their interdependence, than at any previous time in history, with some deleterious social and environmental consequences. (8) While I hesitate at reproducing this fracture in how system function is understood, and I attend wherever possible to the impacts of wind development on consumer attitudes and behaviors, this study focuses on the generation side of the coin, and on one specific generation technology, more out of necessity than a lack of interest in other dimensions of the subject. The vast majority of Danish households are extremely passive participants in the electricity network. Only in rare and specific instances—instances I will address in later chapters—has public opinion or consumer behavior been a decisive factor in wind development.

The Danish energy system cannot feasibly be presented in its entirety, to do so with attention to the micro-level empirical details and dynamics that enrich my account of the wind sector would require a dissertation at least three times as long. A complete picture of the energy system would include both heating systems and transportation systems, only a portion of which are currently supplied by electricity. Even the electricity system cannot be treated fully. Transmission, operation, and fossil generation all receive some consideration, though they remain peripheral subjects, as do competing renewable technologies like solar and biomass. Nor do the following chapters dwell in great length on supporting technologies or associated systems, such as the district heating systems that have helped facilitate the integration of wind power on a mass scale. The especially critical role of grid development in facilitating wind development is singled out for consideration in Chapter 6. All of these complicating factors are, admittedly, crucial to understanding the evolution of electricity networks and energy systems in the aggregate. But they will be addressed here only to the extent they impact the evolution of wind development. Placing such limits on the scope of the analysis is always somewhat artificial, but cannot be avoided, unless one intends to make a map the size of the world.

It is also not feasible for this study to give all participants in the wind energy network equal consideration. For example, turbine manufacturers (OEMs) are so central to the network they can hardly be ignored, and beyond delivering the machines they are frequently involved in other aspects of the development process. The supply chain for turbine parts, on the other hand, will only be addressed to the extent those components impact developers.

Selecting only active participants in wind development as research subjects simplifies the analysis in several ways. First, the shared network in which these actors participate approximates a closed system as much as can be practically expected in a real-world case. It turns out—not by legal requirement, but certainly not by accident—that every wind turbine installed in Denmark was manufactured domestically; the overwhelming majority of the owners of those turbines are also Danish, as is much of the supply chain. The same cannot be said about solar or biomass systems, or about wind systems in most other countries. The reasons for this unusual insularity in the Danish wind sector will be explored further in chapters 3 and 6. The absence of foreign competitors means that all developers in the Danish wind market are subject to the same laws and regulations, and feel the same or similar market pressures. So the study is able to eliminate a lot of the confounding variables that might be encountered in, say, a cross-national comparative study.

Restricting the terrain surveyed to a single country also makes sense since most electricity networks still function at a national or subnational level. Although European electricity markets have been steadily integrating and liberalizing—a process cheered by the wind industry, and directly benefiting many Danish firms—there remains a recognizably Danish electricity system and a Danish wind sector. Denmark's grid is centrally managed by the national government, and the nation-state still imposes a variety of other regulatory, political and cultural constraints on evolution of electricity systems. Some unique features of the Danish system are discussed in chapter 3. Denmark makes an appealing case study for renewable energy development because the wind network has been relatively insulated, and the process of adopting wind technology has been relatively compressed. The fact that Denmark started with no grid-connected renewable generation in the mid-1970s means that almost all of the relevant developmental processes can be traced from their origins in the last five decades. The shifts in the Danish energy system have been clear and dramatic, so most of the empirical phenomena of interest are fairly unambiguous and easy to document.

Since the wind energy network is now mature, additional simplifying assumptions can be made. Wind is the single largest fuel source in the Danish electricity mix today, as the role of central power stations, which burn a mix of coal, natural gas, biomass and waste, continues to decline. Government plans call for a continued expansion of wind energy in the coming decades. To the extent there are more changes to Denmark's electricity regime in store, for the foreseeable future they are likely be a wind-powered changes. This study is primarily backward-looking, however, and the Danes' long experience with wind turbines makes it possible to trace the network through a series of developmental stages. Solar technology, by comparison, has only caught on in Denmark in the last decade, and remains at a much earlier stage of growth. The cost, absent generous subsidies, and reliability of solar generation have historically been impediments to its widespread adoption there. The market shares of technologies like biomass and solar will likely tick upward in the years ahead, but for the past few decades the homegrown renewable champion has been wind power, and the competition hasn't been close.

Turbine design is highly advanced and has become largely standardized around the world. Thus, with wind energy I can largely bracket several explanatory variables that might come into play with less mature technologies. The performance, reliability and cost-effectiveness of wind turbines are not impediments to development. Lack of experience is not an impediment, and a wide range of social actors, from insurance companies to small-town mayors to farmers, have grown comfortable with wind technology. The technical feasibility of supplying more than half of Denmark's electricity needs with wind turbines was first documented by scientists in the early 1980s. So to the extent technical or economic considerations are cited as obstacles to wind development in the present, the appearance of such concerns raises an analytic red flag, and usually signals something noteworthy about the evolution of social components of the network.

Choosing individual wind development projects as my primary unit of analysis has other methodological advantages, not least among them the aforementioned variation it captures in an activity central to the process of building and running an energy system. That variation makes within-case comparisons possible, allowing for some testing of the theoretical and explanatory propositions. The development of new fuel sources also occupies a unique, and uniquely significant, position in the structure and life cycle of an energy network, making the network easier to trace and describe. "Technology," as philosopher Andrew Feenberg has written, "is an elaborate complex of related activities that crystallizes around tool-making and -using in every society." (Feenberg 1992) This crystallizing quality of technological artifacts is no less apparent in the energy sector, and makes turbines particularly helpful sites for launching inquiry into the structure and function of energy systems.

The components of electricity networks tend to fan out from central nodes, and often cluster around the energy extraction infrastructure itself. The visibility and solidity of wind turbines gives them symbolic power, and has very material effects in organizing, rallying, and allying more peripheral network actors. As one example of this connecting and enlisting role of artifacts, think of all the types of expertise required to manufacture a modern wind turbine—from meteorology and quantum physics, to electrical and mechanical engineering, to production management and skilled machining. In the policy domain, consider the project developers, financiers and insurance companies, the neighbors and community activists, the local bureaucrats and elected officials, who all assemble to debate the erection of a new wind turbine at a public hearing. It is difficult to write a detailed history of a wind-powered energy transition without paying serious attention to the turbines themselves. To avoid getting too bogged down in the engineering debates, my focus on turbine developers, rather than designers, makes it easier to foreground the social and political conflicts.

Some political scientists may accuse this research design of selecting on the dependent variable by centering the analysis around wind turbine developments, instead of drivers of development, worried about the possibility of selecting only cases that confirm the theory, and excluding cases in which the independent variable fails to produce the desired effect. That fear is not strictly justified here, as the study examines instances of profitable and popular wind projects, as well as projects that have been disappointments or outright disasters, that have stalled, fallen into disrepair, or been abandoned. As such, the research design observes the old sociology of knowledge principle of symmetry—of applying the same explanatory strategy to the analysis of both successes and failures. At a deeper level, this study adopts a novel approach to explanation, aiming not to isolate causal variables, but to understand how multiple factors combine and interact in complex networks, and how different configurations of a wind energy system alter the character of the development. I expound upon this logic of inquiry in Chapter 2.

The more serious charge is likely to be that this work represents "just another case study." Denmark is a small, peripheral nation in the larger European and global contexts, with many peculiar characteristics that do not easily map onto conditions in other countries. It is more of an outlier than a representative case, raising the question of how readily applicable findings from Denmark can be to other nations in the process of transitioning to renewable energy sources. I have already discussed above some of the advantages of examining wind development in Denmark, as opposed to in larger countries like Germany, China or the United States. Of course, it is precisely the uniqueness of Denmark that is the primary source of its appeal. It could be classified as a "paradigmatic," "index," or "pathway" case (see Gerring and Cojocaru 2016), as it was the first case to demonstrate that a radically new means of organizing an energy system was possible on a national scale. Many breakthroughs in wind energy technology have been achieved in Denmark, and innovative techniques, policies and development models have been pioneered there. Expertise and knowledge have been amassed over decades.

Numerous comparative analyses have already been written of the Danish, German and American experiences with renewable energy development (including Heymann 1998, van Est 1999, Sawin 2001, Aklin and Urpelainen 2018). An advantage of the single-case approach adopted in this dissertation is the ability to examine an advanced energy transition in a depth and breadth unmatched in previous works, while still maintaining the ability to draw some comparative insights from the secondary literature. The lengthy temporal dimension of an energy transition and the wide diversity of actors and systems involved make it difficult to see key internal dynamics influencing transition pathways and processes without engaging in the sort of extended case analysis presented here. Denmark's long and varied experiences wind energy makes it a case of singular richness. It is also a case of special historical importance for understanding the origins and growth of global wind technology. In a recent book on renewable energy transitions, political scientists Michael Aklin and Johannes Urpelainen called Denmark "the admittedly tiny elephant in the room":

> Any political history of renewable energy is incomplete without an analysis of the Danish case. The Danish success story of wind energy is so remarkable that it must be given special consideration in any political history of renewable energy. The Danish case allows us to evaluate our expectations and lay the foundation for downstream studies of the politicization and lock-in of renewable energy in different countries, given Denmark's singular contributions to the technological development of wind energy. (Aklin and Urpelainen 2018, 98)

A second reply to the question of generalizability is that the method adopted in this work is not that of a simple case study; rather, it is a longitudinal analysis of the progress of Denmark's energy transition across five decades, and might more properly be called a "nested" case study (Thomas 2011), or a series of "embedded" case studies (Yin 1989)—a comparative analysis of competing development models within the shared

Danish context. Working from comprehensive government records of virtually every turbine erected in Denmark since the 1980s, I have compared approximately 8,700 individual cases of wind installations. More details on my data analysis methods can be found in Appendix A. Framing the research in these terms highlights a rationale for restricting the analysis to Denmark, since holding constant the national context—including natural resources, climate, economy, culture, etc.—creates something of a natural laboratory for examining the progress of diverging development pathways. Cross-country comparisons of energy policy and strategy are inherently troubled by these dramatic differences in local circumstances. There can be no one-size-fits-all policy prescriptions for sustainability transitions, as insufficient attention to environmental context obscures important processes in the evolution of energy systems, and ignores the need to tailor solutions to the opportunities and constraints posed by those environments, which after all provide the settings in which any new technology must function. I unpack the importance of environmental context for understanding energy transitions in more detail in Chapter 3.

I have tried to explain some of the reasons I find Denmark and the wind energy sector to be fascinating sites for investigating sustainability transitions, however, I want to avoid creating the impression that this will primarily be a story about the construction and operation of windmills. On the contrary, the analysis in the following chapters is largely nontechnical. Though I am conversant in basic principles of wind turbine and electricity network design and operation, and I endeavor to communicate these elements clearly to the reader, I claim no special expertise in electrical engineering or the electricity business. My area of competence, and my primary interest in this subject matter, is in the political dimensions of sustainability. Denmark's energy transition has required far more than steel and fiberglass, and has altered not only rural vistas, but the cultural and political landscapes as well. These transformations, I argue, have not been side effects of installing wind turbines, but essential aspects of the process of remaking the nation's energy system. Many technical improvements in wind turbine design emerged in Denmark, but just as important to the Danes' success with wind energy have been the social and political innovations that contributed to the growth of the wind sector. The Danes have reconfigured more than just their electricity grid. In the early 1970s, Denmark had no energy policy. It had no wind industry. Few experts and no one in a position of authority believed wind could fuel the country's future. Wind turbines were not ubiquitous landscape elements, and had little of the cultural symbolism with which they have been invested today. Denmark had no global reputation as a champion of renewable energy and sustainability. In less than 50 years, all of that has changed. The politics of renewable power systems have evolved dramatically, as have public attitudes about wind energy. How did this all happen?

The Danish wind sector has gone through multiple metamorphoses during this time period, and endured some temporary slowdowns as successive governments have tweaked policy support schemes—a fact that demonstrates the continued importance of policy regimes to creating the conditions for energy development—but the general trend for the past four decades has been one of steady growth of the nation's wind capacity. Integrating all of this distributed and variable wind energy into an electricity system designed for centralized production from a handful of large power plants has required large public investments, smart engineering solutions, and some changing of the old guard, but the technical difficulties in achieving a majority renewable electricity network have proven surmountable. If Denmark is in danger today of falling short of its extremely aggressive climate goals, it is primarily for social reasons. As turbines have grown larger and saturated the countryside, localized protests of proposed wind projects have slowed the pace of onshore development to a crawl, but opinion polls continue to show overwhelming public support for renewable energy development. Government officials and business leaders continue to lean into offshore development, despite persistent worries about the eye-popping costs of building ever larger wind parks ever farther from land.

Danes are justifiably proud of their commitment to greening their country, and their world-leading positions in most areas of the wind energy value chain. There is much other nations can learn from this tiny archipelago in the North Sea. One practical aim of this dissertation project is to transfer some of the knowledge accumulated through decades of Danish experimentation to readers on the other side of the Atlantic. But this prescriptive work of collecting best practices is only a supplementary aim of my project, secondary to and dependent upon my larger effort to document and explain the processes of development that led the energy transition to its current, advanced (but still incomplete) stage, and in doing so challenging the dominant narrative of Danish renewable energy development.

The “success” of Denmark's energy transition is rarely questioned, and many actors in Danish society have stakes in perpetuating a mythology of broadly beneficial, uninterrupted technological progress. The continued expansion of the wind industry is not served by too much scrutiny of this heroic narrative, or by permitting too many dissenting voices to speak for the network—at least in the eyes of those with vested interests in maintaining its present configuration. But the storybook version of this history papers over the many divergent ambitions for and experiences with wind power in Denmark. A sociotechnical shift as fundamental as implementing a new energy regime is bound to produce both winners and losers, and the practical meaning of a “successful” regime change must be interrogated. The path wind development has followed is only one among many possible roads that might have been traveled. Not enough attention is paid to the distinct and sometimes conflicting characteristics of these alternative routes in the literature on Denmark's transition, which typically treats all actors in the wind network as if they collaborated toward a common goal on a level playing field. What is missing from this literature is an analysis of the exercise and effects of power, in the Danish energy system as a whole, but especially within the wind energy network. (9) Attending to those power relations and dynamics allows this study to draw some broader conclusions about the political potential in large-scale technological transitions.

The wind business in Denmark today is a completely different animal than it was 40 years ago, or even 20 years ago. The older models of wind development are being left behind. Relatively few academic sources have noted this fact, and the social and political consequences of this transformation of wind development have not been closely studied, before now. The careful student knows there is much to learn from a more complicated portrait; positive lessons can be taken from even the shortcomings and missteps of Danish wind entrepreneurs. And while critical assessment of the transition is necessary analytic work for theorizing the politics of technological change, it does not diminish the significance of Denmark’s macro-scale achievements.

A consensus has emerged in Danish society around a vision for a sustainable future, and action in the present to make that vision a reality. The contrast with the United States, where organized political opposition and public skepticism have been longstanding impediments to action on climate change, is striking. In Denmark those hurdles have largely been overcome. This study aims to explain how.

1.3 Research Objectives

With its focus on the process of building a political culture committed to sustainability, my study tackles one of the more intractable dimensions of energy transitions. There is no longer much doubt among experts that alternatives to burning fossil fuels are technically feasible. One prominent advocate of this view in the scientific community is the Solutions Project team, led by Stanford engineer Mark Jacobson, which has completed roadmaps for implementing 100% renewable energy systems in all 50 U.S. states and 139 countries around the globe. In a recent paper, Jacobson and his team concluded that “based on the scientific results presented, current barriers to implementing the roadmaps are neither technical nor economic. As such, they must be social and political.” (Jacobson et al. 2015) This view has been echoed by everyone from Nobel Prize-winning economists to corporate CEOs and even by Republican Party strategists.

Political breakthroughs may be sorely needed, but the means of making political progress remain among the most complex and least understood of the drivers of energy transitions. How do societies generate the requisite political will to make massive investments in reorganizing basic social infrastructure, to overcome the resistance of entrenched interests, and to convince a largely complacent public to alter their lifestyles?

There is no shortage of policy ideas for addressing climate change, but what sort of *politics* would make implementing these policy solutions possible? Simply put, I want to understand how societies get on, and stay on, a path to sustainability. In carefully observing the political dynamics of a previously unsustainable energy network in the process of transformation, I am mining one of the most accessible and, given the centrality of energy technologies to modern life, one of the most productive veins for acquiring empirical insights into this question. I think such interventions are one way in which academic research can make practical contributions to the climate crisis response, and help catalyze the necessary social and political changes. I hope this study will contain actionable lessons for lawmakers, regulators, system operators, industry executives, lobbyists and activists.

I also hope to speak to fellow scholars, including those with no professional interest in energy or sustainability. I see the race to construct renewable energy systems as a rich site for observing the unfolding dynamics and emergent properties of social evolution in progress. These evolutionary processes have implications for our understanding of concepts of perennial interest to social scientists. The contours and interactions of several of these evergreen social categories—democracy, technology, political power—are the subjects of sustained analysis in the chapters that follow. In societies heavily reliant on advanced technologies, an overhaul of core sociotechnical systems is bound to have ripple effects throughout the culture. How would the political landscape be altered in a society committed to sustainability? I hypothesize that during this period of technological transition, new expressions of political power—new modes of structuring and governing social systems, new forms of social action—may emerge.

To what extent and by what means these political potentialities can be disseminated and preserved in perpetuity remain open questions that I follow throughout my historical analysis of the Danish case. In conducting these inquiries, my research aims to contribute to several ongoing debates in the scholarly community. The study's primary theoretical ambitions are fourfold.

First, this work speaks most directly to the expanding interdisciplinary literature on the social dimensions of energy transitions. Research in this burgeoning field has described past energy transitions, such as the widespread adoption of coal in nineteenth-century America, in fine historical detail, and has developed conceptual apparatuses for explaining how energy technologies evolve over time. (10) In recent years, scholars have increasingly turned their attention to the renewable energy transitions now underway around the world, of which Denmark is an exemplary case.

My approach to the analysis of the Danish electricity system draws from major currents in this literature, which consistently stresses the complexity, indeterminacy and malleability of the forces driving past transitions. It also highlights the dramatic dislocations and realignments societies experience as they adopt new energy technologies. When coal began to be extracted on a mass scale in the mid-nineteenth century, the availability of this suddenly cheap, energy-dense resource fundamentally transformed life in the Western world. Coal powered the Industrial Revolution, and in the early twentieth century propelled the high modernist vision of society to its material culmination in steel-beamed office towers, titanic ocean-going vessels and a world war. The harnessing of fossil fuels to replace the labor of living muscle was one of the most dramatic and consequential innovations in human history, an unprecedented triumph of

Man over Nature, harvesting wealth beyond the wildest dreams of previous generations, but also unleashing the toxic byproducts of this shift in the balance of power.

It remains largely unknown if renewable energy transitions will follow similar trajectories, with similarly mixed results, or if the distinctive attributes of these technologies augur uncharted journeys and destinations. The present work explores the novel characteristics of renewable energy systems, and the modes of political and social life that are compatible with reliance on such technologies.

This inquiry advances social research on energy systems by offering the most detailed and comprehensive analysis yet published of a national-scale renewable energy transition at an advanced stage. Most accounts of energy transitions have focused on the early stages of innovation and market breakthrough. Likewise, existing histories of Danish wind development have also tacitly assumed that most of the drama occurred in the first few decades, and now that wind energy has “grown up” and achieved mainstream success, development can be expected to continue unfolding along its current trajectory. By examining the growth of this network over the course of 50 years in Denmark, this study captures not only the processes by which the network evolved into its current configuration, but also how a relatively stable system continues to evolve and adapt to changing circumstances, after having achieved widespread adoption. The following chapters attempt to provide scaffolding for theorizing the dynamics of advanced energy transitions. It is not as if, after reaching some level of maturity, wind energy in Denmark has simply settled into a stable equilibrium, secure from outside shocks, internal challenges, and ongoing realignment. For too long scholars have been content to fall back on metaphors of technological inertia, “lock-in” or momentum to describe the mature phase of system evolution. In Chapter 5, I look specifically at the policy environment, and ask how the renewable transition became central to national energy planning in Denmark beginning in the 1990s. This analysis leads me to propose revising and extending theories of path dependence in the public policy literature that are finding new application in recent policy studies of energy transitions.

Both the wind sector and policies to support its growth have changed dramatically since the 1980s, that much is clear. Somewhat surprisingly, these underlying changes to the composition of the network have received only limited analysis to date. It is of course, always harder to describe and theorize imminent and unfolding processes of change, and doing so requires both close observation of events on the ground and critical distance to contextualize and interpret their meaning.

The growing public opposition in Denmark to new onshore and near-coast developments, mentioned above, is one example of this ongoing flux. Localized "NIMBY" protests are a common obstacle to energy development around the world, and have been widely documented in the literature. Until recently, such resistance has remained blessedly rare in Denmark. The sudden emergence of this impediment to the expansion of wind energy can be partly explained by the centralization and industrialization of the wind business, and the subsequent erosion of local ownership and direct community benefits derived from earlier development models. Chapters 5 and 6 take a closer look at the characteristics and succession of these developmental stages in the history of Danish wind power.

Many participants in the Danish wind community I interviewed, as well as the statistical evidence I gathered, suggest that Denmark's distinctive forms of local ownership are critically endangered. Presumably, this decline is cause for concern, if it threatens the progress of Denmark's energy transition by blocking further onshore development. Yet new, hybrid forms are appearing that may counterbalance the loss of grassroots developers. In response to pressure from local property owners and governments, new wind parks are increasingly being built as public-private partnerships, or by a mix of institutional investors and lay citizens. The latest mutations in approaches to wind development are considered in Chapter 6. These kinds of continual adjustments—the tinkering with formulas, the iterative adaptations to changing conditions—make the Danish electricity network a uniquely active site for documenting processes of technological change.

A second field of scholarly activity with which this study engages is the now well-established literature on environmental political thought. This tradition has made significant strides in challenging the human/nature dichotomy that undergirds much of modernism, as well as wrestling with intriguing concepts like posthumanism and ecological democracy. The field remains vexed by questions of how to incorporate nonhuman nature into human political structures, and how to make ecological sustainability a prominent issue of concern to democratic citizens and their representatives. I propose placing new emphasis on technological development—which has traditionally been seen as antithetical to environmental protection—as a site for cultivating both democratic and sustainable values and practices. After surveying a variety of prominent conceptions of ecological democracy in Chapter 2, I conclude that few of the current approaches to political ecology demonstrate much more than a surface-level engagement with ecological science, and ask what a more substantively ecological orientation to the study of political processes might look like. Somewhat counterintuitively, the embrace of ecology opens possibilities for reconsidering technological development, not as an inherent threat to environmental sustainability, but as a potential means of reconnecting humans with the material world.

The empirical chapters of the study document how new constellations of actors and forces are being assembled in Denmark to combat the climate crisis, and assess the socioecological effects of competing technological development models and transition pathways. I look for evidence of the formation of sociotechnical networks exercising an "eccopower" that operates as a mirror image of what Michel Foucault called "biopower," and can function as an antidote to the anti-democratic tendencies of the latter.

My interest in technological development should not be construed as an endorsement of "geoengineering" humanity's way out of the climate crisis. Nor is the concept of "ecopower" synonymous with what French critical theorists have described as technocratic, top-down "ecopouvoir." The question of what democratically-legitimate and ecologically-sensitive development processes might look like in practice is tackled in more depth in chapters 2 and 6.

This conceptual work brings me into conversation with a third, broader tradition of democratic theory in political science. Over the past century, democratic theorists have largely sorted themselves into one of several opposing camps—liberal democracy versus republican democracy, procedural democracy versus discursive democracy, representative democracy versus deep democracy. By synthesizing recent scholarship on "ecological democracy" and "technological democracy," I attempt to sidestep these entrenched debates by refocusing analysts' attention on new sites and expressions of democratic activity. As stated above, I am not interested here in developing an ideal theory of democracy. Rather, my goal is to describe what democratic practices look like on the ground. Political scientists have shown that democracy takes different forms at different times and in different places. As liberal democratic institutions are tested around the world, do energy transitions open up the potential for a new understanding of democracy, and, more importantly, for new democratic practices, to take shape?

Answering this question will require a detour into the analysis of political power, to better understand how power functions in contemporary social systems, and how political power can be directed toward democratic ends. Some of America's most prominent democratic theorists, including the likes of Ian Shapiro, argue that scholars of democracy have given insufficient attention to power. (Shapiro 2003) This observation points democratic theorists in a productive direction, but also reveals the need for more robust conceptions of how power operates today.

A deep dive into the history of wind power may seem like an unusual way to gain insights into innovative expressions of political power. It is true that, in many ways, the discussions in the following chapters depart from the traditional subjects of empirical studies by political scientists. Governments, policies and politicians are all important players in energy networks, and they will feature prominently in the story I have to tell. The policy landscape, policy actors and the mechanisms of policy change are all subjects of sustained discussion in chapters 3, 4, and 5. What I call "habitat formation" is emphasized as a critical stage of policy development. But my focus on wind technology intentionally decenters institutional politics, in an effort to draw attention to less-noticed sites of political contestation, where novel democratic capacities might be built.

A fourth and final goal of this work is to offer a demonstration of what interdisciplinary political research can look like, and what it has to offer students of politics. If political scientists want to contribute to addressing the multifaceted problems of the 21st century, then they will have to venture beyond familiar terrain, forming new competencies and alliances. It is through collaboration and cross-pollination employing a range of disciplinary perspectives and tools that the solutions to the problems of the next century will be found. Yet communication and collaboration across these disciplinary divides remains sporadic and partial, frustrated by numerous institutional, epistemic and methodological commitments. I hope this study will make a small dent in further eroding the disciplinary borders that wall off overlapping investigations in politics, technology and ecology. I have found substantial resonances in work on energy and the environment across university departments, government agencies, business sectors and activist communities. This study is intended to position my own research agenda at these intersections, through my efforts to more thoroughly integrate the analysis of technology, and the methods and concepts of ecology, into my home discipline of political science. In the process, I hope to facilitate more cross-boundary interaction and exchange.

Foucault instructs the analyst of political power to search for its traces in its effects, and to attend to the techniques through which these effects are produced. This study takes that injunction seriously, drawing on the expertise of engineers and social studies of technology to better understand how technical codes, organizations and infrastructures shape the expression of political power in contemporary societies, and how these expressions of power evolve through time. When looking closely at the technological elements of political life, the boundaries between the human and the natural, the ideological and the material, agency and structure, begin to blur. It is precisely in such dense, teeming and underexplored terrain, when the varied dimensions and components of political phenomena become difficult to disentangle and distinguish, that the insights of field ecologists are particularly helpful.

To the extent political ecology is an organized and active field of research, it has traditionally been focused on supporting green activism, political parties, and policies. Few social scientists have attempted to directly apply the methods and concepts of field ecologists to the analysis of political phenomena. The ecological mode of explanation I detail in Chapter 2 is well-suited to studying phenomena that are overdetermined, systemic, and nonlinear. One recent social scientific work that approximates the explanatory strategy I am advocating here is the eminent James C. Scott's *Against the Grain: A Deep History of the Earliest States*. Scott compellingly illustrates how Neolithic city-states were "agro-ecologies" that could only exercise power effectively within a narrow "sweet spot" of environmental conditions. (Scott 2017, 220)

What is unusual (for an American political scientist) about Scott's approach is not only how he frames his conclusions about state formation and disintegration in ecological terms, but the method he adopts in constructing his argument. He characterizes his aims as "specifying the conditions of elementary state making," and thus also "the conditions under which state formation is unlikely or indeed impossible." He describes those conditions as necessary but not sufficient for state formation and persistence, more of a Weberian "'elective affinity' rather than cause and effect." (Scott 2017, 117-126) Because the fall of Neolithic kingdoms was usually overdetermined, "a coroner-archaeologist would be hard-pressed to single out a particular cause of death."

Furthermore, external environmental conditions and events, such as the Little Ice Age "massively constrain what is ecologically possible." (Scott 2017, 188-190)

This study mimics the narrative strategy Scott employed to describe the life histories of early civilizations (a method, it should be noted, borrowed from and still central to the biological sciences). I deepen this approach to historical research by integrating concepts and techniques from some of the leading American naturalists of the twentieth century. And while Scott's evidence is primarily secondhand, drawn from the archeological literature, the history of Danish wind technology presented here is derived from my own analysis of far more granular empirical data, much of it gathered from direct field observation.

When sociotechnical systems and their environments are the subjects of inquiry, identifying simple causal pathways becomes an extraordinarily complex task. In most instances it will not be feasible at all, since the sheer number of variables involved and the level of precision needed make assembling and managing the required data virtually impossible using existing tools. In a recent worldwide study of wind energy development, Scott Valentine identified 32 different social, technical, economic and political factors that renewable energy policy analysts should consider. "The interplay between these influential variables is so complex and contextually bound that attempts to quantify relative influence are highly prone to error," Valentine concludes. "By extension, attempts to identify universally valid truths are futile." (Valentine 2015, 343) This recognition that, for many contemporary subjects of concern, efforts to craft mechanistic and general theories are not only impractical, but also undesirable, requires a reconsideration of the goals and interventions of social researchers.

One insight I draw from this methodological morass is the need to develop a greater appreciation for context in social research. This study begins from the moderating admission that the analysis of each unique case must proceed somewhat differently, remaining cognizant of local circumstances, and watching how individual actors and systems adapt to their social and natural environments, as well as their dynamic responses to changing environmental pressures and historical contingencies. Energy technologies will almost certainly evolve in distinctive ways in different settings.

An ecological perspective has the benefits of more clearly seeing the systemic dimensions of phenomena, and the relations of parts to wholes in real-world processes, rather than attempting to isolate variables in simulated settings. These strengths of an ecological approach in describing affinities and interactions within local contexts, and the fine-grained knowledge such a method produces, can be used not only to explain how particular niches and complexes develop and function, but also to encourage the growth of desired formations and relationships. What ecological methods sacrifice in capacity for the dissection and mechanistic control of phenomena, they make up in the ability to observe, to think, and to intervene holistically, responsibly and creatively.

1.4 The journey ahead

To summarize what has been outlined above, the plan of this dissertation is as follows: Chapter 2 engages with recent developments in the study of democracy and political power, and proposes a new approach to "ecological democracy." After introducing one groundbreaking wind development in Chapter 2, the historical analysis of the Danish case begins in earnest in Chapter 3, with a survey of the conditions out of which wind technology first arose as a revolutionary alternative to the fossil fuel-dependent energy systems of the 1970s. I use this scene-setting to explain how an ecological niche formed in Denmark to support the first generation of wind development. Chapter 4 follows that history into the 1980s, and takes a closer look at the efforts of pioneering actors in the wind sector to expand, refine and entrench this embryonic sociotechnical network. Chapter 5 explains how wind energy went mainstream in Denmark in the 1990s, as private capital flooded the development community, and the renewable transition shifted gears from a fringe movement to a national priority increasingly codified in state policy. The closing sections of the chapter examine how national and local policies interact in shaping outcomes for wind developments in Denmark today. Chapter 6 addresses the growth after the year 2000 of offshore wind, and its consequences for the community development models that had thrived in decades past. With Danish wind development reaching new heights, but facing an uncertain future, the chapter closes by summarizing the dissertation's major findings about the forces that molded Denmark's energy system into its current configuration, what that historical evidence teaches about the broader processes of evolution in sociotechnical systems, and whether any evidence can be found of novel and sustainable democratic practices emerging from this period of transition.

Political scientists have grappled extensively with questions of democracy, but very little with technology, and even less so with ecology. These omissions strike me as substantial oversights, since human societies have always depended on technological apparatuses to fulfill core social functions, and thrived within narrow ecological bounds. What sorts of sociotechnical systems can flourish on a rapidly changing planet?

Humanity is currently in the midst of a dramatic transition in how it produces and consumes energy. Can this period of realignment be leveraged to deepen, to expand, to strengthen democracy? What makes a technological system more or less democratic? What can be accomplished through democratic modes of technological development, and what are the limitations of these approaches?

Ultimately, the questions addressed in this work are exercises in political imagination. Ecological thinkers since at least Aldo Leopold have argued that an expansion of our moral categories and communities will be necessary to orient our societies toward more responsible environmental stewardship. Jedediah Purdy, in a recent historical survey of American discourses on nature, attributes the culture's inability to arrest ecological decline to an atrophying of environmental imagination. "Imagination is intensely practical. What we become conscious of, and what we believe it means—and everything we leave out—are keys to navigating the world," he writes. "Imagination also enables us to do things politically: a new way of seeing the world can be a new way of valuing it—a map of things worth saving, or a future worth creating." (Purdy 2015)

What Denmark's remarkable success cultivating a vibrant wind sector demonstrates above all is that it *is* possible for a modern society to deconstruct ingrained institutions, practices and infrastructures, and rebuild them in more sustainable forms. This study examines the technological and political dimensions of that transition, in the hope that readers everywhere will draw lessons for stretching their own imaginations, beyond the narrow and brittle categories inherited from generations past, and find inspiration to begin building a world with a future.

Today, Danish wind power is a multibillion-dollar, multinational industry, employing tens of thousands of people, and supplying more than half the nation's electricity. Fifty years ago, only hippies in the hinterlands dared to prophesy such a future for wind energy. In the late 1970s, a ragged band of dreamers, dissidents, outcasts—members of a movement even now kept at arms length from polite Danish society, risked their incomes, with little thought to recouping their investment, on a 25-story kinetic sculpture. It was built as practical propaganda, visible for miles around, proclaiming the power of the wind. In the offices of utility executives, over snifters of schnapps, it must have been laughed off as a massive folly. The men in suits envisioned a future in which fission reactors would produce electricity too cheap to meter. Despite having all the conventional forces of society aligned behind them—expertise, policy, industry, the momentum of the established culture—those plans fizzled, without a single nuclear plant breaking ground. And what about those ungainly wings—lifted with few resources but the sweat equity and idealism of a small army of amateurs and adolescents—powering that ill-advised gamble? They still beat out their steady rhythm, singing of the reliable breezes blowing off the North Sea; though the precise timing and direction of those breezes remain maddeningly difficult to predict.

How were the combined powers of billions in investment capital, political elites, and the secrets of the atom bomb ever bested by a bunch of stargazers from cow country? The story begins there, with an unlikely triumph. To the reader, I pose the following question: armed with the lessons of what Danish ingenuity has achieved, how much further, how much more quickly, can the cause of sustainability be advanced around the globe? The time for transformative actions grows short. What latent powers will be discovered, resting in which neglected locales? Who will find the courage for that next bold step into dark and wild territory, mapped only in dreams?

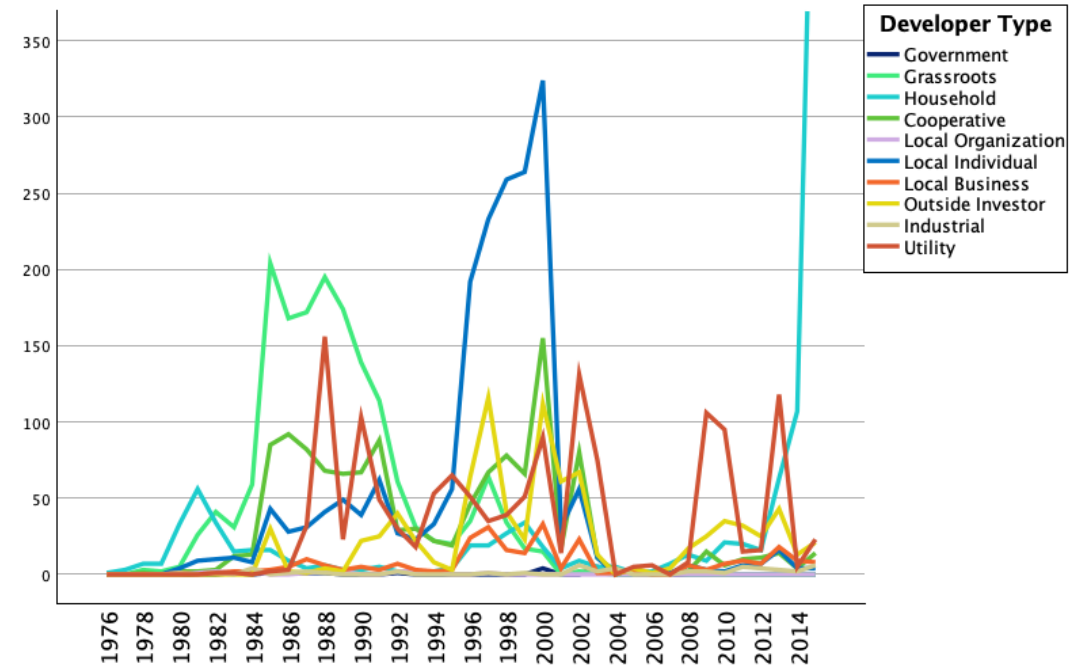

Figure 1.1. A portrait of Danish wind development, from 1976-2015, organized by the number of turbines installed by different types of developers. A full description of the typology of developers can be found in Appendix A.

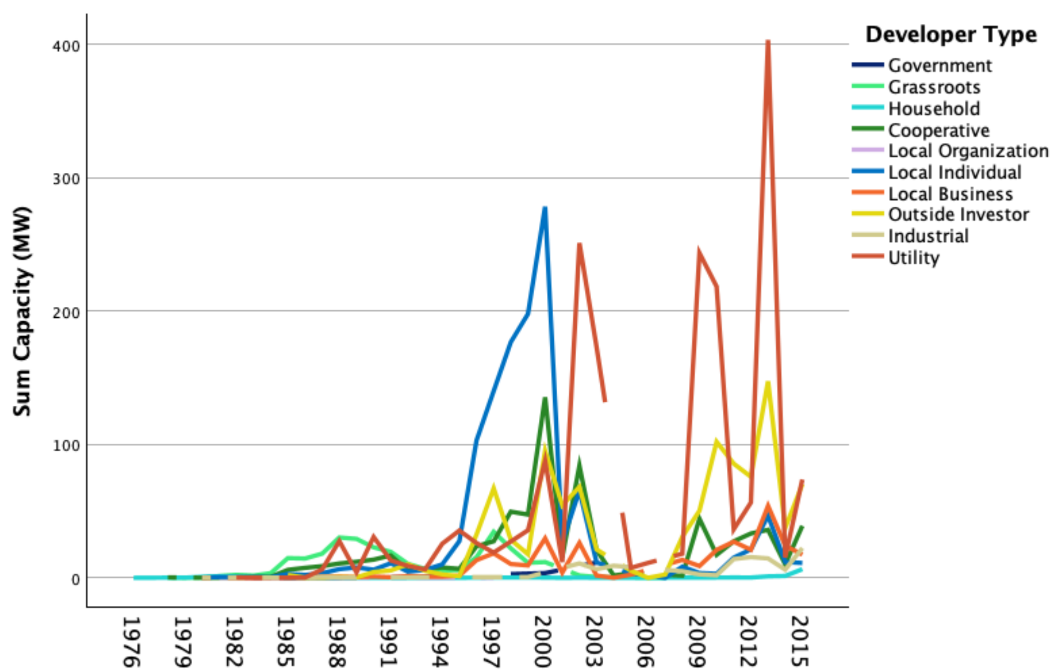

Figure 1.2. A portrait of Danish wind development, from 1976-2015, organized by the capacity (in MW) of wind power installed by different types of developers. A full description of the typology of developers can be found in Appendix A.

Notes

1. A June 7, 2021 press release from the U.S. National Oceanic and Atmospheric Administration reported that the agency's Muana Loa Observatory in Hawaii measured atmospheric carbon dioxide levels reaching 419 ppm the previous month, the highest level ever recorded in more than six decades of tracking. This increase was consistent with annual averages over the last decade, and "there was no discernible signal in the data from the global economic disruption caused by the coronavirus pandemic." https://research.noaa.gov/article/ArtMID/587/ArticleID/2764/Coronavirus-response-barely-slows-rising-carbon-dioxide

2. The literature on climate change is voluminous. The most comprehensive research on observed climate changes, future projections, adaptation and mitigation strategies has been prepared by the United Nation's Intergovernmental Panel on Climate Change. The organization's wide-ranging and frequently-updated library of reports is available for download at their website, https://www.ipcc.ch. Some highly readable books on the threats posed by climate change and the need for transformative solutions include Bill McKibben's *Eaarth*, Al Gore's *An Inconvenient Truth*, James Gustave Speth's *The Bridge at the End of the World*, and James Hansen's *Storms of My Grandchildren*.

3. Regular updates on the utilization of wind energy in Denmark are published by numerous sources, including the Danish Energy Agency (www.ens.dk), the Danish Wind Industry Association (www.windpower.org), and industry marketing organization State of Green (www.stateofgreen.com). While the trajectory of wind energy generation in Denmark has moved steadily upward for decades, this growth is occasionally punctuated by slowdowns in new installations or by variations in the weather from year to year. In 2018, a decline in wind generation of about 5% was blamed on an atypically calm spring. (State of Green 2019) Since the wind is a variable resource, wind turbines' annual power generation will fluctuate in accordance with weather patterns. This variability has a number of interesting consequences. Wind energy detractors like to claim it endangers the reliability of the electric grid, but this has rarely proven to be the case in operation. Instead, grid managers have developed creative solutions for adapting to the technical challenge of variable generation capacity, such as improved meteorological forecasting, expanding the grid through interconnections, maintaining backup generation capacity and investing in storage technologies (see Chapter 6). The variability of wind generation also makes the analogy to agricultural production more direct, as wind farmers might reap a bumper crop one year, and a more meager harvest the next, depending on climatic conditions.

4. Statistics on national electricity mixes are regularly updated on the websites of the countries' respective energy agencies: Danish Energy Agency (https://ens.dk/en), German Ministry for Economic Affairs and Energy, (http://www.erneuerbare-energien.de), United Sates Energy Information Administration, https://www.eia.gov. Additional sources of data cited in the preceding two paragraphs included Green Power Denmark 2023, State of Green 2021, and Enerdata 2023.

5. For a more detailed account of the history of Danish wind turbine manufacturing, and an analysis of how many of today's largest firms can trace their technology back to Danish engineering, see "Why Do Wind Turbines Have Three Blades?" (Darrow, forthcoming)

6. The term "sociotechnical system" was popularized in the works of historian of technology Thomas Hughes, and his approach has close affinities to Bruno Latour's actor-network theory. I use the term to refer to a broader literature centered in science and technology studies that draws from these and related influences, including social constructivist approaches in sociology and a substantial European community writing on the social dimensions of technology. These sources are discussed in additional detail in Chapter 2.

7.The centrality of energy to human affairs is easy enough to appreciate in colloquial terms; just consider the many different usages of the idea—household chores, conversations, even leisure activities require energy; personality types, moods and behaviors can exhibit an excess or deficit of energy; audiences, crowds, and voters can all be energized; even a passage of music or prose can be described as "energetic." The ubiquity of energy in the form of petroleum, and the dependence of so much of modern life upon it, is readily apparent in daily life, and has been exhaustively cataloged by scholars and journalists. The scientific meaning of energy is harder to pin down. For a detailed intellectual history of the concept, see Jennifer Coopersmith's *Energy, The Subtle Concept*. In historical succession, energy has been understood as a life-giving essence, as a motive force, and as the mechanical capacity to do work. In modern, relativistic physics, energy can be defined as "the minimum of the action taken through time." As is apparent from that definition, energy is a notoriously slippery concept in the physical sciences, continuously being converted among a multitude of forms, forms which can be captured only in mathematical formulae. A contemporary physicist grasping for a common-sense definition might attempt to "explain energy as the 'go' of the universe, what makes things happen." (Coopersmith 2010)

8. For a theoretically-sophisticated analysis of how energy systems pattern consumer behavior, see Matt Huber's *Lifeblood: Oil, Freedom, and the Forces of Capital* (2013), which examines how oil consumption is embedded in American culture.

9. While much of the literature treats Denmark's experience with wind power as an unqualified success—see Nielsen 2002 as a typical, not especially grievous example, of the many summary overviews of the subject. It is the industry associations, tourism bureaus and journalists who are more actively engaged in mythmaking around the wind industry. But the minority of scholars who take a more critical and nuanced approach deserve recognition. Among them, the work of Peter Karnøe of Copenhagen Business School has had particular influence in shaping the perspective of this dissertation. Karnøe, discussed at greater length in chapters 2 and 3, was among the first to point out that the "progressive, democratic, and rural political interests" that drove the first generation of wind development have largely disappeared as the utility sector regained control. (Jorgensen and Karnøe 1995) Bonnie Ram of the University of Delaware has, in

recent years, been arguing that the Danish wind industry's "past is just prologue," as the sector has grown from its grassroots origins to an industrial scale. There are few outright critics of wind power in the Danish scholarly community. Probably the most visible skeptic is economist Bjørn Lomberg of the Copenhagen Consensus Center, whose contrarian takes seem more interested in promoting a Hardin-esque free market environmentalism, coupled with a Singer-esque utilitarian ethics, than in conducting any serious analysis of the domestic wind sector.

10. Notable contributions to this literature include David Nye's *Consuming Power: A Social History of American Energies* (1998), which traces the evolution of successive energy systems and their social consequences throughout the history of the United States. Christopher Jones' *Routes of Power: Energy and Modern America* (2014) offers a more detailed look at the transition from a coal-based to an oil-based society. Timothy Mitchell's *Carbon Democracy: Political Power in the Age of Oil* (2011) analyzes the effects of globalized petroleum networks on democratic politics around the world.

CHAPTER 2

VISIONS: DEMOCRACY AND TECHNOLOGICAL TRANSITIONS

"100,000 labourers built the pyramids. They were slaves. Peasants forced into service by the Pharaohs. With their labour, they founded the fame of the kings, like so many others before and since. The Taj Mahal in Northern India was built by slaves who were executed after completing their work, not to reveal construction secrets to other rulers… In today's Denmark, construction companies purchase the labour of workers, who have only that to sell. They build skyscrapers in concrete and glass. In Persia, underpaid workers built the Eiffel Tower of Tehran in honour of the Shah. With oil money… In Tvind in Jutland, workers, teachers and students build their own power station for their own schools - the world's largest windmill, with their own money. They build it together, for the sake of natural energy, for the sake of human society, against slavery, monopolization and nuclear power…

There have been lots of difficulties. From the very beginning we could count on them … By now we are really enthusiastic about them, because we have discovered that it is through solving these difficulties that we move forward… We were able to solve them together - and this gave us a strength that can never be bought from others. A strength created by us, the ordinary people, when we organize together and build our own world… Every day, for half a year, the twenty of us have been running back and forth with steel, with concrete, with messages, with coffee and with visitors. We have become comrades in the struggle both with nature and with the forces of society…

While the experts from F.L. Schmidt advised us against trying to cast the tower without their expensive assistance, their so-called wind power expert abused us over the phone, calling us 'you who are destroying the cause of wind power by trying to build a windmill.' We answered back by expanding the windmill group with 7 more people… While boards of directors of one foundation after the other, state or private, nosed through our applications to find the smallest reason to say no, no and again no to support our work, ordinary people flocked to the building site from all over the country. To see, to talk, and to tell us their thoughts about energy… And while Danish state television again and again gave broadcasting time to the revelations of the Minister of Commerce about the blessings of nuclear power, every week at least 500 people confided to the windmill team and the students at the schools that everyone is in favour of wind power and that only upper-class people want nuclear power… We grew away from the lack of confidence that ordinary people like us can do such a thing as building a large wind power station, our fear of the materials, our ignorance of the laws of physics and the true extent of the forces of nature, our lack of knowledge of even the most elementary concepts of the technological world, this fragmented, split world of experts that no one today can overview, and our habitual thinking about the ability of girls to build anything at all."

- From the Tvindmill Construction Team, translated and reprinted at tvindkraft.dk

2.1 Introduction

The task of remaking global energy systems seems impossibly daunting in the abstract, with all that is implicated in the project. There are national interests, international alliances and geopolitical rivalries at stake; there are entire economies, supply chains, cultures and discourses organized around fossil fuel production and consumption to contend with; there is all the built infrastructure, the industries, the jobs, the ways of life. It is hard to know where to begin.

Thankfully, the renewable energy transition has already commenced, so the question of beginnings becomes a historical one. And, as always, the historian is presented with choices of entry points. The Danish tradition alone is so rich in experience with wind power, one could choose to trace its origins to Poul la Cour's 19th-century experiments, or Johnnes Juul's postwar Gedser mill; the early blacksmith mills deserve more prominent billing than they typically receive (all three pioneering designs are discussed in later chapters). But in retrospect, there may be no more significant episode in launching Denmark's wind energy revolution—and certainly no more dramatic, in terms of scale and ambition—than the construction of the Tvindmill, raised on the spartan campus of a teacher's commune, on the outskirts of an unremarkable railway town, on the western edge of Jutland, as far from the centers of power in Copenhagen as one can get without falling into the sea. There, in the mid-1970s, a shaggy network of amateurs mounted an audacious construction project, armed with a radical political vision, and a practically-oriented philosophy instructing them to build.

Like many Western democracies, Denmark spent much of the 1970s weathering one of the most severe energy crises, and resulting economic downturns, in the nation's history. Beginning in 1973, the fiercely independent but resource-poor Danes had been brought to their knees by the OPEC oil embargoes. Car-free Sundays, skyrocketing home heating bills, and stagnating growth contributed to public unrest and new challenges to the postwar social and political order. With energy security at the top of the policy agenda, and the official plan to build several nuclear power stations stymied by public protests, the utilities felt they had no option but to continue relying on fossil fuels, the discovery of North Sea oil offering temporary relief. It was left to the people to imagine another way forward.

So on a gray morning in May 1975, four hundred men, women and children, outfitted in bell bottoms and Faroese wool sweaters, gathered in a field outside Ulfborg, 10 kilometers from the North Sea and on the way to nowhere, shovels in hand, and together broke ground on the foundation for Tvindkraft. It would take three years and thousands more hours of volunteer labor to complete the mammoth undertaking—behind schedule, over budget, and, against all odds, achieving major breakthroughs in renewable energy technology, succeeding where the world's leading engineers had failed. (1)

The windmill project was hatched inside Tvind, a collective of associated schools and charitable organizations that grew into an international network throughout the 1970s. Under the charismatic leadership of Mogens Amdi Petersen, the group attracted thousands of adherents and a steady drip of controversies.

The origins of Tvind can be traced to a communal house in Odense, Denmark's third city, where Amdi Petersen resided in the late 1960s with a group of long-haired anti-nuclear activists and idealists. In the hippie spirit of the times, the housemates purchased an old bus and planned a tour of the Far East. Participants later credited that first bust trip with deepening their relationships, sharpening their ideology, and inspiring Petersen to propose an international school on wheels. Even then, Petersen exhibited the ability to influence people with his intellect and ambition. He entertained illusions of grandeur, according to former associates, comparing their bus trips to Mao Zedong's Long March. "He considered himself a revolutionary, a leader of a movement that would take place in Denmark, or even all of Western Europe," one close associate told journalists. (Smith et al. 2016)

By the early 1970s, the Travelling Folk High School was officially accredited by the Danish Ministry of Education. With the motto "the world is our classroom," five school buses were retrofitted with beds, desks and kitchens. The courses began with several months of practical education in subjects like bus maintenance and communal living, as well as book learning about the trip's destinations. Foreign trips lasted four months, followed by several more months back in Denmark in which students would produce reports on what they had learned in their travels. The first bus excursions took teachers and students through Turkey, the Middle East, and on to India. The school grew quickly to more than 200 students, and new trips were planned to Latin America and later Africa. (Jamison 1977)

The success of the traveling schools inspired the group to extend its educational philosophy to the training of schoolteachers, so a four-year college was established, Det Nødvendige Seminarium, "The Necessary Teacher Training College." Abandoned farmland was purchased on the outskirts of Ulfborg to house the teachers' college and the traveling school. The students and teachers spent much of the fall and winter of 1972 constructing the buildings in which they would live and learn. A third school, an alternative high school catering to troubled Scandinavian youth and emphasizing self-directed learning, was established on the premises soon after. By 1974 the community living on the Tvind campus swelled to around 800 people. (Jamison 1977)

At around the same time, the core members of Tvind formed the Lærergruppen, or the Teachers Group. Members of the Teachers Group made up the leadership of Tvind's growing network of schools and charities, and they adopted a communal lifestyle. The Teachers Group is organized around principles of common economy, distribution and time. The teachers' state-paid salaries are pooled into a shared fund, of which only pocket money is returned to members for their personal use. The rest of the money funds Tvind projects around the world, as well as covering the members' room, board and basic needs. Decisions about how to allocate human and financial resources are made collectively and by consensus, though many skeptics claim Petersen and his lieutenants pull the strings behind the scenes. Bourgeois notions of privacy and comfort are sacrificed in favor of collective pursuits, and some former members say coupling and spending time with family were actively discouraged.

Tvind's unorthodox methods have long had detractors. Critics regularly liken the insular Teachers Group to a cult, and that stigma has stuck to the organization. Most Danes I spoke to view Tvind with bemusement, as somewhere between kooky and criminal. It is easy enough to find accounts from embittered former members alleging all manner of improprieties—including gross negligence in the supervision of minors, sexual predation by leadership, brainwashing, intimidation and suppression of dissent. In the most serious documented incident, eight teachers drowned in 1983 piloting a Tvind-owned vessel of doubtful seaworthiness through a February gale in the North Sea.

Experienced seamen stated the ship was too small to be sailing in such bad weather, and questioned the competence of the crew. (Thomsen 1998) This sort of amateurishness, bordering on recklessness, is typical of other Tvind projects, the windmill included.

The descriptor “Maoist” gets used with some frequency to describe working and living conditions on the Ulfborg campus, and exposés of Tvind have become regular features in Danish media. In recent decades, several high-profile court cases accusing Tvind leaders of financial mismanagement have further tarnished the organization’s public image, and left insiders feeling besieged and persecuted by the state. Current Tvind members contest the negative characterizations of the group, and say the scrutiny only strengthens their commitment to one another. To many on the outside, the principles of the Teachers Group look authoritarian and exploitative, submerging the interests of the individual to the will of the group (or merely the will of its guru). To group members, these same principles are what free them from the servitude and conformity of a capitalist society. “The more we are together, the more different you can be. You have an opportunity to develop as a person,” said Anna Hoas, a graduate of the traveling high school programs and a Teachers Group member since 1982. “I feel very safe being a part of this, because I have everything I need.”

Hoas only keeps 20% of her teacher’s salary for personal use, and works collectively with a small “cluster” of 10-20 other teachers. “It frees up a lot of RAM in my brain,” Hoas said of the arrangement. “My prime mission is to make opportunities for unfortunate young people in Denmark.” (2)

Hoas estimated that of approximately 50,000 people who have been affiliated with Tvind through the decades, perhaps 500 have had a bad experience. The lifestyle and philosophy are decidedly not for everyone. There have been too many complaints, from too many sources, about the organization and its leadership to entirely dismiss the persistent rumors. Tvind is no utopia. And yet as a visitor to the Ulfborg campus, I left with the impression that this bastion of faded hippiedom is more misunderstood than malevolent. The Tvind campus today is certainly more open and welcoming to outsiders than the average corporate headquarters. Tvind's rank and file members are friendly and thoughtful; some may dismiss them as hopelessly idealistic, but on a small scale and in relative anonymity they appear to be living by their principles to a degree few Westerners achieve, sacrificing some comforts of modern life to pursue social and political projects to which they appear genuinely committed.

The present work is not concerned with adjudicating the charges against Tvind. This portrait of the group is presented in an effort to describe the historical and cultural context in which Tvindkraft was built. The goal is to understand how the turbine was raised, and to evaluate the consequences of such methods of renewable energy development. While Tvind's politics may be controversial in Denmark, they are a boon to analysis, providing an unambiguous data point for assessing the fortunes of competing development pathways. Tvind's philosophy is both practical and nakedly political. What can be accomplished when starting from such premises, and adopting such practices? It seems reasonable enough to ask whether Tvind's culture of risk-taking and challenging establishment thinking were the very qualities that helped the windmill team succeed. German and American R&D programs had attempted similarly ambitious experiments with wind energy. Even with nine-figure budgets and the world's most talented engineers at their disposals, these experiments failed in spectacular fashion. Frequent Tvind collaborator and cheerleader Preben Maegaard, of the Nordic Folkcenter for Renewable Energy, argues that if a more recognizable and palatable organization had accomplished anything nearly as innovative as Tvindkraft, they would have been lavished with prizes and grants. Public disapproval of Tvind's leftist ideology, he claims, has led industry and academia to undervalue the group's contributions to the development of wind technology. (Maegaard 2009)

Many aspects of the development of Tvindkraft were quite remarkable, but it is not my intention to mythologize the windmill or its construction. It was a messy process and an imperfect product; mistakes were undoubtedly made. The participants admit as much. One can debate the extent to which Tvindkraft exemplifies Danish engineering, or its place in the history of the wind industry. But it remains an undeniably singular technological artifact. It was always intended to make a statement, and does so even more loudly today, sporting a red-and-white checkered paint job designed by one of Denmark's most storied architectural firms for the turbine's 25th anniversary. Peering upward from its concrete base, Tvindkraft, looks almost medievally clunky, weighty, unsubtle—a gauntlet thrown down in an ongoing dispute over the meaning and composition of the good life.

The windmill project embodies Tvind's philosophy of marrying practical and political goals. In this sense, the Tvind teachers were more conscious than many in the wind sector today of the fact that infrastructure development—with its attendant benefits for organizational and skills development—is a powerful means of political development.

On the one hand, the decision the Teachers Group made in 1974 to allocate significant funds to the project was an immediate, practical necessity. They took on substantial financial risk, given the unprecedented nature of the challenge and their total lack of experience. It is hard to imagine any insurer, lender, or corporate CEO would be so daring to greenlight such a high-risk investment on the terms Tvind members accepted. But Denmark was in the midst of an energy crisis, and it was December. They were cold and in danger of going broke. There didn't appear to be a lot of attractive alternatives. Building the turbine themselves, much like they had built their own classrooms and sleeping quarters, was a cost-saving measure. According to Mette Bryndum, a member of the windmill construction team, their experiences the previous winter were fresh on the teachers' minds, when the price of a liter of heating oil had nearly quadrupled. (Tvindkraft.dk)

But Allan Jensen, who has been the turbine's caretaker since the early 1980s, stressed that the project was always seen by Tvind members as a hybrid of practical and political aims, confirming other accounts that conclude the same. Today Allan shares responsibility for the windmill with his partner, Britta. Britta manages the books and Allan supervises maintenance. "When we built the windmill, we said we were building it against monopolization, for clean energy, and against nuclear energy," Britta said.

"…And to show that it was possible for ordinary people to do such a thing," Allan chimed in. (3)

Amdi Petersen is often credited as the visionary behind the Tvindmill, its chief proponent in the face of delays, redesigns, and cost overruns, and the final arbiter in many key decisions. In his public messaging, Petersen discussed the thinking behind one critical decision:

> (…) our next step will be the development of some quite concrete models. For example, we can make moulds in which people can make their own blades. They

> are often the biggest problem. So we will start doing that very soon… That is quite in the spirit of the wind. It cannot be monopolised. Nobody needs to hold back. Just come… all our experiences are there for the benefit of everyone." (Maegaard 2013)

Petersen's explanation reveals several key aspects of Tvindkraft's importance to the history of wind technology. Although contemporary engineers are sometimes dismissive of Tvind's bespoke design and low-stress operation, its technical innovations, as Preben Maegaard argued, cannot be denied, and are probably underappreciated. Maegaard and others reasonably suggest Tvindkraft deserves as much credit in advancing turbine design as any other early design. It provided proof of concept for many components that have now become industry standard, such as pitchable blades for stall control and advanced electronic controls; its synchronous generator has only more recently caught on, as manufacturers are increasingly producing direct drive turbines. (Maegard 2009) Certainly the most significant imprint Tvindkraft left on the current technological state of the art was in its blade design. Tvind members were among the first to manufacture large fiberglass wings, with an aerodynamic design and an innovative solution to wrapping the glass strands around the blade root, which had been a common failure point in many early turbines.

The idea for this revolutionary blade design came from Ulrich Hütter, the foremost wind engineer in Germany. A decade later, he gained notoriety with the total failure of the massive Growian, a test turbine raised northwest of Hamburg and dynamited after only a couple hundred hours of operation. With Tvind, he would make a far more lasting mark on the wind industry. Hütter sent Tvind his designs for the fiberglass blades, and even visited during construction. So, like all myths, the idea that the turbine was the product of total amateurs is of course a little more nuanced in reality.

The windmill team did have excellent expert consultation and engineering assistance. Along with Hütter, professers from the Danish Technical University—DTU, the hub of Danish nuclear research—provided free technical support. Engineers Peter Sten Andersen, Per Lundsager, Helge Petersen, Erik Lundtag Petersen, and economist Frede Hvelplund all made direct contributions. (Nielsen 2001) The original design for the windmill only called for providing heat to the school buildings, since the team did not believe they could sufficiently control the power input from the mill to generate smooth electricity. Ulrik Krabbe from DTU is credited with providing the solution to that limitation, offering his research team to design a power converter. As a result, the Tvindmill splits its power output evenly between heat and electricity. Krabbe praised the "charisma and awe-inspiring organizational talent of Amdi Petersen" for convincing him to join the "thrilling" project as a pro bono consultant. (Nielsen 2001, 94)

But while the benefit of all this expert advice was essential to the outcome of the project, it should be looked at as precisely that—advice. These academic experts played a role in the project similar to the engineering consulting firms hired by corporate developers today. The Tvind team farmed out some of the technical work, but stayed involved every step of the way, and made all the final decisions. While the question of who designed the Tvindmill could be disputed, given the input provided by Hütter and DTU, the identity of the developer is clear—it was a Tvind project.

The amateur input in the project was real as well; it was pervasive, often decisive, sometimes breathtakingly bold. The head engineers, in practice, were the windmill team, a rotating cast of a few dozen Tvind students and teachers who worked full time on construction, in exchange for their room and board. Britta Jensen, an alumna of the construction team, estimated that, at its largest, the group grew to 35 members whose average age was 21. (Naylor 2023) The group met constantly throughout construction, reviewing plans and solving unanticipated problems, sometimes with the input of expert advisers. All options on the table were debated and decisions were made by consensus. Expert recommendations were on occasion rejected in favor of an alternative route. Some of the cribbed-together workarounds the team devised were ingenuous. When they realized they needed twice as much concrete as they had originally expected, a potentially budget-busting miscalculation, they bought an old mixer and learned to pour concrete themselves. The blueprints for the wings may have come from Hütter, but the Tvind team had to bring them off the page, pour them into the molds, and lift them to the sky. No Dane had ever poured fiberglass for a windmill before. The teachers certainly didn't know how. Their do-it-yourself ethos carried the day. A platoon was dispatched to master the trade, taking classes and practicing by producing several fiberglass boats. The technical advantages of making turbine blades from fiberglass, in everything from aerodynamics to cost, proved so significant that they became a universal feature of commercial machines soon after early manufacturers like Vestas picked up the design. The blades that now drive every new turbine off the assembly line can trace their ancestry directly to Tvindkraft. While the larger blades were being fabricated, the team simultaneously worked on a smaller-scale model for a household turbine design that could be widely disseminated. The smaller, 5-meter blade mold was later purchased and commercialized by Erik Grove-Nielsen, the industry's first blade manufacturer, who had a brother on the windmill team, and who outfitted the first Vestas turbines with the blades from that mold.

In perhaps the most idiosyncratic, and most chuckle-worthy, quirk of modern turbine design, the orientation of virtually all commercial turbines today can be read as a visual swipe at Tvind's politics. From a technical perspective, it does not matter which direction a turbine's rotor spins, but it looks unsightly if they are turning in different directions on the horizon. For that reason alone, almost all utility-scale turbines spin in the same direction—clockwise. The Tvindmill was designed to turn counterclockwise. But Grove-Nielsen and his wife were self-described "individualists," and they despised Tvind's collectivist politics. So when Grove-Nielsen started manufacturing blades, his wife convinced him to flip the orientation, so they would spin in the opposite direction of Tvindkraft. (Grove-Nielsen 2013) When Danish manufacturers like Vestas and Bonus, outfitted with Grove-Nielsen's blades, triumphed in the early years of global competition, their blade design became the global standard. All over the world, arrays of wind turbines spin in unison, clockwise, a consensus that spread without controversy or even consciousness, as the outcome of a series of historical accidents, but which can trace its roots back to dining-room-table politics of the Grove-Nielsen household. It's a silly, but vivid, example of how political motives can be obscured in the diffusion of technology.

The clockwise-orientation of today's rotors is also a visible reminder not to overromanticize the influence of Tvind's example. As important as the project was for the development and diffusion of wind technology, many decisions the windmill team made were not embraced by the wind industry that sprang up in its wake. In addition to turning counter-clockwise, which makes no difference in how the turbine operates, the Tvindkraft rotor was also positioned downwind of the tower, which makes a big difference. The windmill team had assumed this design choice would simplify operation, but it ended up creating more headaches for them. Tvindkraft suffered from a flaw common in downwind rotors, which are subject to excessive wear from the shadow created in the airflow by the interference of the tower. As a result, the mill's blades had to be completely replaced in 1993.

The construction process was more often a seat-of-the-pants reaction to new exigencies than the careful implementation of a pre-drawn plan. Major design changes were agreed to and components substituted on the fly. With limited resources, the team frequently had to make do with whatever talent and materials they could find. The main shaft was scrounged from an oil tanker in the Rotterdam scrapyards. The generator was salvaged from a Swedish copper mine. (Christensen 2013) The team was making it up as they went, and it was turning out to be a much bigger and more complicated project than they had anticipated. Construction, originally scheduled to be completed before Christmas 1975, dragged on for three years. Amdi Petersen continued to advocate for finishing the project as costs ballooned from an initial estimate of DKK 1.5 million, to 3 million, and eventually topped 6 million. (Nielsen 2001, 90-94)

While there was no alternative to the literal scrappiness of the Tvindmill's construction—off-the-shelf components did not exist for wind turbines of that size, and there were no experienced manufacturers or installers to turn to—the one-of-a-kind design is still regularly cited in the engineering community as a reason for discounting its importance to the contemporary industry. No one would build such an oddly-configured turbine today, the reasoning goes, it is highly inefficient and impossible to mass produce. It's not scalable. The most common knock against Tvindkraft is its light workload. Because the moving parts in the nacelle were found to produce damaging vibrations at high speeds, the turbine has never been operated at full power. The hulking turbine is rated at 2 MW capacity—large even by today's standards—but at full speed only generates about 900 kW, which it splits between heat and power. (Maegaard 2009) By choosing to run in a lower gear, placing less stress on the machine parts, Tvindkraft has managed to outlive many more technologically-advanced machines. No corporate CEO would accept the sorts of tradeoffs the Tvindmill team did—the sacrifices in efficiency would doom the project's profitability. Today's turbines are tuned to squeeze every last kWh out of their projected 20-year lifetimes.

Of course, Tvindkraft was built in direct opposition to such profit-centered thinking, and in managing to keep the mill running for more than four decades, it has proven to be a savvy long-term investment for the schools. Many aspects of the project—from allowing inexperienced teenagers to make design decisions by consensus, which led to miscalculations and waste, which in turn forced suboptimal design alterations—could be framed as errors, inefficiencies that illustrate the weakness of the Tvind approach to development. But the windmill team should be cut a lot of slack for raising a first-of-its-kind prototype. Few, if any, innovations anticipate all the design features of later generations of the technology; and probably none are launched without significant trial-and-error. It must not be forgotten that the world's leading military-industrial powers made even graver errors when they attempted similar feats of wind engineering. Many early turbine experiments ended in utter failure, at much higher costs. Instead of smirking at Tvind's amateurish development, a criticism that feels like it misses the entire spirit of the project, one could instead choose to emphasize the group's impressive resourcefulness and stick-to-itiveness.

Whatever its shortcomings, on the whole Tvindkraft was a pioneering technical achievement. But it was always intended to be much more than that. Remembering Amdi Petersen's statement quoted above, the project was expressly a "demonstration" of what ordinary people can do, and in a folk spirit of practical education. These were not ancillary benefits, but core components of why and how the turbine was designed and constructed. Without these features, Tvindkraft would have been a very different windmill (or, more likely, would not have been built at all).

Another central plank in Tvind's political project was their stance against monopoly. They did not seek to own or profit from any of their technological innovations. Their discoveries would be for the benefit of all, they would file no patents, and they spread their technical blueprints and methods widely. The influence this knowledge had on the early industry (discussed more in Chapter 3) cannot be overstated.

In an important sense, and something that is often misunderstood about Tvind, this rejection of intellectual property was not a counterculture stance inspired by communist ideology, but the outgrowth of a well-established tradition of rural self-reliance and cooperation that had been practiced in Danish farming communities for centuries. Farmers often pooled their money in business ventures like slaughterhouses and dairies, and to acquire large machinery that no one family could afford on its own. Tvind's open dissemination of technical knowledge was also typical of other early Danish wind experiments. Thus, it would be a mistake to view the Tvind movement as a radical break with mainstream Danish culture. It might be better described as a sort of 1960s leftist twist on a rural Danish tradition of practical education and economic cooperation.

The critical question for this study is how the building of Tvindkraft advanced these broader social and political aims. The group's contributions to the development of wind turbine technology were significant, but would merit little more than a footnote in the present investigation, were it not for the nakedly political intentions behind those innovations. Amdi Petersen and his compatriots were visionaries, in the sense that Sheldon Wolin has used the term, as both an inherited paradigm or worldview and a source of political imagination, innovation and novelty. Wolin's essay only discusses transformative vision in terms of the "acts of thought" of "epic" political theorists, so it's hard to say for certain if his concept can be stretched to include an alleged cult leaders who pour their philosophies in concrete. But it is evident that both the dimensions of vision Wolin describes can be found in Tvind's political program. When the group set out to build Tvindkraft, they were drawing on a rural folk tradition, and also carried with them socialist ideas about communal living, economy and property that informed how they approached technological development. Tvind's leaders were also innovating within and challenging those inherited traditions, and that their ambitions matched the disruptive scale Wolin associates with epic theory. Tvind did not merely want to build a windmill, or heat a school. They wanted to revolutionize the whole of Danish society from the ground up.

It is a characteristically navel-gazing presumption that philosophers are the ones best-suited to critical reimagining of the established order. Wolin pitches the paradigm-shifting philosopher as a sort of political actor, in the sense that speech is an act, akin to a founder or lawgiver. He admits, however, that most, if not all, epic political theorists have failed to transform society in accordance with their visions. Given the unimpressive track record of revolutionary theory, it is somewhat surprising that Wolin does not make more of an effort to identify other, more efficacious, sources of political creativity. (4) But he shares this fixation on the articulation of ideas with other democratic theorists, such as Hannah Arendt and Benjamin Barber, who place practice and action at the heart of political life, yet still prioritize discourse and deliberation as the exemplary democratic activities. It is somewhat puzzling—a riddle that the following pages will attempt to unravel—that philosophers have not given more attention to *technē*, to the practical arts, as a core dimension of political action. To the extent technology is made a focal point of political thought, its colossal modern scale is usually treated as an oppressive external force, closing off possibilities for genuine democratic practice. This prejudice persists in the face of ubiquitous historical examples of political actors consciously leveraging technological projects as means of mobilizing political power and pursuing their political objectives. As both ancient and recent history attest, from the Great Pyramids to the moon landing, kings and presidents and their counselors have never had trouble recognizing the importance of building. Yet for political philosophy, the model of democratic politics is still the assembly, and not the workshop. In spite of these ingrained predispositions toward the armchair, the senate chamber and the seminar room, it remains the case—as Socrates reminds his impatient pupils in *Republic*—that imagining a new world in thought is not the same thing as *making* a new world.

Critically, the Tvind teachers did not content themselves with crafting catchy slogans like “Let 100 windmills bloom,” or with proselytizing in the newspapers, or even with drawing up blueprints. Talking and planning were only preludes to doing. They actively encouraged the flowering of the renewable energy society they envisioned by constructing two of the most innovative turbines to be found anywhere in Denmark, and helping many kindred spirits follow in their footsteps. Theirs was always a get-your-hands-dirty sort of vision. The empirical question that will be tackled in the chapters to follow is how far that vision spread, and how deep its roots sank. What can you get done politically by building a windmill?

The remainder of this chapter aims to understand why political scientists, and especially democratic theorists, have had difficulty even raising this sort of question, and taking technology seriously as a site of political activity. Recent scholarship on "ecological democracy," remains uncomfortably hemmed in by the problem framings and battle lines it has inherited from the broader tradition of democratic theory. The result is a discourse around environmental politics that contains only a thin veneer of either democracy or ecology.

In the next section, I argue that nearly all strands of postwar democratic thought bracket both the environment and technology out of the realm of the political, in no small part because of their reluctance to confront modern mechanisms of power. The following section shows how contemporary theories of multidimensional power shift attention away from institutional or discursive politics and toward technological politics, opening a path to resolving the tensions between modern technology, democracy, and environmental sustainability. This return of politics to the material world inspires me in the next section to propose adopting an ecological perspective on social and technological change, and I discuss how insights can be mined from the ecological sciences and adapted for this purpose. The closing section of the chapter revisits Tvind in the present, to examine how the group and their radical political agenda have fared.

2.2 Democracy and Technology

The Tvind ethos and its manifestation in a grassroots renewable energy project were as much products of the historical moment as they were inspired by Danish folk traditions or Maoist philosophy. Tvind was an outgrowth of the counterculture and environmental movements that swept Europe and the United States during the heady and hopeful 1960s, when a wave of social unrest and activism appeared to signal a democratic renewal on the horizon. The movements achieved some lasting political victories in creating green parties, environmental agencies and regulations, and pushing environmental science into the mainstream. But they also grew more cynical and alarmist through the setbacks of the 1970s, before retreating in the 1980s, beat back by a resurgent establishment in the form of the neoliberal state, trickle-down economics, and consumerism, all awash in a seemingly inexhaustible well of cheap oil.

For these political movements, building a wind turbine would not be out of character at all; such experimentation fit comfortably within their bottom-up philosophies and tactics. Movement activists already understood that the rampant exploitation of fossil fuels posed threats of planetary proportions, and the recognized need for viable alternatives led environmentalists to be early adopters and advocates of a wide range of innovations in sustainable living. The first generation of renewable energy technologies that sprouted in this time period grew up with environmentalism and its attendant critique of the capitalist, state-centric international order. These movements frequently overlapped, with members, ideas and techniques moving freely from one closely-associated group to another. The ideas of E.F. Schumacher and other proponents of what would later be called the appropriate technology movement were widely read and discussed in Denmark. Sustainability activists saw the promise of renewable energy as much more than a means of fulfilling material needs in a manner that was gentle on the earth. The development of these technologies was understood to be a central front in a political struggle against the anti-democratic forces of modern capitalism and the nation-state. Writing about the German greens, political scientist Carol Hager argues that many people were attracted to environmental causes precisely because they were seen as opportunities for political engagement and contestation. “Through grassroots activities, participants viewed themselves as taking charge of their own lives, of practicing democracy in a new, deeper way,” Hager writes. “They were not only challenging the legitimacy of existing politics, but also trying to develop a new politics.” (Hager 1995, 2)

There was optimism among proponents of the “small is beautiful” appropriate technology movement that the adoption of human-scaled, distributed and relatively simple technologies like wind and solar power would usher in a democratic revival. The sort of democracy envisioned by most adherents would be predominately grassroots, participatory and localized. The advocates of appropriate technology favored a “soft path” of energy development, as opposed to the “hard paths” of nuclear and fossil fuels, which were seen as problematically entangled with militaristic and centralized state power. Some who subscribed to the soft path model had utopian visions of the radical political realignment that would follow from adopting these new technologies. Others rejected this naive technological determinism, and took the opposite view, as science writer David Dickson argued in a contemporaneous book, that “a genuine alternative technology can only be developed—at least on any significant scale—within the framework of an alternative society." (Dickson 1975, 13)

Amory Lovins, who was one of the leading voices of the appropriate technology movement, and coined the phrase "hard and soft paths," had a more nuanced perspective on the social consequences of technological transitions. He recognized that renewable energy technologies had the potential to develop along a hard path as well as a soft path, and the choice of paths was a multi-dimensional problem. For Lovins, the difference between hard and soft development paths was primarily structural, and included not only technical elements, but the organization of social systems as well. Lovins, who was more concerned with policy analysis than social theory, can be forgiven for writing somewhat vaguely about how he understands the relationship between social and technical change, though he acknowledges that "the skein of causation is thoroughly tangled." (Lovins 1977, 152) In his landmark *Soft Energy Paths*, he seemed to suggest that the path of future energy development is primarily a matter of political choice, but once a society starts down a particular path, it can become increasingly difficult to reverse course, and the political effects of choosing one pathway over another can diverge substantially over time. (Lovins 1977, 54-57) He clearly viewed particular technical configurations as tightly-coupled with corresponding social organizations and ethical stances. He believed "soft" energy technologies, which for him were by definition renewable technologies, were flexible and pluralistic, compatible with a range of political values and policy mechanisms. Hard technologies, on the other hand, have an almost deterministic effect of producing social and political centralization, as well as increasing inequality. (Lovins 1977, 148-150) Following Lovins, political scientist Langdon Winner argued in his classic essay, “Do Artifacts Have Politics?” that renewable energy should be placed in the category of “flexible technologies,” as opposed to “inherently political technologies.” Flexible technologies were capable of being adapted to function in a range of political contexts. “The social consequences of building renewable energy systems,” Winner wrote, “will surely depend on the specific configurations of both hardware and the social institutions created to bring that energy to us.” (Winner 1986, 39)

Winner’s assessment of the “flexibility” of renewable energy systems remains valuable for its emphasis on the indeterminacy of technological change, and its assertion that technological choice and development are inherently political processes. He and Lovins deserve credit for at least posing the questions of whether and how renewable technologies can support democratic politics. Writing at a time when renewable electricity generation was still in its infancy, they could hardly be expected to make a detailed inventory of the long-term impacts adopting these technologies would have for democratic systems, cultures and practices. The remainder of this work will put on their mantle and, with the benefit of five decades of hindsight, attempt to make some progress in charting the path the appropriate technologists of the 1970s could only envision traveling.

The questions Lovins and Winner raised about the compatibility of democracy and technology have received little consideration in the debates occupying democratic theory, which took a decidedly procedural and discursive turn in the latter decades of the twentieth century, as the combatants busied themselves carving up terrain mapped by the likes of Robert Dahl, John Rawls and Jurgen Habermas. It is somewhat surprising that contemporary democratic theory has largely turned a blind eye to technology, given how prominently *technē* features in the political writings of the tradition's Ancient Greek progenitors. As I argue in greater detail below, the aversion many twentieth-century philosophers have expressed toward modern technology, which is usually treated either apprehensively as a threat or dismissively as apolitical, results from a predominantly instrumentalist (and wholly inadequate) view of the subject that much of the theoretical literature takes for granted.

Something similar could be said about the analysis of power, which somehow managed to escape notice in many postwar debates over how to perfect a triumphant democracy. The ubiquitous Dahl, after all, established his reputation by proposing a definition of political power still being taught in university lecture halls to this day: "A has power over B to the extent that he can get B to do something that B would not otherwise do." (Dahl 1957) It is baffling—or perhaps revealing—that his famous concept of power makes only token appearances in, and then quickly exits, his taxonomic studies of democratic systems of governance. Even Dahl himself, in a late interview, expressed dismay that the field had not moved on from his analysis of power, and in his estimation had "made no progress" since his own contributions, along with those of Harold Lasswell and Jim March, in the 1950s. (Munck and Snyder 2007, 146).

Dahl's approach to politics was perfectly suited to the clubby confines of New Haven's city hall, where he earned his spurs as an empirical social scientist, an experience that shaped many of his instincts about where to look for political activity, and what to count. Dahl's basic conception of politics is strikingly Madisonian, as the organized competition of diverse interest groups. It is no surprise, then, that when he comes to breaking down the possible forms of democratic governance, Madisonian representative democracy, built around institutionalizing group competition over leaders and policies, receives primacy of place in his analysis. The only alternative to a representative scheme that Dahl deemed worthy of serious consideration—in a classic primer on the subject used to train many a student of politics—was simple majority rule, which he referred to as "populist democracy."

With this circumscribed range of democratic forms at his disposal, Dahl then employs formal reasoning to show that neither obtains its stated ends. Whether other conceptions of democracy are possible, and what luck they might have in achieving some kind of rational coherence, is a question Dahl does not investigate. The conclusion he draws from this thought experiment is that agreement on substantive grounds for legitimating democratic rule cannot be found. The democracy philosophers speak of has no referent on the planet we inhabit. Dahl instead proposes searching for evidence of "polyarchy," a term he coins to describe the degree to which real-world regimes exhibit characteristics of open competition through representative schemes. For scholars of democracy, one repercussion of Dahl's framing of the problem was how it entrenched the literature in endless disputes over the conditions for, and characteristics of, and the merits and flaws of liberal, institutional, representative "democracy." Scholars who noted the appearances of democratic-looking activity beyond these narrow confines were too frequently drowned out in the din.

John Rawls, and one could say the liberal tradition broadly, inherited Dahl's concerns about how to justify democratic principles in a world of competing values. Rawls felt that in order for the social order to be legitimate, some sort of foundational compact, some shared set of commitments, was needed. If citizens couldn't count on sharing compatible conceptions of the good, they could at least reach agreement on what is just, which on his definition meant agreement on fair procedures for making collective judgments. Rawls' solution to the problem of foundations is formally elegant, so long as one makes all kinds of assumptions about human nature consistent with liberal individualism, and as long as a blind eye is turned to the ways power distorts these rationalist architectonics. A charitable reader might venture that while no real-world context is likely to conform to the theoretical idealizations, Rawls still offers a pragmatic framework for negotiating political compromises, assuming some degree of initial agreement on the basic ends sought. Yet relying on highly idealized notions of political subjects and circumstances to inform a practical guide to action seems a perilous endeavor.

While Anglo-American liberal democrats abandoned the pursuit of a substantive basis for democracy, the European tradition tried to rescue a sort of consensus, building on the discursive program established by Jurgen Habermas, who shared with the liberals the motivating concerns of discovering legitimate grounds for the exercise of political authority, and the assumption that those grounds can only be secured through the application of reason to public affairs. If rationality is the end that must be sought, Habermas argues the only safe place to find it is in "communicative action."

Habermas is a little more sophisticated than Dahl in imagining alternative models of democracy, or he is at least more attentive to the history of democratic theory. In Habermas' telling, the contest is mainly between Lockean liberalism and the revival of classical republicanism by the likes of Montesquieu and Rousseau. Yet he reaches essentially the same conclusion as Dahl—neither of the main alternatives for democratic governance can justify itself on rational grounds. For Habermas, the solution is not to give up the hope of a rational democratic process, but to try to forge a middle way. He offers standard critiques of both the liberal and republican conceptions of democratic citizenship—the former is too thin, the latter too demanding. The fix he proposes is to restrict the domain of rational (and thus legitimate) political activity to the deliberative organization of a "legal community." Politics, then, becomes just one strand in the tangled web of social activities that constitute the lifeworld, "neither the peak nor the center, nor even the formative model of society in general, but just one action system among others." (Habermas 1996, 30)

Many readers with an appetite for a thicker account of democratic politics have been left unsatisfied with that meager portion, and claim Habermas robs the realm of the political of much of the activity that keeps it humming with life. Chantal Mouffe complained that by aiming for public consensus, "what such a pluralism misses is the dimension of the political. Relations of power and antagonisms are erased, and we are left with the typical liberal illusion of a pluralism without antagonism." (Mouffe 1996, 246-247)The bloodlessness of contemporary liberalism has had the unintended consequence of delegitimizing democracy in the eyes of many citizens, Mouffe argues, creating an opening for populist and authoritarian movements which, for all their dangers, are at least capable of appealing to the passions that are an ineradicable component of politics.

Agonist thinkers typically associate radical democratic politics with activism, social movements, opposition parties and artistic expression. (see, for example, Wolin 1996) While they deserve credit for reintroducing power into political analysis, and for freeing the concept of democracy from the narrow confines of institutional forms and processes. they have still not given enough consideration to the relationship between technology and democracy to be of much help in the present investigation, an oversight pointed out by geographer Andrew Barry in his recent book *Material Politics*. Writing about the construction of oil pipelines, Barry finds the agonist emphasis on dissensus useful for understanding environmental controversies, but adds that democratic theory can no longer ignore material infrastructure as “the passive and stable foundation on which politics takes place; rather, it is argued, the unpredictable and lively behaviour of such objects and environments should be understood as integral to the conduct of politics.” (Barry 2013, 1-2)

Creative provocations like Barry’s remain decidedly on the fringes of both democratic and environmental thought, where the deliberative turn led by Habermas remains dominant. In recent scholarship on environmental political theory, the contributions of Australian scholars John Dryzek and Robyn Eckersley loom particularly large. (5) Both are dedicated discursive democrats, who cite Habermas as the biggest influence on their approaches to tackling environmental problems.

In her monograph *The Green State*, Eckersley labels her project “critical political ecology” and describes her methodology as a sort of “immanent critique.” Eckersley frames her study as a reconsideration of environmentalism’s dismissal of the neoliberal state as “ecocidal,” and an attempt to transform and reclaim state power in the service of an environmental agenda by proposing new regulatory ideals for a “green democratic state.” Rather than fundamentally challenging the existing order, Eckersley feels obliged to accept its inevitability. “One can expect states to persist as major sites of social and political power for at least the foreseeable future and that any green transformations of the present political order will, short of revolution, necessarily be state-dependent," she argues in defense of her state-centric analysis. "Like it or not, those concerned about ecological destruction must contend with existing institutions." (Eckersley 2003, 5)

As Andrew Barry has argued, contra Eckersley, this move to incorporate political challenges and controversies within the apparatuses of the state is a sort of "anti-political impulse" which places "limits on the possibilities for dissensus and restrictions on the sites in which political contestation can occur." (Barry 2001, 207) If achieving a sustainable society requires engaging the institutions of the state on their own terms, in anything remotely resembling the present context of national and international politics, democratic citizens may have cause to despair.

Eckersley attempts to further burnish her critical bona fides by explaining that her aim is to "rehabilitate the classical Frankfurt School's preoccupation with the links between the domination of human and nonhuman nature," and to expand the boundaries of the moral community to include the broader biotic community. (Eckersley 2003, 10) By the time she finishes expounding her theory of the ideal green state, it ends up sounding a lot like liberal cosmopolitanism, except citizenship has been extended to all entities affected by or put at risk by state policies. Her concrete proposals include diversifying representation in government institutions, ensuring a voice for environmental advocacy in the policymaking process, and adopting the precautionary principle. In her closing pages, Eckersley seems to recognize that her proposals may not amount to quite the radical departure she had promised at the outset, and suggests her vision of an ecological democracy should be thought of as a "radical extension" of the liberal project, not anti-liberal, but post-liberal. (Eckersley 2003, 137)

John Dryzek, Eckersley's contemporary at the forefront of environmental thought in the southern hemisphere, adopts a more recognizably critical stance. Unlike Eckersley, Dryzek decenters state institutions from his analysis, and identifies democratic discourse as an activity occurring primarily in the "public sphere" of civil society. He is clear-eyed about liberalism's poor track record on environmental issues, and recognizes the severe limitations in attempting to steer established institutions toward sustainable outcomes. "The first task of any liberal democratic state must always be to secure and maintain profitable conditions for business," Dryzek writes. "Any state operating in the context of such a system is greatly constrained in terms of the kinds of policies it can pursue." (Dryzek 1998, 585) In a nod to Sheldon Wolin's concept of "fugitive democracy," he argues that democratic public spheres often arise in opposition to state power, and that deliberative democracy "must be critical in its orientation to established power structures, including those that operate beneath the constitutional surface of the liberal state, and so insurgent in relation to established institutions." (Dryzek 2000, 2) In an earlier essay, he pulls no punches in assessing the failures of capitalism, liberal democracy, and the administrative state to confront ecological threats. "The three institutions are each thoroughly inept when it comes to ecology," he concludes, arguing "that any combination of them can only compound error, and also that any redeeming features are to be found only in the possibilities that they open up for their own transformation." (Dryzek 1992, 19)

Dryzek is fully cognizant of the difficulties involved in his effort to green liberal democracy. He accepts that when beginning from a pluralism of values, no democratic procedures can guarantee ecologically benign outcomes. Dryzek admits that Habermas is just as “anthropocentric as orthodox liberals,” and buys human freedom “at the expense of the domination of nature.” (Dryzek 2000, 148) Dryzek thinks he can “rescue communicative rationality from Habermas” by extending who can be part of the political community, but holding on to “reasonable discourse” as the standard for legitimate agreements. (Dryzek 1998, 589) “Rather than jettison democracy in the search for an ecologically rational political economy, we might better proceed by detaching democracy from liberal anthropocentrism, while retaining an emphasis on deliberation and communication,” he suggests. (Dryzek 2000, 147)

Dryzek sees a bigger role for scientific advisory committees in the policy process, and envisions scientists playing the role of advocates in public discourse, speaking for nature and in doing so realizing a sort of political equality for nonhumans “in the capacity to be represented.” (Dryzek 2000, 153) He points to indigenous rights movements as examples of international public spheres, reasoning that it is often those experiencing the devastation of their local ecosystems firsthand who can most accurately and persuasively articulate the problem. (Dryzek 1998, 596) When it comes to proposals for institutional reforms, Dryzek isn’t any more radical than Eckersley, as much of what he suggests already exists in some form, and hardly seems sufficient to transform the liberal establishment.

At the root of the difficulties discourse democrats have imagining how to infuse the contemporary political order with concern for the environment is an undertheorized and antiquated notion of what it means to exercise political power, a weakness they share with the broader liberal tradition. The agonists argue that liberals attempt to erase the ways in which power distorts democratic processes. The whole idea of fair and neutral procedures only masks the effects of power. The biggest barrier to communication with nature is not that its cries are unintelligible to us, but that some political actors are either unwilling to listen, or are actively working to silence, distort, or derail any sort of accord with nature that might threaten to disrupt the status quo of unfettered domination, and the profits reaped from that arrangement. These power dynamics are deeply rooted in the basic economic processes and material conditions of modern life, operating large out of sight and beyond the reach of formal political discourse and institutions of governance.

Neither Dryzek nor Eckersley gives much consideration to technology as a possible means of working around the deliberative impasse on the environment, a silence that can likely be traced to their Habermasian conception of politics. It's not that Habermas fails to appreciate the power of modern science and technology, he simply excludes these forces from the realm of properly political activity. The influence of Habermas' Frankfurt School mentors is conspicuous in a 1970 essay that imagines an increasingly technological and bureaucratic society as a dystopian nightmare. He argues that the "technocratic consciousness" promoted by the twentieth-century alliance of science, capital and the state is alienating, though not precisely apolitical. He seems to endorse Herbert Marcuse's view, quoted from *One-Dimensional Man,* that "technology is always a historical-social project: in it is projected what a society and its ruling interests intend to do with men and things." According to Habermas, the problem with social systems built on "technical reason" is not that they lose their political content, but that their "political character becomes unrecognizable" to participants, removing teachnological decisions "from the scope of reflection and rational reconstruction." Technical rationality is concerned only with "relations of possible technical control and therefore requires a type of action that implies domination, whether of nature or of society." (Habermas 1970, 82) Max Horkheimer and Theodor Adorno spun similar conclusions into a critique of Enlightenment reason, as did Max Weber.

Modern technologies are undoubtedly immensely powerful and productive, but the wealth and comfort they deliver seduce the populace into believing that scientific and technological progress are ends in themselves. As government becomes increasingly dedicated to the perpetual growth of industrial capitalism, politics becomes oriented not "toward the realization of practical goals but toward the solution of technical problems … The solution of technical problems is not dependent on public discussion. Rather, public discussions could render problematic the framework within which the tasks of government action present themselves as technical ones. Therefore the new politics of state interventionism requires a depoliticization of the mass of the population." (Habermas 1970, 102-103)

The antidote to this horror story is not to abandon the modernist project of the rationalization of society, but to substitute a different form of rationality, one with emancipatory potential that preserves a role for public participation in the political process. The critique of instrumental rationality is a familiar one that Habermas shares with many of his philosophical forebears, though his views on technology are even darker than those of his friend and mentor Herbert Marcuse. Given that technology represented "a universe of instrumentalities," Marcuse argued it had the potential to develop in any number of directions, and "may increase the weakness as well as the power of man." Technology does not supply its own ends, and the more pervasive it grows, the more it "will become dependent on political direction." (Marcuse 1964, 235) Modern technologies for the most part seek to dominate nature, but Marcuse suggests an alternative technology could instead aim at the "pacification" of nature.

Marcuse senses that the exploitative instrumentalism associated with capitalist technology and so decried by critical theorists is just one configuration of technological power among other possibilities, and that an alternative technological politics might possess different properties. If the emergence of a "liberating" technology is possible, what might it look like, and how might it arise? Marcuse does not provide very persuasive answers. One of the core ambitions of this dissertation is to make some progress on that question.

Habermas dismisses the entire project out of hand, saying the prospect of a qualitatively different science or technology "will not stand up to logical scrutiny," at least not if "science is to retain the meaning of modern science inherently oriented to possible technical control." Technology, the handmaiden of science, has an "immanent connection" with instrumental action. It could not be otherwise. (Habermas 1970, 88)

Of course, many philosophers and sociologists of science and technology would contest these reductive definitions of their subject matter. Habermas is only able to treat science and technology so dismissively because of his weak theorization of these concepts, and their relationship to one another. Andrew Feenberg, one of the most respected philosophers of technology alive today, has said as much, writing that Habermas' "defense of modernity now seems to concede far too much to the claims of autonomous technology. His essentialist picture of technology as an application of a purely instrumental form of nonsocial rationality is less plausible after a decade of historicizing research in technology studies … Marcuse was right after all to claim that technology is socially determined even if he was unable to develop his insight fruitfully." (Feenberg 1996)

In asking how a sustainability transition might be carried out democratically or serve democratic ends, the Habermasian tradition offers little help. When the likes of Dryzek and Eckersley talk about "ecological democracy," all they seem to mean is democratic discourse that internalizes environmental interests. There is nothing particularly ecological about these approaches, they could swap out their concern with flora and fauna for space aliens and their basic claims about what counts as a fair political process would remain unchanged. The failure to adopt an ecological perspective limits the ability of these theories to envision innovative forms of political action that might precipitate transitions to more sustainable societies. They have difficulty imagining politics beyond the confines of existing liberal democratic institutions of governance. This institutional conservativism is partly a consequence of an aversion to thinking seriously about power. Liberals tend to equate power with domination, and dream of a politics free of any power but the "forceless force of the better argument."

In the next section, I seek out a more robust theory of the relationship between modern technology and political power. Before proceeding to that discussion, it should be asked if perhaps I have picked on easy targets, while ignoring theories of democracy with more promise for my purposes. I have so far considered primarily liberal theories of institutional democracy, perhaps scholarship that places more emphasis on direct democracy would be better suited to my purposes.

The intuition that citizens should play an active role in their own governance is an ancient one, of course, and a cornerstone of republican thought. In the modern context of mass democracy, the importance of an engaged citizenry has been championed by the likes of Thomas Jefferson, Alexis de Tocqueville and Hannah Arendt. In contemporary democratic theory, Benjamin Barber has been a leading proponent of the idea that democracy is something that should be done by the people, a view he argues for in his now-classic book *Strong Democracy*. Barber would seem a natural ally of the arguments being advanced in this chapter, as the first half of his book is dedicated to a thorough dismantling of liberal democratic thought. In the second half of the book, Barber develops his antidote to the weak tea of liberal democratic politics, beginning from the assertion that "the realm of politics is first and foremost a realm of human action," of "doing (or not doing), making (or not making) something in the physical world that limits human behavior, changes the environment, or affects the world in some material way." (Barber 1984, 122) This framing would seem capable of admitting the collective endeavor of constructing material infrastructure as a potential form of democratic political activity. But in the final analysis, technological development plays little role in Barber's program for strong democratic reforms, beyond as a means of transmitting communications. Remarkably, after stressing the primacy of action, Barber works his way back to talk. "At the heart of strong democracy is talk," he contends, and talk "has been at the root of the Western idea of politics since Aristotle." (Barber 1984, 173)

To complete the picture, Barber does add that strong democratic politics is not *just* about talk. After a political community has had plenty of conversation and reached a collective decision comes the "common work" of "doing together what it has envisioned and willed together." (Barber 1984, 209) I might ask whether the doing must always come after the talking; a common thread in all of these strains of democratic thought seems to be that judgment precedes action.

When it comes time to propose a slate of reforms to American politics, most of Barber's ideas about common work sound like traditional civic republicanism, with a dash of New Deal social welfarism. He is a big proponent of national service, and intriguingly hints at the democratic potential in public works projects, though he seems interested primarily in the solidarity that is built up within civilian corps, rather than any material transformations of the social environment those corps might effect once they put their shovels to the ground. Technologies only play a significant role in his calls for expanding electronic voting. Modern communication technologies smooth the way for members of the public to weigh-in on policy with greater frequency and speed, and at far less cost to either citizens or the state.

As Barber tells it, the jobs of citizens in a democracy basically boil down to piping up in public forums, having their votes counted, and serving as grunts in the implementation of state projects. For all of his efforts to flesh out an account of "strong" democratic citizenship, in the end Barber's conception of "public works" is thin and traditional.

Perhaps a fuller discussion of the work of the public could be found in the writings of the American pragmatists, and their foremost political theorist, John Dewey, whom Barber cites as an inspiration. One would expect a philosophical school that prizes experience over contemplation, custom and habit over reason and calculation, to endorse a relatively hands-on brand of politics. So it comes as a bit of a shock that even Dewey seems stuck on speech. In *The Public and Its Problems*, he describes democracy as an ideal that can only be approached in practice, through striving to create a community of shared concerns. The chief political problem for modern democracies is that no “great community” has yet emerged to match the scale and complexity of mass society. In order for a substantively democratic community to form, the public must become “articulate,” because “communication can alone create a great community.” Democracy “will have its consummation when free social inquiry is indissolubly wedded to the art of full and moving communication.” (Dewey 1927, 142, 184)

If Dewey thinks citizenship entails doing anything more than reading newspapers and hosting dinner parties, his political writings give little indication of what other forms of public activity might promote the growth of democracy. He has even less to say than Barber about the “common work” of a democratic way of life. Protecting free public discourse, freedom of social scientific inquiry, and the free transmission of research findings to the public are his primary concerns.

The subject of technological change does play a substantial, and I think overlooked, role in Dewey’s political philosophy. In numerous passages throughout *The Public and Its Problems,* he sounds like an outright technological determinist. Riffing on Thomas Carlyle’s claim that the invention of the printing press made democracy inevitable, he adds, “invent the railway, the telegraph, mass manufacture and concentration of population in urban centers, and some form of democratic government is, humanly speaking, inevitable.” (Dewey 1927, 110) These technologies have a more profound influence on social organization than any strictly “political” inventions, such as national borders or laws. The associated activities they make possible are “so massive and extensive that they determine the most significant constituents of the public and the residence of power. Inevitably they reach out to grasp the agencies of government; they are controlling factors in legislation and administration." (Dewey 1927, 107) The chain of causation works as follows: "Roughly speaking, tools and implements determine occupations, and occupations determine the consequences of associated activity. In determining consequences, they institute publics with different interests, which exact different types of political behavior to care for them." (Dewey 1927, 44-45)

Although Dewey unequivocally associates the rise of modern democracies with the industrial revolution, he is as wary as the Frankfurt School critical theorists of the political consequences of this transformation. Technology may be knitting humans together in ways never before dreamed possible, but these ties are binding us to their machine logic, rather than freeing us to explore the fullness of our humanity. At times, Dewey sounds like an orthodox Marxist in both his pessimism about the current state of technological society and his utopianism about the emancipatory potential of technological instruments properly utilized. "If the technological age can provide mankind with a firm and general basis of material security, it will be absorbed in a humane age," he writes. "When the machine age has thus perfected its machinery it will be a means of life and not its despotic master. Democracy will come into its own..." (Dewey 1927, 217, 184) But in its present, imperfect form, industrial technology has so "expanded, multiplied, intensified and complicated" social action that "the resultant public cannot identify and distinguish itself." (Dewey 1927, 126) This confusion has left people feeling politically impotent, "caught in the sweep of forces too vast to understand or master. Thought is brought to a standstill and action paralyzed." (Dewey 1927, 135)

The problem is that political innovations have not kept up with the pace of technological and social change. Humans are now living in a globalized and deeply-interconnected world, but still trying to manage their affairs with seventeenth-century political ideas and institutions that are showing their age. "Man has suffered the impact of an enormously enlarged control of physical energies without any corresponding ability to control himself and his own affairs," (Dewey 1927, 175) The great challenge of the present, then, is to find means of adapting political forms to this new social reality. Whenever Dewey discusses the materiality of social ties—which, again, is with some frequency—he resorts to a very particular formulation, referring to these associations as "non-political forms of living together," and "non-political forces [that] are the expressions of a technological age." (Dewey 1927, 73, 129)

What is it that makes these technologically-mediated ties non-political in nature? Clearly, they are central to organizing modern life, *binding*, *forming*, even *forcing*. Yet Dewey, like most philosophers of his era, treats technology as mere instrumentality, as subhuman, as an external influence that should probably be eyed warily. "The Great Society created by steam and electricity may be a society, but it is no community," he concludes. (Dewey 1927, 98) No argument is made for this proposition. A political community is one sort of thing, a technological society is another, and there is no overlap between the two.

He notably does not claim that participation in governance (the traditional republican criterion for citizenship) or sharing in the costs and benefits of association (the consequentialist's chief metric) is essential to democracy; these are merely "additive concerns" which "demand communication as a prerequisite." (Dewey 1927, 152) In the final analysis, Dewey is more interested in the development of social knowledge than he is in the study or promotion of democratic action, as is apparent from the closing lines of *The Public and Its Problems*:

> There is no limit to the liberal expansion and confirmation of limited personal intellectual endowment which may proceed from the flow of social intelligence when that circulates by word of mouth from one to another in the communications of the local community. That and that only gives reality to public opinion. We lie, as Emerson said, in the lap of an immense intelligence. But that intelligence is dormant and its communications are broken, inarticulate and faint until it possesses the local community as its medium. (Dewey 1927, 219)

The irony of quoting Emerson is so glaring that I can only assume Dewey intended it as a dig against this most antisocial of American philosophers. The "immense intelligence" Emerson is speaking of in this passage from "Self-Reliance" is certainly not social intelligence (which I rather suspect Emerson would have considered an oxymoron), or any other kind of reasoned, voluntaristic belief, but instead the pre-rational intuitions which we perceive most forcefully and most reliably through direct experience of nonhuman nature. Dewey, whose major work of metaphysics and epistemology is titled *Experience and Nature*, has precious little to say about either of those subjects as they relate to politics. Apparently, they are pre-political concerns. Politics is something people do through the medium of speech. The final paragraph of Barber's *Strong Democracy* sounds a remarkably similar note, where he argues democracy must be defended:

> …in speech itself, in the Greek faculty of reason called *logos*, the distinctive feature that sets humankind off from the animal kingdom and bestows the twin gifts of self-consciousness and other-consciousness… [From this perspective] the right of every individual to speak to others, to assert his being through the act of communication, is identified with the precious wellspring of human autonomy and dignity. Thus it was that in Greece *Isegoria*—the universal right to speak in the assembly—came to be a synonym not merely for democratic participation but for democracy itself. (Barber 1984, 311)

Surely Barber does not believe that "the universal right to speak in the assembly" is an adequate definition of democracy today, though it may well have been how the male citizens of ancient Athens understood it. The transposition of these Attican conceptual artifacts to a radically different context may go a long way toward explaining why modern philosophy has had so much trouble attending to the nonhuman and material worlds. The preceding survey of the literature has revealed a wide range of democratic theorists fixated on speech as the principal political activity, precluding any consideration of extra-linguistic activities or non-speaking actors. In analyzing how these thinkers arrived at this focus on discourse, a regular culprit appears, and his name is Aristotle.

Some of the core ideas contemporary political scientists hold about their subject matter can be traced back to a single iconic passage from the first book of Aristotle's *Politics*. Many democratic theorists, Dewey and Barber and Wolin among them, reference this passage explicitly. In defending his assertion that man is by nature the "political animal," Aristotle cites the clear "gregariousness" of human beings, which to his mind exceeds that of any other species, even highly social creatures like bees. Here is Benjamin Jowett's translation of the celebrated passage:

> Nature, as we often say, makes nothing in vain, and man is the only animal whom she has endowed with the gift of speech [*logos*]. And whereas mere voice is but an indication of pleasure or pain, and is therefore found in other animals (for their nature attains to the perception of pleasure and pain and the intimation of them to one another, and no further), the power of speech is intended to set forth the expedient and inexpedient, and therefore likewise the just and the unjust. And it is a characteristic of man that he alone has any sense of good and evil, of just and unjust, and the like, and the association of living beings who have this sense makes a family and a state. (*Pol.* I.2, 1253a10-20)

The reason speech is so central to politics, then, is that it is the means by which moral judgments are communicated, and it is "partnership" in these "moral qualities" (in Harris

Rackham's translation) that defines both the household and the *polis*. Dewey lambasts Aristotle's reasoning, writing that "to explain the origin of the state by saying that man is a political animal is to travel in a verbal circle. It is like attributing religion to a religious instinct, the family to marital and parental affection, and language to a natural endowment which impels men to speech." Theories of this sort are "of a piece with the notorious potency of opium to put men to sleep because of its dormitive power." He cites Aristotle's appeal to man's "gregarious instinct" as "the outstanding example of the lazy fallacy." (Dewey 1927, 9-10) Despite these uncharacteristically furious broadsides against Aristotelian essentialism, and, more generally, against teleological explanation, Dewey tacitly accepts, and then in his own political theory replicates, all of the other major assumptions the Philosopher makes in this passage about the nature of politics.

There exist all manner of reasons to question the adequacy of Aristotle's framing for describing the basic conditions of contemporary political life. Even accepting his long out-of-fashion claims about human nature and the teleology of biological characteristics, one could still ask whether humans are truly the only species that possesses the ability to communicate through language and to make moral judgments. Donna Haraway is just one well-known contemporary theorist who has persuasively argued for the richness of two-way communication and "ethical relating" between humans and their pets. (Haraway 2003) Scientific research on animal communication has made enormous strides in recent decades, undermining long-held beliefs about the uniqueness of human language. Suzanne Simard, one of the most famous forest ecologists alive today, thinks that even the trees are talking to one another, warning of danger and coming to one another's aid through electrical signals and the exchange of nutrients pulsing across their interconnected root systems. Perhaps the old chestnut about humans being the only creatures endowed with speech tells us more about our ignorance of the world around us than about our superiority.

My aim here is not so much to undercut the political importance of speech, but to question the elevation of speech above all other forms of social activity. It is certainly true that infrastructure development requires lots of planning and communication. As described in the introduction to this chapter, the Tvind Schools' mania for meetings and open debate is notorious, and the troubled track record of those gatherings raises concerns about idealizing "free" deliberation. But I'm not writing about the Tvind teachers because they modeled the art of deliberative governance. The group has remained relevant in Danish politics and the renewable energy industry not because of what they said, but because of what they built. The meeting minutes have been lost to history. The windmill still stands. It's that gap from discussion and decision to action that political scientists need to get better at traversing.

When scholars make discourse the foundation of politics, they tend to lose sight of all of the other fascinating things people do together. Humans are not the only animals that use tools, but no other species has organized social life so completely around technological infrastructure.

Aristotle also played a crucial role in establishing the traditional opposition between the natural and the artificial, in defining *technē* as the capacity of humans to invent things not provided by nature, and in some cases even contrary to nature. (Rosen 1993, 81) For his part, Dewey decries the artificial "split between man and nature" as a prejudice that must be overcome, in the context of critiquing the scholarly preference for “pure” over “applied” science. (Dewey 1927, 173) Dewey’s vision of democracy needs lots of applied scientists, citizen scientists, getting their hands dirty, working with *things*. Yet just like Aristotle, he assumes from the outset the very split he later protests; as a definitional matter, he considers the subject of politics a strictly human affair.

One reason it has been so difficult for political theorists to shed this anthropocentric baggage is the associated assumption that politics is the property of a community, understood as a group committed to shared ends or values. As I have discussed above, philosophers from Aristotle, to Kant, to Habermas, to Dewey have all defined political community on these terms. It is the difficultly of achieving any such community in a pluralistic society that led the liberal democratic tradition to invest political authority in the equally problematic fiction of the sovereign individual. I do not wish to abandon the notion of community—the sense of *something* shared seems essential to the meaning of politics—but to rehabilitate it from an ecological perspective rather than an Aristotelian one. There are any number of ways that community ties could be established, and even that a sense of common purpose could be nurtured, without relying on the sort of express contracting imagined in the idealizations of philosophers.

The most insidious element of the conception of politics advanced by theorists from Aristotle to Dewey to Habermas to Wolin is not even its exclusive association with state institutions, but the notion that political authority is fundamentally the authority to make *decisions*. In all of these theories, there is a subtle slippage from activity to judgment. Even Hannah Arendt, who aims to resurrect an understanding of politics as the *vita activa*, and associates human freedom with “our capacity for action, for changing reality,” (Arendt 2000 [1967]) believes that political action proper is all about speech, that acting is inherently social and communicative and therefore it requires speech. The things humans do with their hands in the dirt is mere *work*. Yet as Socrates cautioned his youthful interlocutors in *Republic*, in speech we may only build cities in the heavens. Political science needs a better means of describing how brick-and-mortar cities get built on earth.

One way to recover the missing material elements of politics may be through analysis of the operation of power. If the tradition of democratic theory has not known what to do with modern technology, it has at least begun to address its weakness on the subject of power. As I have documented in the preceding section, power dynamics are curiously absent from many of the tradition's canonical texts. Some democratic theorists seem rather queasy about power, and write as if the goal of democratic politics should be to banish power from the equation.

The need to refocus democratic theory on the dimension of power has motivated recent works by prominent political scientists Ian Shapiro and Clarissa Hayward. In *The State of Democratic Theory*, Shapiro mocks the deliberative tradition for its "touching faith" in the ability of talk to bring people together, and criticizes the idealized discursive practices described in these theories for attending "too little to the ways in which power relations influence what deliberation should be expected to achieve in politics." (Shapiro 2003, 10, 32) He proposes that "a central task for democracy is to enable people to manage power relations so as to minimize domination." (Shapiro 2003, 3) Shapiro still thinks this task needs to be carried out within the institutions of the state, which he pragmatically, but not very convincingly, argues should be the focus of democratic theory since government is where most power is wielded, making it a likely site of domination.

He writes off the Foucauldian analysis of power as barren, having “not led to, or even facilitated, discussions of better and worse ways of managing power relations.” (Shapiro 2003, 37)

The same charges that Shapiro levels against democratic theory generally can be, and have been, applied to recent work specifically focused on environmental democracy. In a review of major figures in what I’ve called the Australian School—including the works of Dryzek and Eckersley discussed above—Harlan Wilson identifies places where core objectives of each of their theories would benefit from more robust consideration of the effects of power. “Empowerment,” Wilson writes, “is the essence of democracy.” (Wilson 2006, 293) It is not enough, Wilson says, to talk about rights and citizenship and distributive policies, without giving sufficient weight to the distorting effects of power imbalances. Ironically, this very weakness of the deliberative approach frustrates the authors’ overarching goal of making environmental concerns into matters of political concern. It is an opportunity missed, because focusing more on power would put environmental inequalities front and center in any discourse on improving democracy.

As environmental economist James Boyce has put it, “our willingness to abuse the environment is founded on our ability to abuse each other.” (Boyce 2002, 135) In his own characteristically incisive way with words, Boyce is echoing a basic principle of the environmental justice literature that scholars like Robert Bullard have been proselytizing for decades. According to this school of thought, environmental and human exploitation are intimately linked. Improvements in the substance of democracy would also have to entail ameliorating environmental injustices. Efforts to make society more democratic have the potential to interact with the promotion of more responsible environmental policies in symbiotic ways, stimulating and reinforcing one another.

The environmental justice perspective points toward a source of democratic legitimacy that can tolerate pluralism of values. When Dahl criticized equality as an ultimate end of democracy, he only understood political equality in the sense of one person one vote, or the equal representation of all interests and points of view in deliberative decisionmaking and governance. Dahl felt that perfect equality on those measures was unattainable, and not even desirable, as most people are willing to make some sacrifices in equality in order to allow other ends to flourish, such as privacy, property and competition. But Boyce's framing of political equality in terms of power, can grant Dahl's point about the imperfectability of equality as a value, and still advance the claim that societies that distribute power more equitably can be considered more democratic.

The critique of substantive democracy—the idea that no core democratic values could be defended—was always suspect, and equality, especially with respect to the distribution of power, seems a reasonably safe place to start building consensus about the meaning, organization and practice of democracy. As legal scholar Jedidiah Purdy has recently written, "at its core, democracy is a disposition of power." The etymology of the word refers to rule by the *demos*, "the ordinary free people of the polity, which today should mean everyone in our political order." (Purdy 2022, 6) If democracy is conceived as the impulse to pursue and preserve an equitable distribution of power within a political community, there is a deep symbiosis between environmentalism and democracy. By the end of this chapter, the insight that democracy and the environment are related on the dimension of power will allow me to develop a more substantively ecological democratic theory than the deliberative or liberal traditions has produced. I have been arguing that a core problem for democratic theory in its late modern incarnation has been insufficient attention to power. Addressing that deficiency demands a closer look at how power operates today, and the effects of power on democratic practices.

2.3 Technology and Power

The preceding section documented how democratic theory spent much of the twentieth century running away from what was presumed to be the corrupting influence of power on democratic processes. Why has the existence of political power been viewed as such a threat? This allergy to power would seem to suggest some real limitations in how political scientists have conceptualized this core concept of their discipline.

It has long been obvious to anyone who looks closely at political power that the old Dahlian definition is not going to get the job done. Dahl's conception of power as influence is downright Madisonian, crafted for the noisy disputes of elite parliamentarians. Influence peddling is not really a popular occupation, and as such thinking about power in this way is almost inherently anti-democratic.

Happily, much progress has been made in the analysis of power since Dahl first published his famed definition, which has the virtues of being simple and explicit, making it an easy target for criticism. Among the most influential of those critics is Steven Lukes, who kicked off what Ian Shapiro has called the "faces of power debate" by labeling the Dahlian pluralist approach "one-dimensional" and arguing for a more three-dimensional conception of political power.

Among the many limitations of the one-dimensional concept are its inability to see non-decision or nonparticipation as effects of power relations, to locate power in the absence of conflict, or to address how the exercise of power could be unconscious or unintentional. To address thee deficiencies, Lules proposed that a second dimension of agenda-setting power included the ability to shape the terms of debate, and what issues even come up for debate in the first place. To illustrate second-dimensional power, both Lukes and later John Gaventa cite Matthew Crenson's *The Un-Politics of Air Pollution* (1971). Crenson found that the local reputation of U.S. Steel was able to forestall efforts to reduce air pollution in Gary, Indiana, without the company having to directly address the issue or confront anti-pollution activists. (Lukes 2005, 46) This silencing of debate and inertia of the status quo will be familiar to students of environmental politics. It can be seen in the success of U.S. oil companies like Exxon in suppressing concerns about climate change and keeping the issue off the national political agenda for decades, or in the dismissive attitude Danish utilities and policymakers displayed toward renewable energy in the 1970s, pushing instead to develop nuclear reactors despite a complete lack of public support (see Chapter 3).

While an improvement on Dahl's myopic analysis, the two-dimensional perspective also flattens the operation of power, Lukes argues. Among the hidden faces of power are not merely the ability to write the rules, control the agenda and gatekeep participation, but also to shape the very preferences, values and knowledge of all parties. "Is it not the supreme exercise of power," Lukes writes, "to get another or others to have the desires you want them to have—that is, to secure their compliance by controlling their thoughts and desires?" (Lukes 2005, 27)

Scholarly analysis of the third dimension of power has a deep and somewhat disreputable history in twentieth century political thought, growing out of orthodox Marxist debates about why the working classes consent to the domination of their bourgeois masters and so often adopt bourgeois values. Antonio Gramsci attributed the failure of a revolutionary class consciousness to develop to the "hegemony" of capitalist ideology. Georg Lukacs proposed that subordinate classes developed a "false consciousness" at odds with their objective interests. These ideas have been controversial, in part because they smack of structural determinism, and because they suppose social scientists can occupy a privileged position of discerning real class interests, contrary to their members' expressed preferences. The vulgar version of these worries is that such concepts, at least in the caricatured form they are usually repeated, suggest that the socially disadvantaged are unconscious dupes unable to recognize their subjection and fight back. Numerous studies—notable among them James C. Scott's works on peasant resistance—have demonstrated that such presumptions are empirically false. Lukes' reply is that the theory of false consciousness, citing Scott's own work, has both thick and thin versions, and as Scott says, "the thick theory claims consent, the thin theory settles for resignation." (quoted in Lukes 2005, 126) Despite Scott's "compelling" accounting of the "ingenuous strategies and tactics" of the powerless, this catalogue of petty acts of resistance "does not show that there is not also widespread consent and resignation" that is best understood as an effect of power relations. (Lukes 2005, 131) Lukes ultimately advocates for viewing false consciousness merely as "the power to mislead," manifest in everything from censorship and misinformation to repressed desires and magical thinking. (Lukes 2005, 149)

In 1980, John Gaventa applied and expanded on the three-dimensional theory of power to explain the "quiescence" of Appalachian coal mining communities in the face of more than a century of exploitation by absentee landlords. On Gaventa's telling, "generalized discontent is present" among coalfield residents, and occasionally bubbles over into open resistance, but mostly "lies hidden and contained." (Gaventa 1980, 252)

For Gaventa, the feeling of powerlessness he observed in Appalachia was mainly a product of second-dimensional power—"a set of predominant values, beliefs and institutional procedures that operate systematically to the benefit of the colonizer at the expense of the colonized"—combined with third-dimensional power—"the shaping of wants, values, roles, and beliefs of the colonized." (Gaventa 1980, 31-32). Importantly, the three dimensions of power were interrelated and worked to reinforce one another. Gaventa's chief contribution was in detailing the obstacles to overcoming the collective effects of three-dimensional power. The difficulties entailed in building and maintaining a counter-mobilization explain why colonized populations often appear docile on the surface and resigned to their fates. Conflict is largely contained to the second and third dimensions, preventing its outbreak in formal political arenas.

Gaventa dedicates ample space to considering the resources the powerless need to mount effective resistance. (6) Curiously, Gaventa has little to say on the subject of technology, despite noting that it was "in flux" in coal country at the time of his study. (Gaventa 1980, 252) He mentions newspapers, television, and documentary films as tools of third-dimensional power, but appears to think of these media technologies primarily as transmission vehicles for ideas and values. Similarly, his frequent mentions of structural conditions and material concerns tend to get sidelined by his focus on the construction of rural Appalachian consciousness.

The advances of Gaventa and Lukes already thoroughly complicate the Dahlian portrait of power, but the place of technology in this picture had still not been brought into focus. Like many political theorists, Steven Lukes spent the latter decades of the twentieth century absorbing the innovations Michel Foucault introduced to the study of power. While the encounter did not make Lukes a card-carrying Foucauldian, it did spur him to completely rewrite the book that had made him famous. He briefly considered whether Foucault had revealed a “fourth dimension” of power, but never pursued that intriguing line of inquiry. (Lukes 2005, 88) Lukes remained uncomfortable with many of the implications of Foucault’s writings. If power is pervasive, and individuals and identities are constituted as effects of power relations, then it would seem that one cannot rationally consent to this state of affairs, undermining liberal ideas of freedom that Lukes is at pains to defend. Furthermore, Lukes criticizes Foucault for treating power only in its negative sense, as an inescapable force of domination, and having no real theory of empowerment. Perhaps Lukes’ strongest objection is that if power is everywhere and in everything, as Foucault seems to suggest, then the concept loses its analytic usefulness for political scientists. Citing Charles Taylor, Lukes argues that the theory of political power must distinguish between “an imposition” and “other influences.” (Lukes 2005, 113)

Whereas democratic theorists like Lukes and Shapiro somewhat grudgingly acknowledged the importance of Foucault’s provocations, but seemed eager to brush off the encounter as painlessly as possible, Clarissa Hayward fully embraced the Foucauldian conception of power, and gave sustained consideration to its implications for democratic practices. Through a comparative analysis of two Connecticut elementary schools—one in a poor, black neighborhood that emphasizes discipline, and another in a wealthy white town that emphasizes student participation in decision making—Hayward argues that it is time to "de-face" power: "We should define power, not as an instrument some agents use to alter the independent action of others, but rather as a network of boundaries that delimit, for all, the field of what is socially possible." (Hayward 2000, 3) What she finds in her case studies of the elementary schools is that power is not so much exercised by one group over another, say, by teachers over students. Rather, power constrains all actors, even the relatively advantaged, and limits the range of possible interventions in each school. While she accepts Foucault's assertion that "power is co-extensive with the social body; there are no spaces of primal liberty between the meshes of its network," Hayward rejects his characteristic pessimism about escaping domination and his hesitance to stake normative claims about better and worse power relations. (Hayward 2000, 6)

By attending to how power structures "fields of action," Hayward develops a critique of the liberal conception of freedom as noninterference, and instead suggests, following theorists like Hannah Arendt, that freedom should be understood as "political freedom: a social capacity to act, alone and with others, upon the boundaries that define one's field of action." (Hayward 2000, 8) From this new vantage, Hayward argues, power and democracy are linked, suggesting an alternative evaluative criterion to the schemes proposed by the likes of Habermas and Dahl: Power relations warrant criticism when they are “defined by practices and institutions that severely restrict participants’ social capacities to participate in their making and re-making.” (Hayward 2000, 4)

Although Hayward includes among the mechanisms of power “laws, norms, standards, and personal and social group identities,” (Hayward 2000, 8) she is still unable to see political power in technological systems. If the study of power is about understanding the networks of forces that delimit the boundaries of possible actions, it seems almost self-evidently true that technologies must be among those constitutive elements bounding social practices. It is somewhat curious to me that so many political theorists have latched on to Foucault’s observations about “discourses of power,” yet so few have focused on his parallel and equally emphasized formulation of the “techniques of power.” There is no denying Foucault stresses the way power is directed in speech, in knowledge codes, in institutional procedures. But among the multitudinous contemporary technologies of power, he also prominently includes the machinery, the infrastructure of modern life—from the guillotine, to the prison, to the invasive instrumentation and medication of psychiatric and sexual health. An army of acolytes has since applied Foucault’s concepts of governmentality and biopower to build an ever-expanding inventory of the technological tools modern individuals employ to self-discipline, to conform, and to construct their identities. (7) The recognition of these hidden, unnoticed, or normalized manifestations of power was among Foucault’s most important contributions to political theory. His writings directed scholars away from more traditional concerns with overt expressions of elite or institutional power, and toward the “microphysics” of power in everyday life.

Foucault proposes power should be understood not so much as a thing, or a property of actors, but as a relational concept. If power must have an essence, it is perhaps best to characterize it as vectors of force rippling through the interwoven fabrics of the social and material worlds. The modern subject is not some primitive, pre-political atomic unit, as the entirety of liberal thought assumes, but is produced and reproduced as an effect of power relations. In the first of his series of lectures at the College de France, he gave what is, to my knowledge, one of the first and clearest articulations of power as a property of networks:

> Power must, I think, be analyzed as something that circulates, or rather as something that functions only when it is part of a chain. It is never localized here or there, it is never in the hands of some, and it is never appropriated in the way that wealth or a commodity can be appropriated. Power functions. Power is exercised through networks, and individuals do not simply circulate in those networks; they are in a position to both submit to and exercise this power. They are never inert or consenting targets of power; they are always its relays. In other words, power passes through individuals. It is not applied to them. (Foucault 1976, 29)

Power circulates, according to Foucault, by a multitude of "infinitesimal" processes, including discourse, but especially through the materiality, the physical infrastructure and the organizational structures of modern technologies. To locate power, Foucault advises turning attention to "techniques," "tactics," "procedures," "instruments," "operational methods," "verification mechanisms," "apparatuses," and "material operations." (Foucault 1976, 30-34). What social scientists term "discourses" or "technologies" are simply ways of categorizing different constellations of nodes in these networks. It is not obvious to me that, at root, there is any essential difference between the two. Presumably, the former places more emphasis on the ideational than the material, but on closer inspection, all of these networks contain both material and ideational components. There is no “discourse” about climate change without mass media technologies, and a proliferation of novel scientific instruments, and melting ice caps.

His is notably and unavoidably a more structural-functionalist account of power than those that have been considered in the preceding pages, but that does not imply it is rigid or deterministic. There may be no escaping power relations, on Foucault’s account, but that does not mean humans are trapped. On the contrary, networks of power have a fluidity to them, an ingrained indeterminacy, they are constantly evolving. Leverage points do not disappear in these networks, they are multiplied.

The key lesson from Foucault’s work on power, at least for this study, is that any attempt to analyze its modern manifestations will be radically incomplete until technology is treated seriously as a political force. Political scientists have struggled to account for the interactions between social actors and organizations, technological regimes, and external environments in their analyses of political problems. Empirical research on energy transitions in the United States remains tilted heavily toward policy analysis, where the state is the central actor. Political *economy* is all the rage in political science and economics departments—scholars seem happy to admit that markets, institutions, and policies are inextricably intertwined—but political technologies or political ecologies remain a bridge too far.

My intention is not to disparage scholarship on energy transitions written from political economy or policy perspectives. Few factors have a greater influence on the composition of contemporary energy systems than price signals. And the policy choices of government officials do matter, at all levels, particularly for renewable energy development. But these factors are not sufficient for explaining technological change in almost any circumstance I am aware of, and certainly not in the historical evolution of renewable energy systems, as the following chapters will demonstrate in the Danish case. Policy studies typically fail to account for the ways market players and policymakers are themselves embedded in and shaped by broader social and technological systems.

In the rare instances when political scientists foreground technology in their explanations, the tendency is to treat it almost as an external force, intruding on human affairs. One such example in the political science canon is Benedict Anderson's *Imagined Communities*, today considered the preeminent study of nationalism. Anderson's explanation for the emergence of nationalism as a distinctively modern political phenomenon centers on the printed word, which made possible the mass media of novels and newspapers, which in turn rewired readers' psychology to think of perfect strangers as brothers and sisters in an amorphous cultural community. Sweeping and eloquent, Anderson's narrative is also both linear and deterministic—once the printing press is invented, the American and French revolutions become almost historical inevitabilities.

Political scientist Jane Fountain offers a perspective on technological change that is more comfortable with complex networks. Although Fountain does not adopt a sociotechnical systems framework, a lot of her "technology enactment" theory is consistent with it. (8) Fountain clearly shares my interest in radical technological shifts—she describes the internet as a "revolutionary lever for institutional change"—but her technology enactment framework seems better suited to explaining the stability of institutions than describing their fundamental reorganization. Fountain finds that state actors usually enact technology "to reproduce existing rules, routines, norms, and power relations." Deeper institutional change is a product of unintended consequences, which “lead to subtle modifications of structure to accommodate new technology. The accumulation of unintended, subtle modifications may lead to more dramatic shifts in structure and power.” (Fountain 2001, 89-90)

Fountain also locates the power to initiate technological change primarily in the hands of “public managers,” civil servants with decision-making authority. In this respect, her theory is similar to Hughes' focus on “system builders” as the agents of technological evolution. While Fountain, like Hughes, recognizes that environmental shocks can encourage organizational change, this part of the story is relegated to the background of her theory. According to Fountain, radical innovations like the internet act as “enablers” or “catalysts.” I look more closely at how outsider actors (like the Tvind teachers) and environmental pressures (like the oil embargos) become catalysts for system change, and the ways in which technology “disrupts complex ecologies of institutionalized power relationships.” (Fountain 2001, 205)

One of the advantages of Fountain's theory is its recognition that the mode of technology enactment is a form of political action—new technologies are often implemented in a manner that preserves existing power relations or advances the interests of the parties involved—with political effects on society. This is a marked improvement over much political science that treats technology as an external given, and thus not a site of political contestation.

Fountain stresses that there is no inevitability to the adoption of information technologies, and it's not just whether government agencies use the internet, but how they use it, that shapes the political structures of those agencies. Information technology opens new political possibilities, but entrenched institutional interests will shape which of these possibilities are pursued. These assertions raise the question of the role technological change plays in originating new forms of political expression: Is there really anything unique, anything revolutionary, about the politics of information systems, contrasted with the bureaucratic politics of the modern state? An analogous question can be asked about my own empirical case: Are the politics of renewable energy systems qualitatively different from those of conventional energy networks? Do they have the potential to take more democratic forms?

No American political scientist I am aware of has framed this question more directly than Carol Hager, who sets out to "explore the connection between environmental and democratizing concerns" in her aptly-titled monograph, *Technological Democracy*. Noting that ever since the industrial revolution scholars have wondered whether technology is "a tool of emancipation or enslavement," Hager asks, "what are the prospects for citizen participation in the modern technological state?" (Hager 1995, 1) Disappointingly, it quickly becomes clear that Hager is operating in a Weberian mode, and she is more interested in the critique of *technocratic* values and decision-making processes than she is in the close analysis of *technological* change. Her case study is a local protest movement that arose in Berlin in opposition to plans to construct a large coal-fired power plant. But Hager does not dwell on the political salience of coal or nuclear power, or their alternatives, as technologies, as infrastructure, or as nodes in larger energy networks. Instead, she tells a fairly traditional social movements story, taking readers inside grassroots organizations, to street protests, and to public meetings. To the extent she is interested in technology, it is primarily as a site of contestation between citizens and the state. Although Hager observes the democratic potential of citizen participation in planning and development processes, she rarely discusses a direct role for citizens in technological innovation, adoption, or diffusion.

The results of her investigation into the political potential of that Berlin protest movement—the *Burgerinitiative*, or BI—were mixed, though in interesting ways. It's clear, Hager concludes, that one benefit of grassroots citizen participation in such movements is how they conjure an "alternative experience of reality" to contrast with the status quo political imperatives:

> Citizen action helps reverse the dominance of bureaucracy over politics that Weber and Habermas criticize by exposing the power relationships hidden behind the bureaucratic facade of expertise and neutrality. By proposing alternatives, new social movements challenge those who claim that the dominant forms are inevitable or the only rational forms. (Hager 1995, 226)

In Germany, as in Denmark, anti-fossil fuel and anti-nuclear activists helped popularize several substantive critiques of the political establishment and the energy system it favored. Activists rejected the logic of policymaking as a negotiation of interests, and instead called for deliberative procedures aimed at reaching consensus. They expressly linked the absence of democratic participation to decisions that were destructive of the natural environment. (Hager 1995, 2)

But Hager sees limited evidence, and has limited hope, of that alternative vision taking root in public institutions. Instead of reforming the political system in more deliberative directions, the protest movements were incorporated into it, with the rise of Green parties giving political representation to this constituency. The results were inevitably less than ideally democratic. "Activists showed that they could keep up with the technical discussion, but they have not shown that they can build a broad-based activist politics around it," Hager concludes. "Grassroots activism has dwindled while green parties flourish.” (Hager 1995, 228-229) It is worth noting here that a similar popularization of anti-nuclear and environmental movements occurred in Denmark from the 1970s through the 1990s (documented in greater detail in Chapters 3 and 5).

Hager’s argument, ultimately, is not for more democratic technology, but for more deliberative democracy. And she is even more pessimistic about the prospects for the former than she is for the latter. “In the sense of rationality, technology is incommensurate with BI organization and action. It would be difficult to conceive of a communicatively structured science or technology,” she ultimately concludes. She explains in the closing pages that the title of her book “contains an implicit question: can technological policy making be democratic?” (Hager 1995, 227-228) In her final analysis, she seems to answer this question mostly in the negative.

The most important takeaway from Hager’s case may not be how the protest movement challenged public decision-making processes in Berlin, but how it changed the citizens who participated. Hager points out that through their interactions, members of social movements “experience personal growth and develop a sense of their own efficacy.” (Hager 1995, 221) She also sees an important network effect: “the informal networks of communication formed through grassroots activity make large-scale collective action possible.” In the language of Lukes, Gaventa and Foucault, Hager is talking about the development of third-dimensional and (what Lukes almost called) “fourth-dimensional” power—Foucauldian power flowing through the capillaries of tangled networks. Both Hager and her activists seem disappointed in the limits of their interventions with the formal policy process. But the empowerment of citizens she discovers, through the development of new capacities both as individuals and in groups, is still no trifling thing. “The major results may lie in these experiments in citizenship,” Hager writes. (1995, 226) The Danish case demonstrates that an analogous growth of citizen capacities can be seen in processes of grassroots technological development.

In a later edited volume, Hager herself drew closer to linking technological and political development. This time looking at not-in-my-backyard (NIMBY) protest movements in Germany—some of them local protests against wind power developments—Hager sees an explicit link between public protest, technological innovation, and political innovation:

> NIMBY conflict contributes far more to the development of new technological solutions than is commonly acknowledged. First, the development of counter-expertise helps to delegitimate technocratic policy making on the one hand and to legitimate alternative sources of technical expertise on the other. This can create a positive atmosphere for innovation … Technological innovations that emerge from NIMBY protests are sometimes initiated under pressure from citizen groups … Sometimes these innovations are proposed by the groups themselves.

Not only have citizens demonstrated the ability to shape the direction of technological development through protest movements, these critical confrontations with technological systems shape the participants themselves, and the societies in which they live, an effect that may ultimately have greater significance for the development of an ecologically sustainable democracy. These protest movements help “forge new social networks and broaden civic competence generally, while reinforcing local culture and traditions” and “may activate formerly disenfranchised people or transform the nature of their participation, from that of victims seeking compensation for environmental harms to citizens actively shaping their own futures.” (Hager and Haddad 2015, 10) In other words, they become politicized; they develop capacities, both as individuals and as participants in larger sociotechnical networks, that allow for novel forms of political engagement.

Hager's analysis is helpful in thinking about new sites of political contestation, and new possibilities for citizen empowerment in a technological society. But her deliberative framework still conceives of political power narrowly as the ability to influence government policy, which limits the kinds of relationships she can envision between citizens and technologies. On Hager's account, technology is a social force largely exogenous to public life—an issue to be debated and decided, but not in itself constitutive of publics or of citizens as subjects of power.

As I have been arguing in this section, contemporary analyses of power demonstrate that scholars must look beyond elite actions, public preferences, and formal policy processes if they hope to see the full scope of how power operates. But political scientists who give serious consideration to technology as a domain of political activity remain outliers in the field. The postwar reevaluation of technology as a social force has occurred mostly in interdisciplinary spaces, first through work on post-positivist philosophy and sociology of science, which bloomed in into a now vibrant and diverse scholarly community usually referred to as "science and technology studies," or simply "STS," adding insights from history, anthropology and engineering along the way. Since that literature is far too broad to succinctly summarize here, I will focus on one prominent strand of STS approaches, popularized by historian Thomas Hughes. As a representative of broader STS perspectives on technology, Hughes is a sensible choice, as he has expressly pointed to the analogies between his own formulation of "sociotechnical systems" theory and the most well-known theoretical perspective to emerge from the STS literature, the “actor-network theory” of multi-hyphenate scholar Bruno Latour. Hughes’ most influential works deal explicitly with large electricity systems and energy transitions, and those works are now treated as canonical by historians of technology.

The most complete discussion of Hughes’ ideas on the evolution of technology can be found in his 1983 book *Networks of Power*. Like Latour's hybrid networks, for Hughes technological system components included not only human managers and material artifacts, but also organizations, institutions, policies, knowledge, social norms, and even natural resources. The boundaries of these systems are difficult to define, as the social world is composed of systems nested within and interacting with other systems in a “seamless web.” Systems are understood in functional terms as solving social problems or fulfilling goals. (Hughes 1987, 53) Over time, systems grow, incorporating more aspects of the environment into the system. (Hughes 1987, 52-53)

Though Hughes was not explicit about how systems grow, it is implied that the growth of systems is analogous to the expansion of Latourian actor-networks, as a basically acquisitional process of enlisting new actors, adding new components, making new connections and thus increasing the size of the network. On Hughes’ account, the development of a technological system culminates in the acquisition of “technological momentum,” a sort of inertia, or “soft determinism,” possessed by large, mature systems similar to “technological lock-in” that makes these systems resistant to change. “As they grow larger and more complex, systems tend to be more shaping of society and less shaped by it.” (Hughes 1994, 112) These mature systems often steamroll competitors, but they can lose momentum when confronted with critical problems, which may come in the form of changes in external conditions or technological bottlenecks, which Hughes calls “reverse salients,” “out of phase” components that act as drags on the overall system. (Hughes 1987, 73) A new system is initiated by a “radical invention,” which he defines as new technological developments that are not integrated as components of existing systems. Entrepreneurs guide their new inventions through the stages of innovation, transfer, competition, and finally consolidation, at which point the new system has grown stable, gained momentum, and developed a unique “technological style,” which is how Hughes describes the individualized characteristics particular systems develop in response to their local environmental conditions.

Like much work on the history of technology, Hughes focuses more on the earlier stages of technological development, and more attention needs to be paid to the later-stage dynamics of mature systems, which will become a central concern of the later chapters of this empirical study. Another weakness of the theory is that Hughes was less interested in the external dynamics of relationships between systems, and between a system and its environment, than he was in the internal dynamics, which he describes as a series of evolutionary stages, of system development. Daniel Breslau has criticized the broader energy transitions literature (which draw heavily from Hughes and related historical work) for its inadequate attention to the “social landscape, including the range of organized interests in society.” Breslau suggests that “an analysis of the configuration of those forces and its change over time is critical to assessing the potential of alternate transition strategies.” (Breslau 2013, 327)

Studies of energy transitions from a sociotechnical systems perspective have also been criticized for giving insufficient attention to the political dynamics of technological change, failing to provide a satisfactory account of the influence of either formal, institutional politics or informal power relations. (Geels 2011) That gap in the literature creates a natural opening for political scientists to contribute their expertise to advance the analysis of technological change. This dissertation project is attempting to exploit the combined strength of putting these two epistemic communities in direct conversation with one another.

When empirical political scientists have drawn explicitly on Foucault's analysis of power, it has often encouraged them to flirt with conceptions of technology and its political potential that more closely resemble the Hughesian account than the Habermasian one. This evolution has been visible most prominently in the career of James C. Scott, and the dialogue with his student, Timothy Mitchell. Scott's early works were notably more traditional in their theoretical approaches to political economy and comparative politics. His first books became classics of the "peasant studies" literature on development. In *The Moral Economy of the Peasant,* Scott examines twentieth-century peasant rebellions in Southeast Asia. In explaining peasants' disillusionment and dissatisfaction with colonial society, he emphasizes their rational decision making and offended moral sensibilities. Traditional peasant communities believed in a moral right to subsistence, Scott argues, and peasant politics were organized around this subsistence ethic. (Scott 1976, 3, 6) Motivated by these values, peasant societies pursued risk-averse agricultural technologies and practices. "The fear of dearth explains many otherwise anomalous technical, social, and moral arrangements in peasant society," Scott writes. (Scott 1976, vii) Choices like planting more than one variety of seed and farming on scattered strips were "classical techniques for avoiding undue risks often at the cost of a reduction of average return." (Scott 1976, 4-5) What's important to note here is that, according to Scott, social norms drove the choices peasants made about which technologies to adopt, and not the other way around. Even though agricultural technologies played an important role in peasant strategies of resistance, they become nonfactors in Scott's explanatory schema. The work is firmly rooted in behavioralist and rational choice ideas about agency, and Scott is primarily interested in giving a rational account of individual behaviors that appear irrational, on the surface, to Western eyes trained on Western notions of economic efficiency.

This avoidance of technological choice as an explanatory factor is even more glaring in Scott's book *Weapons of the Weak*. (1985) Scott's main target in that work is popular political science theories of hegemony, and in vivid anthropological detail, he shows the numerous petty strategies peasant villagers adopt to resist the domination of capitalist market forces. By the 1980s, Scott is fully engaged with the "faces of power" debate, and even cites Gaventa's work discussed above. But he is not yet citing Foucault. Technologies are becoming even more central to his narrative—in fact, it is the introduction of Western agricultural machinery and techniques that most violently intrudes on the traditional way of life in the Malaysian village where Scott sets his drama—but his analysis of peasant resistance does not yet fully appreciate this technological dimension to his story. The evidence that technological change is a central driver of village politics is ripe for the picking in his pages, which detail a transition in rice cultivation beginning in the 1970s with the introduction of double-cropping. The villagers' initial embrace of these new production methods quickly fades to disillusionment, as the economic costs become apparent, combined with shifting environmental conditions in the form of drought. The *coup de grace* comes in the form of new combine harvesters, which Scott explains,

> were made possible in large part by the same economic forces that had earlier improved the incomes of village wage workers. Only in the context of relatively higher harvest labor costs and the possibility of harvesting virtually year round under double-cropping did the investment in large combine harvesters become profitable. The direct and indirect impact of machine harvesting has been enormous… (Scott 1985, 111)

Scott is presenting a shift in peasant attitudes as a product of interlocking economic, environmental, and technological conditions. But this contextualist account mostly disappears from his theoretical conclusions about resistance to hegemony, where he emphasizes the agency of relatively powerless individuals to resist the seemingly overwhelming powers of global capitalism and colonialism and the inequalities it produces.

Dramatic shifts in the technological paradigm of rice farming are foundational to Scott's story about resistance in Sedaka, but they are treated as a "point of departure," rather than factors that potentially explain the forms of resistance. The introduction of irrigation, tractors and combine harvesters are admittedly a "massive transformation in the techniques of production," but Scott relegates them to the "middle ground" of the social landscape where they are "subject to the interpretations that villagers give them." (Scott 1985, 49) Timothy Mitchell is highly critical of this notion that a distinct level of cultural interpretations stands separate from and above the everyday practices themselves. Mitchell argues the practices of modern, state-centered, industrial capitalism produce the effect of not being a part of social life as a result of their distance, regularity and uniformity. But this effect is deceptive, and technological regimes like "the controlling and distribution of irrigation waters are practices like any other part of social life.” (Mitchell 1990, 571) Scott's account misses the manner in which modern power creates a seemingly unbridgeable divide between the technical and natural on one side, and the social and political on the other. (Mitchell 1990, 573) This divide depoliticizes technical systems and choices.

To his credit, Scott seems to have absorbed the critiques from Mitchell's essay on “everyday” power, and his later books *Seeing Like A State* and *The Art of Not Being Governed* exhibit a markedly different tone and presentation in addressing resistance to domination. Both books are concerned with the efforts made by states to rationalize and standardize social forms. *Seeing Like A State* is dedicated to the inevitable shortcomings of such efforts. *The Art of Not Being Governed* examines how highland peoples successfully resisted the imposition of state authority (at least until the mid-twentieth century). The importance of technological systems is now front and center. Fixed field grain agriculture produces the proliferation of state power, Scott argues, and brings with it new modes of social life built around private property, patriarchy and large families. (Scott 2009, 9) The “imperial project” of subjugating nonstate spaces and peoples was necessitated by the explosion of concentrated populations and the new division of labor, and made possible by “distance-demolishing technologies.” (Scott 2009, 11)

The expansion of state power facilitated by “instruments of statecraft” is exemplified by practices of scientific forestry and agriculture, which “represented fairly simple interventions into enormously complex natural and social systems.” (Scott 1998, 343, 352) This “potent but narrow perspective” allowed for unprecedented gains in agricultural efficiency and productivity, but remained “troubled both by certain inevitable blind spots and by phenomena that lie outside its restricted field of vision.” (Scott 1998,

348) A good example of such blind spots are the surges in crop-damaging insect populations brought on by devoting enormous acreage to monocultures and the pervasive use of pesticides. (Scott 1998, 280) Scott views the pretensions of technoscientific state order as hubris that promotes ignorance of the radical complexity and changeability of circumstances. This imposed order is at best “fragile and vulnerable” and at worst “wreaked untold damage and shattered lives.” (Scott 1998, 352)

Where villagers in Sedaka were resigned to the imposition of new technologies, the peoples of Zomia in *The Art of Not Being Governed* recognized that decisions to forage or slash-and-burn “expressed a political option” and were understood as “forms of political secession.” (Scott 2009, 334) It should perhaps come as no surprise that in these later works, Foucault shows up in Scott’s bibliographies for the first time.

How do political explanations change when scholars begin to acknowledge the entanglement of natural, technical, and social systems? There may be no better example of a recent attempt at political science in this vein than Timothy Mitchell's *Carbon Democracy*, which traces how the unique characteristics of fossil fuels and the technologies employed to recover them shaped the politics of their respective ages. Mitchell’s entry into this topic is through political science literature on the “oil curse,” which posits that petrostates tend to exhibit weak democratic governance because leaders do not rely on tax income from citizens, and thus are less responsive to public demands. Mitchell finds this explanation overly simplistic, and criticizes it for failing to pay attention to the specific material conditions and organization of oil production. It is not merely how the income from oil production is distributed, but the very manner in which this sociotechnical system is structured, that has implications for democracy. To demonstrate this point, Mitchell contrasts the organization of oil production with that of the energy technology it largely replaced on the world stage, coal.

In the coal age, workers “forged successful political demands by acquiring a power of action from within the new energy system. They assembled themselves into a political machine using its processes of operation.” (Mitchell 2011, 12) Coal mining and transport relied on a substantial labor force, and this centrality of labor to the system gave workers the ability to disrupt coal production, making union organizing and labor strikes effective tactics for demanding accommodations for workers. Mitchell argues that the material properties of coal, and the specific modes of organizing labor created to exploit it, empowered workers to make political demands by threatening the energy supply, winning concessions from their bosses and from the state. These labor movements ultimately gave rise to the twentieth-century welfare state, at least in Great Britain. Mitchell refers to this push for greater social equality as “substantive democracy.” (Mitchell 2011, 9) This workers' movement was countered in the second half of the twentieth century as oil replaced coal as the primary fuel of industrialized nations.

Oil had very different characteristics, and Mitchell details how Britain shifted from coal to oil power after World War I, largely to undermine the political sway of the coal mining unions. (Mitchell 2011, 31) The liquidity of oil—which allowed it to be pumped, piped and shipped in tankers—and the relatively small number of workers needed for oil production, as well as the unequal geographic distribution of oil reserves, mostly outside Western European social democracies, made it more difficult to resist the application of this technology in the service of dominant, capitalist, imperialist elite interests. The particular properties of oil and its extraction techniques, as well as the networks established for its circulation and consumption, allowed for the emergence of new expressions of political power that emphasized formally democratic governance while chipping away at substantive democracy. Bruno Latour later praised the innovativeness of Mitchell's explanatory strategy. "Mitchell is not content to emphasize the "spatial dimension" of the workers' struggles; that would be a truism," Latour wrote. "He draws attention to the very composition of what the bond with coal or with oil does to the earth, the workers, the engineers, and the companies." (Latour 2018, 62)

The new energy regime produced a series of remarkable socio-political innovations, not only shifting the meaning of democracy from substantive demands for equality to formal concerns with process, but also inventing "the economy" as an independent sphere of activity, posing environmental protection as a problem, and organizing cultures around growing consumption. (Mitchell 2011, 231-235)

Oil has limited the egalitarian aims of democracy, Mitchell claims, largely because "it followed more flexible networks" than coal. "Unlike the movement of coal, the flow of oil could not readily be assembled into a machine that enabled large numbers of people to exercise novel forms of political power." (Mitchell 2011, 237, 12) How might a society organized around sustainable energy production and consumption be different from those built around carbon? Mitchell does his best to resist giving a deterministic answer, "as though each form of energy produces a corresponding politics." Technological development does not remove uncertainties, he writes, "it causes them to proliferate." (Mitchell 2011, 238) Thus technical choices are always also choices about the kinds of social and political organization desired, and the manner in which particular solutions are engineered and implemented matters.

Mitchell does not even attempt to assess the forms renewable energy development is taking around the world; his story is about oil, and is a backward-looking history of twentieth-century energy systems. Lacking evidence of large-scale renewable energy systems in operation to draw from, he isn't able to say much of anything specific about how these sociotechnical machines might be built and function. He claims that disruptive new technologies can create opportunities for political change, but there is “no inevitability” to the outcome of technological innovations. Instead, writing in language reminiscent of Winner or Lovins, he concludes that “the possibility of more democratic futures, depends on the political tools we address to this period of transition.” (Mitchell 2011, 254) It is on this tantalizingly suggestive note that the empirical evidence from ongoing energy transitions, like the one already well underway in Denmark, should be instructive. As the North Sea archipelago has built out the world’s most advanced wind energy system, how have the meaning, function, and practices of Danish democracy changed?

Mitchell may not get much further than raising questions about how technological change can be leveraged for emancipatory projects, but neither did Foucault. There has been a longstanding and widespread worry in the academy—leveled loudly by Foucault’s critics and acknowledged even by his fans—that the style of historical political analysis he popularized is ultimately impotent, great at deconstructing the existing modes of domination, not so adept at charting paths toward more democratic futures.

Power, in Foucault’s telling, operates almost exclusively as a force of domination, seemingly foreclosing the possibility of human freedom. In an interview conducted just months before his death, Foucault explicitly addressed and rejected this narrative, giving one of the clearest elucidations of his relational conception of power, and hinting at how freedom might be achieved even if power relations are inescapable. These relations are not solid structures, he explains, but “mobile, reversible, and unstable.”:

> In order for power relations to come into play, there must be at least a certain degree of freedom on both sides. Even when the power relation is completely out of balance, when it can truly be claimed that one side has “total power” over the other … This means in power relations there is necessarily the power of resistance because if there were no possibility of resistance (if violent resistance, flight, deception, strategies capable of reversing the situation), there would be no power relations at all … if there are relations of power in every social field, this is because there is freedom everywhere. Of course, states of domination do exist … be they economic, social, institutional, or sexual, the problem is knowing where resistance will develop. (Foucault 1994, 34-35)

Foucault did not continue this train of thought to predict when and where resistance to domination will crop up, but I can see several conclusions about the structures of more democratic power relations that seem to follow from what he says above. As a question of strategy, democratic activists can take heart from Foucault’s portrait; power relations are never settled, openings for resistance are ever present, the trick is in finding the most fertile openings to exploit and try to plant the seeds of alternative practices. If states of domination limit freedom of movement for those on the receiving end of the relationship, and achieve an aura of solidity that is difficult to reverse, then an emancipatory political project would be one that seeks a more equitable distribution of power, providing individuals with many options and avenues to intervene. A democratic political system would adopt measures to prevent asymmetries and the ossification of power, preserving the potential for existing relations to be reversed.

Of course, Foucault never said any of these things, these are merely my own extrapolations from his late-period lectures and interviews. The concern that his method of analyzing power has little emancipatory potential remains pervasive, and clearly has some has merit. Foucault's published writings operate almost entirely in a critical, deconstructive mode, concerned with dissecting and revealing the hidden operations of power. Throughout his life, he had much greater difficulty articulating a positive vision of the forms emancipatory political practices might take. During an interview six years before his death, he bristled at the notion that critical movements should formulate policy agendas, claiming their role was instead to challenge entrenched power, to problematize normalized discourses of liberal, capitalist, disciplinary society:

> "Under no circumstances should one pay attention to those who tell one: 'Don't criticize, since you're not capable of carrying out a reform.' That's ministerial cabinet talk. Critique doesn't have to be the premise of a deduction which concludes: this then is what needs to be done. It should be an instrument for those who fight, those who resist and refuse what is. Its use should be in processes of conflict and confrontation." (Foucault 1991, 84)

In recent critiques of critique as a tool, social theorists Bruno Latour and Dipesh Chakrapbarty have questioned whether Foucauldian-style critical analysis was up to the task of dealing with the climate crisis. (Latour 2004b) The approach of treating human beings as effects of power was "an effective tool in dealing with national and global forms of domination," Chakrabarty writes, but insufficient in the context of a warming world, which confronted humanity collectively, as a species, to a degree never before experienced. (Chakrabarty 2009, 221) He suggests an alternative path forward: a broadening and multiplication of the lenses applied to social analysis. This would require more engagement and collaboration across boundaries, as Chakrabarty writes, "climate change calls on academics to rise above their disciplinary prejudices." (Chakrabarty 2009, 215)

Dissatisfaction with the limits of critical theory was linked explicitly to "the problem of technology" by Sheldon Wolin, who in a detailed commentary on the

Frankfurt School critical theorists and their progeny, argues that it was the fear of technocratic dominance that prevented the likes of Horkheimer and Adorno from offering a positive account of social progress. The disquieting implications of the Second World War for the Enlightenment project left Horkheimer and Adorno feeling that philosophy had no recourse but to embrace "a "negative dialectics," its task to defend "difference," individuality, and what remained of high culture." (Wolin 1993, 184) Wolin's own conclusion about this trajectory was that "critical theory ends in self-confessed powerlessness … it gave up on the idea of developing a social praxis for fear it would lead to embracing instrumentalism." (Wolin 1993, 182-183)

Wolin traces the roots of this deeply-ingrained discomfort with technology back to Plato and Aristotle, and the attempt to tame political power through its mastery by reason and science. Critical theorists are far from the only philosophers have fallen under the sway of the Athens, I have already detailed the influence of Aristotle on democratic theory in the previous section. The Straussians theorists who are the audience for Wolin's commentary are all too happy to defer to the wisdom of the Ancients, and turn their attention to Plato's dialogues to disentangle the knotted meanings of *technē*. Writing the introduction to the edited volume in which Wolin's essay was printed, famed bioethicist Leon Kass tries to understand in what sense technology is a "problem" for us moderns. The nature of technology changed, he argues, when it became associated with the project of modern science. "Technology, in its full meaning," Kass writes, "is the disposition rationally to order and predict and control everything feasible, in order to master fortune and spontaneity, violence and wildness, and to leave nothing to chance." (Kass 1993, 4)

He falls back on the Greek virtue of moderation as our best hope of containing these dangers.

The political scientist William Galston's contribution to that same volume offers another example of how easily social thought can arrive at the view "technology has run amok." At times, Galston seems to know better, making assertions that are consistent with the sociotechnical systems view of technology as deeply embedded in human affairs. He argues that technology cannot be understood as "pure means," since it shapes "human activity and political possibility." He points out the significance of the unintended consequences of technological development, which demonstrates that such developments are not always under human control. He claims that the effects of technology for democracy are "complex but not, on the whole, negative." (Galston 1993, 238, 246) Despite these nods at a more complicated picture of the interrelation of politics and technology, Galston defaults back to Kass' association of modern technology with a mechanistic, rationalizing and totalizing Science. He wraps up his essay with an inventory of what he sees as the most serious dangers technology presents today—it weakens human connections and distances us from one another, it "exacerbates the vice of acquisition without limit," and speeds the pace of social change, producing a corresponding increase in social dislocation. (Galston 1993, 248-250) He ends by blaming television for elevating images over words.

We moderns have been so conditioned to thinking of technology as something alien that even well-intentioned efforts to understand technological politics tend to fall into this trap of assuming a radical separation, and the attendant fear of an external force that is out of control. The ingrained suspicion of technology so typical of modern philosophers reveals, as Wolin points out, how they are actually aligned with the scientific rationalism they seek to critique. Both projects ultimately aim at control, at getting a handle on social problems through the application of reason. All that is distinctive about the conservative impulses of a Kass or Galston is that they seek recourse in moral reasoning, hoping to constrain technology within classical schemas of virtue and right.

Wolin manages to beat the Straussians at their own game, and in his close reading of the Platonic dialogues he locates a third way, between the conservative suspicion of the craftsmen's ignorance of political matters, and the immoderate pursuit of an objective science of politics. In the example of Socrates, Wolin sees an alternative attitude toward technology. As his self-defense in the *Apology* makes apparent, Socrates regards exile as a fate worse than death, a stance Wolin interprets as reflective of the belief that political thinking requires "a homeland," a local setting. "Exile is the worst of fates for a theorist because it decontextualizes theoretical activity, freeing it of political ties and referents," Wolin writes. "Theorizing requires a civic setting." (Wolin 1993, 185) Throughout the dialogues, Socrates praises craftsmen for possessing a type of wisdom that is "not pure reason but reason as culturally embedded." Wolin believes that Socrates was "calling attention to the competence of ordinary beings, the praxis that arises from reflection on experience, that is transmitted by a culture, and that represents the power resident in the technologies of everyday life." The Plato of *Republic* has no qualms about the application of this craft knowledge to the arts, but thinks it oversteps its limits when it meddles in politics, leading him to propose a notoriously elitist, anti-democratic vision of the ideal political organization. A more populist view of political rule can be found in the

Protagoras, where the title character claims “the skills needed to run a city are part of a human capability for sharing in justice and a moral sense.” From this perspective, politics is a technē that can be taught and learned through practice. (Wolin 1993, 187) “Technē, we might say, is thus not the monopoly of technology or other technical applications of reason,” Wolin argues. “The human capability of acquiring skills is not like the philosopher’s claim to knowledge, the basis of a claim to power that excludes other claims. It is, instead, a claim that people cannot share in justice unless they share in power.” (Wolin 1993, 188)

What Wolin describes as this Socratic approach to technology is decidedly more democratic than the accounts of the Straussians, or the Frankfurt School, or Foucault. It conceives of democracy not on the basis of rights, or legal procedures, but in active and relational terms, as a set of practices shared among members of a community. Wolin ends his essay with the proposition that the true opponent of technocratic dominance is not philosophy, but democratic politics.

James C. Scott reached some similar conclusions about the political folly of trying to shear the application of reason from its context in *Seeing Like A State*. Scott’s analysis of high modernist technological systems, at first glance, seems to confirm the worst fears of a Heidegger or a Habermas about the application of scientific knowledge and technological tools as instruments of governance. But Scott’s aim is not to show the inevitability of technocratic domination; rather, he uses a series of richly-detailed case studies from regimes around the world to demonstrate the contingency and fallibility of such attempts to standardize, simplify, and control. Scott credits the modern capitalist state with disseminating a very potent form of technological power. These flattening technologies make possible a sort of “tunnel vision” that “brings into sharp focus certain limited aspects of an otherwise far more complex and unwieldy reality … An overall, aggregate, synoptic view of a selective reality is achieved, making possible a high degree of schematic knowledge, control, and manipulation.” (Scott 1998, 11) While this bracketing of reality makes possible an unprecedented expansion in the scope of centralized control, it is also highly fragile because of the many “blind spots” it produces, its weak “peripheral vision,” and its “shortsightedness.” (Scott 1998, 290-293)

Scott contrasts this brittleness of modern technological power with the adaptability of pre-industrial technologies, particularly in the realm of agriculture. He compares the monocropping techniques favored by Western scientific agriculture with the polyculture practiced by traditional West African farmers, and also cites critiques of industrial agriculture by the likes of Rachel Carson and Wendell Berry. The agronomist attempts to “transform and homogenize field conditions” to match predetermined metrics, resulting in “the virtual elimination of local knowledge.” (Scott 1998, 301-302) The real work of standardizing knowledges and techniques, Scott pointedly observes, is not in devising formulas with universal application—such theoretical constructs are always shorthands, thin glosses on and distortions of a far richer reality, in other words, fantasies—but “is, above all, a question of changing the environment so that it is more standardized to begin with.” (Scott 1998, 339) Craft agricultural practices work according to the reverse logic: the cultivator begins with understanding the local ecology “and then selects or develops varieties that will likely thrive in this setting … The variety of cultivators in such a community is in large part a reflection of the variety of both local needs and ecological conditions.” (Scott 1998, 301-302)

When Scott observes farmers at work, he finds “they are constantly inventing and experimenting … crafting unique amalgams of strategies that reflect their aims, their resources, and their local conditions.” (Scott 1998, 304) Scott employs the umbrella term “mētis,” which he borrows from French theorists Marcel Detienne and Jean-Pierre Vernant, to describes the “practical skills and acquired intelligence in responding to a constantly changing natural and human environment.” The types of activities that require mētis are “exceptionally difficult to teach apart from engaging in the activity itself.” Practitioners must possess “feel,” a sort of muscle memory that, often unconsciously, facilitates adjustments to changing conditions. (Scott 1998, 313)

Mētis is strong precisely where technē is weak—in knowing how to act appropriately in context. As Wolin argued, this sort of practical knowledge is a necessary condition of political action, and attempting to reason devoid of context is to make oneself politically impotent. In Scott’s telling, it is at least likely to lead to disappointment:

> A mechanical application of generic rules that ignores these particularities is an invitation to practical failure, social disillusionment, or most likely both. The generic formula does not and cannot supply the local knowledge that will allow a successful translation of the necessarily crude general understandings to successful, nuanced local applications. (Scott 1998, 318)

The more general the rules, the more translation they will require to be of any practical use, the more poorly they will fit in a wide variety of circumstances, the less likely they will be to withstand the daily wear and tear of constantly brushing up against the bumpy and bustling material world without bursting at the seams. It is mētis, rather than the technē of modern scientific and industrial processes, that is better-suited to dealing with “complex material and social tasks where the uncertainties are so daunting that we must trust our (experienced) intuition and feel our way.” (Scott 1998, 327)

Most contemporary environmental problems exhibit these sorts of complexities and uncertainties. So, for that matter, do most political problems. Rationalist methods do purport to offer penetrating insights, so long as all variables in the system can be defined and separated, environmental factors and controls can be held constant, and the noise in the data can be smoothed out to amplify the signal—conditions that obtain nowhere in reality, not even in laboratory settings. Bruno Latour’s *Laboratory Life* provides one detailed accounting of the exhausting efforts researchers undertake and the enormous resources they mobilize to produce the illusion of objectivity. The current, and growing, replication crisis in scientific publishing gives further indication of the unsteadiness of these methods of control. The flexibility of mētis, by contrast, enhances its stability and survivability, its capacity to absorb shocks and shift with the winds. Where technē is brittle and vulnerable to changing conditions, mētis is more responsive and resilient, qualities that are prized in both ecosystems and political systems.

To praise mētis in these respects is not to ignore its limitations. Mētis can be parochial and protectionist in the way of all local politics. The social conditions in which mētis is cultivated, Scott worries, are threatened by the global spread of liberal individualist, capitalist culture. (Scott 1998, 335) And yet Scott’s account of mētis has more affinities with democratic politics than the alternative. “What has proved to be truly dangerous to us and to our environment,” Scott believes, “is the combination of the universalist pretensions of epistemic knowledge and authoritarian social engineering.” (Scott 1998, 340) Over the past century, it has been the most repressive political regimes—from Nazi Germany, to Stalinist Russia, to Mao's and Xi's Chinas—that have most fervently embraced technocratic governance. Hannah Arendt similarly linked the logics of positivist social science and totalitarian politics in the closing pages of *The Origins of Totalitarianism*. The imperialist impulse of the scientific-industrial complex wants to remake everything in its own image, and recognizes no other forms of legitimate knowledge, expertise, or social practice. Mētis is more pluralistic, more open to engagement, more willing to adopt and adapt what it can from the encounter with other cultures. These characteristics may help make mētis more creative, more inventive. "It is in fact the idiosyncracies of mētis, its contextualness, and its fragmentation that make it so permeable, so open to new ideas," writes Scott. (1998, 332)

Scott's defense of craft knowledge in *Seeing Like a State* strikes me as a good example of the sort of alternative technology Wolin called for. Scott made a fair bit more progress in giving these alternative practices some empirical definition than did Wolin, who was perhaps a little too sanguine about the emancipatory potential of "epic" political theory and protest movements. Both Scott and Wolin develop accounts of technological praxis in opposition to the more traditional understanding of technology as the instrumental manipulation of the material world to serve human purposes. What Scott calls mētis and Wolin calls Socratic technē are both practical, relational and context-dependent forms of knowledge. These concepts express what I might call an ecological orientation.

Wolin's analysis is helpful in another sense for thinking about the characteristics of a more democratic technoscience. He criticizes Platonic rationalism as fundamentally undemocratic in its contention that the demos was incapable of acquiring the knowledge needed to make sound political judgments. Earlier in this chapter, I discussed how this question of competence had become a stumbling block in democratic theories hoping to embed ecological concerns in political discourses and procedures. Any communicative theory of democracy runs into the problem that nonhumans and ecosystems appear to lack the minimum capacities (namely, language) to participate in deliberative procedures. The traditional resolutions of this dilemma have been either to deny nonhumans membership in political communities, which limits the potential for transforming ecological concerns into political concerns, or to make awkward attempts at finding some way to "speak for" mute constituencies in policy processes. But as I argued above, this reduction of politics to decisonmaking procedures fails to capture many of the dimensions and mechanisms of contemporary political power. When the broader sociopolitical landscape is brought into view, it becomes apparent that humans and nonhumans already collaborate quite functionally in manyways. Perhaps it is through these "machines," to use Timothy Mitchell's terminology, that the needed political capacities can form, and political communities could be defined in more robustly ecological terms.

Seeking a path back to nature through technology might, on first impression, sound like a bafflingly incongruous pairing, perhaps even a contradiction in terms. In this section, I have shown how the literature on political power identifies technologies as central components of modern political orders, and a key mechanism by which power operates today. Scholars have long feared that this technological power would serve authoritarian ends, but I have argued that those doubts issue from a severely outdated conception of what technology is, and how it functions in social systems. If technological developments are expressions of political processes, then the study of these dynamic systems reveals human actions firmly rooted in the material world.

But is it not modern technologies, and first and foremost fossil energy technologies, that are causing the climate crisis? How, then, could technologies also be the solution to that crisis? There is no such thing as a unified, overarching technological logic, as thinkers in the Enlightenment tradition, from Heidegger to Horkheimer to Habermas, all wrongly assumed. Rather, there are many different *technologies*, and their unique configurations may produce widely divergent politics. I have described the attempts of several scholars to identify the characteristics of an alternative to the dominant logic of instrumental, authoritarian technology, what Amory Lovins called the "soft path," James C. Scott called "mētis," and Wolin called "Socratic technē." I intend to test these claims about contrasting modes of technological practice with empirical evidence from competing development pathways in the Danish wind sector. I believe I can build on these distinctions by characterizing the strengths, and the limitations, of a more pluralistic, contextualized, and adaptable approach to development, as well as by describing what happens when such practices collide with and confront more rationalist, capitalist development models.

I would approach this path with more trepidation if I did not find myself in such good company. Scott has begun to more explicitly embrace an ecological turn in his later works. What began as a permaculture-inflected paean to mētis in *Seeing Like a State* expanded into a focus on alternative technological practices and their political effects in *The Art of Not Being Governed*, and in his most recent book, *Against the Grain*, evolved into an ecological mode of explaining political organization and development. Asking what caused the formation of the earliest centralized states in Mesopotamia, Scott concludes that these states were "narrow agro-ecologies," that could organize and exercise authority only within the confines of "well-watered, rich soils that could support the concentration of labor and grain that was the basis of their power. Outside this ecological "sweet spot," in arid lands, in swamps and marshes, in the mountains, they could not rule." (Scott 2017, 220) This explanatory strategy is evidence of a fairly dramatic evolution in Scott's own methods for investigating political questions over the sweep of his career. As described above, his first book employed the classic behavioralist technique of pinpointing the individual beliefs that motivate political actions. In *Against the Grain,* Scott adopts almost the reverse approach, studying the formation and persistence of state power in terms of the environmental conditions needed to support this type of political organization. The primary unit of analysis is no longer the individual belief, but the system as a whole. The strategy is no longer to isolate causal variables, but to layer on descriptions of the interlocking human and natural systems that allow this mode of organization to function.

Bruno Latour offers perhaps the most dramatic example of a social scientist whose close study of technological systems morphed, in the latter half of his career, into an attempt to develop a "political ecology," a project he even formulated in verb form, as a demand to "ecologize." (Latour 1998) Timothy Mitchell became a fellow traveler in some of Latour's efforts to organize an interdisciplinary community of scholars around this research agenda (see, for example, Latour, Schaffer and Gagliardi 2017). But in much of Latour's writing, "political ecology" is little more than an abstract slogan, only late in his life did he begin engaging directly with ecological science, and then he did so—notably—mostly in the form of practical, hands-on collaborative experiments. None of his academic monographs contains any sustained discussion of the findings of ecologists.

In the remainder of this chapter, I will attempt an initial sketch of some of what could be gleaned from such an encounter. Of course, I am a political scientist with extremely limited formal training in ecological science, and I do not expect to provide a definitive account of such a vast subject. Instead, I merely hope to highlight some of the tools ecology offers for investigating the questions of political and technological change animating this dissertation. In later chapters I put these tools to use in my effort to explain the progress of Denmark's renewable energy transition, as one small demonstration of the viability of such an approach to contribute to what must ultimately be a collaborative, anti-reductionist, open-ended project of finding sustainable ways to live in a warming world.

If Bruno Latour accomplished anything during his decades-long career, I would venture that he demonstrated no point more exhaustively or convincingly than the artificiality of the distinction between nature and culture, drawn most forcefully by liberal philosophers like John Locke and Thomas Hobbes. Many contemporary critics have argued that it is precisely liberal ideology—expressed through the capitalist economic systems, the extractive industries, and the thin practices of politics and methods of governance it helped create—that is driving the climate crisis. At the very least, any politics of nature which posits Mankind as Master and the Earth as his Dominion has been defined from the outset in antidemocratic terms.

For Latour, the flight of contemporary politics from reality ended in the nihilism and irresponsibility of Trumpism, and similar political movements that are simultaneously revanchist and escapist. He argued a reorientation was needed to bring politics back "down to earth," by which he meant reembedded, recontextualized, brought back into intimate contact with the material world we inhabit. (Latour 2018) One recurring conclusion of the literature surveyed above is that there can be no such thing as a context-free rationality. An understanding of one's context is a precondition of political judgment. When Hobbes separated the human arts from the products of nature, he did so within a very specific social and political (and technological, and environmental) milieu, hoping to develop a science of politics that could challenge the authority of God and His churches. To pursue those goals, he applied what looked to him like the most productive tools of his day—the budding sciences of mathematical proof and formal logic, or what he called "ratiocination." In that environment, the application of rationalist methods to politics was a liberatory political project in a variety of ways. But Hobbes' world is not our world, his problems are not our problems, his tools are not the only ones available to us. God, to paraphrase Nietzsche, has been dead for centuries. The problems humans must confront today are largely problems of our own creation, the consequences of pursuing our fantasies of omnipotence and of our clumsy attempts at playing God. If Latour is correct, and the puzzle today is to figure out how to bring politics "down to earth," then it seems reasonable to inquire how the sciences that specialize in the study of earth's systems might contribute to that effort.

2.4 Ecology and Democracy

This chapter began with a question about the democratic potential of technological transitions. An analysis of the most influential theories of democracy found them ill-suited to answering this question, since the tradition has largely understood democratic politics in institutional and procedural terms, and especially in terms of talk, making it difficult from these perspectives to see nonhumans or technological systems as politically relevant. But there is widespread agreement among competing schools of democratic thought that the tradition has historically been weak on the subject of power. A closer look at recent scholarship on political power revealed that technological development should, indeed, be viewed as a profoundly political process. One distinctive effect of training attention on technological politics—as opposed to focusing on discourses or procedures or institutions, terrain on which political scientists have historically been more comfortable—is how this perspective emphasizes the embeddedness of human action in the material world, and the complex webs and flows of living things and inorganic matter on which social projects rely. Attending to technology, somewhat counterintuitively, steers political analysis in an ecological direction. “Technologies live in complex ecologies,” the MIT sociologist Sherry Turkle once wrote, discussing how the social meanings and functions of the telephone have evolved over the course of a century. (Turkle 2011, 188)

I am cognizant this mere suggestion will sound like heresy to many of my colleagues in the discipline, but in its reticence to engage with ecology, political science finds itself falling behind the curve of a growing trend in both popular and academic cultures. In recent years, ecology has become a buzzword, favored by advertisers and journalists, even politicians, and popular discourse is awash in ecological metaphors to describe social phenomena. The shortands of "media ecosystem" and "information ecosystem" to describe the news media, social media, and other digital environments are now pervasive. (9) Commentators across the ideological spectrum are thinking about political subjects in expressly ecological terms. (10) It seems that just about everyone is thinking about their organizations and cultures in ecological terms—everyone except professional political scientists, with a few noteworthy exceptions.

A major study on democratic backsliding commissioned by the American Academy of Arts and Sciences under the leadership of Danielle Allen, the most prominent democratic theorist working in the United States today, characterized civic life as "the ecosystem of associations and groups in which people practice habits of participation and self-rule and reinforce norms of mutual obligation." The report faulted previous studies of democratic decline for focusing on "only one component of this dynamic ecosystem." The report recommended that reinvigorating America's democratic culture would "require an infusion of coordinated support so they can develop together into a thriving ecosystem, support that comes not only from established organizations in the field of civic work, but also institutions and associations of every kind, at every scale, and in every sector." (AAAS 2020, 3, 61)

Could these frequent associations of social phenomena with ecological processes become something more than metaphors? The explosion of interest in ecology has yet to gain much of a foothold in disciplinary social science, which remains broadly positivist in orientation, and skeptical of claims that human systems depend much on or share much in common with their natural environments—such assertions smack of scientism and would seem to deprive humans of their unique agency to shape their own fates. By contrast, most field ecologists take quite literally the proposition that human environments *are* ecosystems, and increasingly they are studying these "artificial" environments as such.

My aim here is not to engage in ontological or ethical debates about human ecology, but only to ask in a pragmatic spirit how ecological tools might be put to use in studying processes of political change. Many of the sources I have cited in previous sections—from Eckersley, to Scott, to Latour—have demonstrated an interest in ecological thought, concepts and values, but none has made much effort to engage with or apply the tools of ecological science. I think that direct engagement is overdue. In this section, I offer an initial assessment of how some theoretical concepts, empirical methods, and explanatory strategies from the ecological sciences might be adapted to political inquiry. I begin by surveying the history of political ecology in the social sciences, then summarize some takeaways from my study of ecological science, and close with responses to several common concerns about the approach I am advocating. In the chapters that follow, I will attempt to apply those ecological tools to give an account of how Denmark became a world leader in wind energy production.

2.4.1 Political Ecology in the Social Sciences

While the intuition that human societies must evolve in a more ecologically responsible direction is becoming widespread, it is not new. Writing in the years following the explosions of the first atomic bombs, pathbreaking naturalist Aldo Leopold explicitly called for such a moral and political development, which he viewed as both "an evolutionary possibility and an ecological necessity." (Leopold 1966 [1949], 238-239)

Thinking of human individuals and communities as embedded in broader ecosystems was still relatively novel in postwar America. As the environmental movement gathered momentum in the 1960s and 1970s, ecological concepts filtered into popular consciousness, and a raft of social thought began reevaluating humanity's place in nature. A lot of this early work on human ecology attempted to directly apply principles derived from the natural sciences, but arguably strayed too far in that direction, and could be labeled "ecocentric" in its outlook. Prominent examples of this school of thought would include the philosophers Murray Bookchin and Arne Naess. I will discuss some problems with Bookchin's "social ecology," which relied on generalizations and analogies that were both politically and scientifically suspect, later in this section. Naess called his philosophical movement "deep ecology," and was more careful to stipulate that his own "ecosophy" was intended as a practical, and personal, ethic, that was "inspired by ecology, but it cannot be derived from ecology or any other science." (Naess 1989, 39) In Naess' formulation, deep ecologists are committed to two core ethical principles: first, that all life, including nonhuman life, has intrinsic value; and second, that the flourishing of a diversity of life forms is an intrinsic good. Feminist theorist Val Plumwood has criticized Deep Ecology for promoting the importance of the nonhuman world, while making "notably poor connections with human ecological issues," marginalizing "the human side, the many highly significant hybrid forms of environmental activism that are concerned with environmental justice and with situating human life ecologically." (Plumwood 2006, 61-63) Naess stresses that the specific principles he articulates are his alone, and makes the case that these values are well-suited to life in the remote and rugged mountains of Norway, but he lacks a political account of how an ecological ethic might take root in society. Thus while the proposals of ecocentrists are philosophically provocative and substantively engaged with ecological science, they tend to be much less sophisticated in their attention to the practical realities of politics, and have remained marginal, even within the environmental community. Bookchin thought the adoption of an ecological worldview would lead humans to embrace anarcho-communism, whereas Naess envisioned a more personal awakening and transformation. For the purposes of this study, it will be enough to say that neither of these largely normative visions is of much help demonstrating how to conduct empirical analysis of historical social change along ecological lines.

One of the most robust attempts to apply ecological science to human affairs can be found in the works of the Odum brothers, Howard and Eugene, who collaborated on the first widely-used ecology textbook. Eugene began his 1998 book *Ecological Vignettes* with the proposition that since there are many parallels between human concerns and natural processes, "it stands to reason that we can learn a lot from ecology, the science of the environment, that can help us understand and deal with our human predicaments and dilemmas." (E. Odum 1998, xiii) But like many scientists who dabble in policy, the Odums could be accused of being overconfident in their scientific theories and uncritical in their application of that science to human affairs. Most of the policy analysis in *Ecological Vignettes* amounts to a critique of laissez faire capitalism, a defense of the limits to growth thesis, and a call for "mature" societies to focus on qualitative rather than quantitative development. A chapter titled "what we don't learn from nature" includes a brief discussion of the dictum "count on scientists to recognize problems but not to solve them." But Eugene has few concrete ideas about how policymakers should interact with scientists, other than that the former should listen to the latter more. “The way it is supposed to work,” Eugene writes, “is that scientists research problems and suggest solutions that hopefully enable the public and its representatives (legislators, etc.) to better deal with societal problems.”

Eugene believed ecology could play a “major role” in bridging the gap between experts and the lay public, since it is “an integrative rather than a reductionist discipline.” (E. Odum 1998, 43) It is a useful suggestion, but his own writing demonstrates little of that integrative spirit in its discussions of politics and public policy. The odd reference to Emile Durkheim or Langdon Winner aside, he provides little evidence that his social prescriptions are informed by social science. Instead, his default strategy is to show how wrongheaded bureaucrats are from the perspective of ecological theory.

Eugene Odum at least talked a lot about policy, even if he didn’t demonstrate much expertise on the subject. His brother Howard was even more abstract and grandiose in his proposals. Howard Odum is remembered as one of the progenitors of systems ecology, and is most famous for developing the theory of energy flows, which remains a core concept in the field today. But Howard become so enamored with his own theory he began to see it as the fundamental principle of all life, and the key to explaining everything, including all human history. His “maximum power principle” bears an intriguing resemblance to some of Friedrich Nietzsche’s statements about the “will to power,” and perhaps shares a little of Nietzsche’s megalomania. In a book he co-authored with his second wife, Elisabeth, the Odums purport to explain everything from the organization of primitive societies, to industrialization, to modern geopolitics, in terms of their “energy basis.” (Odum and Odum 1981)

Howard became fascinated with electrical circuits, and developed his own notation for diagramming the what he saw as the closed circuits of energy systems. His was an increasingly mechanistic approach to thinking about the structure and function of both human and natural systems, and as critics have pointed out, his effort to make the calorie the fundamental unit of ecological science was starkly reductionist, seemingly at odds with his brother's description of ecology as an "integrative" discipline. (Hammond 1997)

I am being hard on the Odums here because I think what they were doing was unique, creative, forward-thinking, and boundary-pushing, if only half-baked. Certainly, Eugene was a fellow traveler in advocating the cross-pollination of ecology and politics. Howard shared with this author a deep interest in the history of energy transitions. The general notion of energy flows remains a helpful way to conceive of ecosystem dynamics, even if his development of that theory led him in increasingly esoteric and non-ecological directions.

Even though some of the Odums' more radical ideas have been left behind, ecology grew out of its somewhat kooky phase and only gathered momentum, finding firmer footing as a mathematical science in the latter decades of the twentieth century. In the social sciences, "political ecology" coalesced as an organized field of academic inquiry in the 1990s, though even its leading lights are continuously admitting that it is a "broad and wide-ranging approach" whose "theoretical coherence nonetheless remains in question." (Peet and Watts 1996). Paul Robbins, author of a textbook on political ecology for undergraduates, suggests research in the area should be understood as a "community of practice" united around some common premises, concerns, and texts. One of those core premises is the assertion that "environmental change and ecological conditions are the product of political processes." (Robbins 2012, 19-20) That simple statement already reveals quite a bit about the scope of this literature. As Robbins suggests, most work in political ecology emphasizes social explanations, and adopts a critical political economic stance that assumes space is organized and resources are distributed in ways that serve the prevailing social order.

This orientation reflects the field's origins within development and peasant studies, in works critical of modernization theories and environmental determinism. Much of the work being published in the field today could still be characterized as "critical development studies." In this respect, the field shares a common intellectual heritage with the works of James C. Scott discussed in the previous section. Through the decades, political ecologists have dedicated substantial effort to contesting the "naturalness" of circumstances like resource poverty, environmental degradation, and the exploitation of marginalized communities.

So one way to think of political ecology is as a close sibling of political economy research that takes "natural" rather than economic systems as its primary locus of analysis. I keep putting "natural" in scare quotes, because political ecologists have been among the leaders in volume of ink spilled challenging the artificial separation of the human and the natural, which could be counted as another foundational premise of the literature. Marxist geographers David Harvey and Neil Smith remain lodestars. A major theme of their works has been how capitalism structures human experiences of space and time. Harvey's books on these subjects have often dealt with themes of globalization, imperialism and neoliberalism. Smith is most famous for popularizing the idea of "uneven development" under capitalism in his book of the same name. A theoretical attempt to rehabilitate orthodox Marxism as an approach to development studies, much of that book is dedicated to explaining how industrial capitalism produced modern nature ideology, and increasingly even produces the material substratum we think of as the "natural" world. "The differentiated results of this production of nature are the material symptoms of uneven development," Smith writes. (Smith 1984, 50) He notably doesn't say much of anything about ecology, the term doesn't even appear in the book's index.

This is a surprisingly common critique of research in a field that defines itself at the intersection of political and ecological concerns, but whose practitioners frequently lament that they haven't been particularly good on either subject. In the early 2000s, geographer Peter Walker published a pair of companion pieces asking why there was so little politics and so little ecology in a field so named, and called the field to task for its "failure to provide an intellectual environment that nurtures the integration of ecological and social science." (Walker 2005, 80) Peet and Watts had previously characterized "the absence of a serious treatment of politics" as a frontier where new research was expanding the field with "efforts at integrating political action—whether everyday resistance, civic movements, or organized party politics—into questions of resource access and control," and cited Peter Haas' research on the "epistemic communities" of international environmental agreements as one such example. (Peet and Watts 1996, 10) On the other side of the equation, Diane Rocheleau has complained that "while the social side of PE burgeoned in the 1990s the biophysical dimension languished … Equal emphasis on biological and social dimensions of ecology was discouraged as awkward, if not impossible or undesirable, and on at least one occasion I thought I was in danger of excommunication for the transgression of invoking 'biological metaphors'" on a panel at an academic conference. (Rocheleau 2008, 723)

Sadly, ecological science remains an afterthought in most political ecology research strategies. In outlining a program for "liberation ecology," Richard Peet and Michael Watts include no discussion of how ecological theories, methods or practices might contribute to that effort. Instead, they consider frameworks including discourse theory, the "cartography of development," and research on social movements. They frame political ecology as "a specialized branch of critical social theory," (Pete and Watts 1996, 36) making it difficult to distinguish work in the field from cultural anthropology or critical geography. Having emerged primarily out of those disciplines, political ecology should perhaps be expected to emphasize their methods and preoccupations. The open-access Journal of Political Ecology, started and run by anthropologists, explicitly limits submissions to work that "uses tools drawn from political economy, multi-scalar analysis of environmental issues and ecologies, access to resources (e.g. by race, gender, status, wealth), environmental and social justice, feminist, materialist and intersectional theories, and studies of vulnerability and disadvantage." Paul Robbins surveys a similar range of "critical tools" used by political ecologists in his textbook, discussing common property theory, Marxist political economy, peasant studies, feminist development studies, environmental history, postcolonial studies, Foucauldian approaches to the analysis of power, and actor-network theory. (Robbins 2012, 49-81) He dedicates an entire chapter of the textbook to "challenges in ecology," which is almost entirely concerned with the human causes of environmental degradation. He does include some general discussion of how ecologists measure declines in natural systems, but doesn't attempt to instruct students in the use of these techniques, even though he concludes research in the political ecology of particular regions “requires an acute attention to the ecological characteristics of the landscape in question.” Researchers must able to “establish the overall type, rate, and direction of, possibly multiple, environmental changes,” “determine the environmental context in which such changes occur, including preexisting variability and dynamics,” and “examine the capacity, rate, and direction of routes of ecological recovery following changes or cessation of impacts.” But “in truth,” Robbins admits, “political ecology has not always been entirely attentive to these methodological or conceptual problems.” He chalks that weakness up to “the enormity of the undertaking,” but concludes that the more limited goal of showing “the influence of political economy on such already complex systems” is achievable. (Robbins 2012, 119-120) This shunting aside of the science is fairly typical scholarship in the field, much of which seems to treat “ecology” as a synonym for “natural resource management.”

Understandably, interdisciplinary communities of scholars almost always wrestle with fractured identities. Textbooks like Robbins’ are less concerned with acknowledging ties to the ecological or political sciences than they are with distinguishing what makes the field unique from other closely-associated disciplines. As such, Robbins identifies five distinctive theoretical propositions, or “dominant narratives,” uniting scholars in political ecology—that the intervention of states and global markets tends to degrade otherwise sustainable production, that conservation efforts tend to wrest control of resources from local producers, that conflicts over access to environmental resources are reflective of broader struggles between social groups, that environmental policies shape the identities of individuals subject to those regimes, and that “political and economic systems are shown to be underpinned and affected by the non-human actors with which they are intertwined." (Robbins 2012, 21-22) Later, he summarizes these critical theoretical perspectives as either "hatchets" or "seeds": "political ecology is a tradition that aggressively dismantles other accounts (wielding its intellectual hatchet), while making space for, and nurturing, other possibilities (planting intellectual and practical seeds)." (Robbins 2012, 98)

The emphasis on planting "seeds," understood as imaginative alternatives to hegemonic modes of social organization and production, speaks to the field's normative and activist bent. No doubt inspired in part by its roots in Marxian analysis, work in political ecology has shown a longstanding interest in subalterns, social movements, and social justice. "Political ecology seeks not simply to be retrospective or reactive, but to be progressive," Robbins writes. (2012, 99) Political ecologists tend to see the production of nature under capitalism as fundamentally exploitative, and as a result take a keen interest in, and often sympathize with, social movements resisting hegemonic power. Environmental justice has become a central theme of much of the research being published in the field today.

Robbins is speaking about one relatively cohesive academic literature among many varieties of political ecologies. In European scholarship, the term "political ecology" has historically had an activist connotation, and is usually associated with the policy agendas of green parties and the effort to embed environmental values in social institutions. While that agenda appears to have growing political momentum—the 2018 parliamentary election in Denmark is a case in point—it has also produced a significant backlash. French theorists like Pierre Lascoumes have criticized green parties for departing from their origins in popular social movements and evolving in excessively state-centered and technocratic directions. I already discussed above how Carol Hager's German protestors raised similar concerns about the popularization of green politics in their country. Lascoumes feared the integration of ecological values into state bureaucracies portended a dystopian future. Building on the Foucauldian concept of "biopower," Lascoumes hypothesizes that "ecopower" could emerge as a new, more expansive mode of social control. "Social conformity would henceforth be enforced less by disciplining individual bodies than by monitoring, regulating, "normalizing" the processes through which entire social groups develop their identities. Eco-power inaugurates a second stage … by extending surveillance and control beyond human society to every other form of life." (Whiteside 2002, 143) Lascoumes is not the only scholar who has detected a dark underbelly to environmental movements, and I will return to those worries at the end of this section.

Bruno Latour has been another frequent critic of the European approach to political ecology, and framed his 2004 magnum opus *Politics of Nature* as an attempt to reclaim the term from the "stagnation" of the green movements. (Latour 2004a, 1) In a later book, Latour credited the European Greens for "introducing objects that had not previously belonged to the usual preoccupations of public life." In doing so, they have "successfully rescued politics from an overly restrictive definition of the social world," and changed "what is at stake in the political sphere." But the green movement foundered, he argues, due to its inability to resolve the apparent contradiction between modernization and environmentalism, frozen like Buridan's ass between competing social and ecological demands. "The Green parties remain rump parties everywhere," he concludes, as if writing their obituary. “They never quite know what foot to put forward.” (Latour 2018, 46, 58) The root of the problem for green politics, Latour seems to think, is that the parties have not yet redefined the terrain of politics radically enough. They have accepted the ingrained modernist separation and opposition of the political and the natural, and in doing so have missed an opportunity to forge alliances between the causes of social justice and environmental sustainability. Latour’s aim is to politicize the assembly of this shared material world, rather than assume its givenness.

Latour became so disenchanted with political ecology by the end of his career that he concluded “it is perhaps time to stop using the word ‘ecology’ except to designate a scientific field … The adjective “political” ought to suffice from now on.” (Latour 2018, 90) But he never followed through on his threat of abandoning ecological science, as evidenced by his collaborations with prominent biologists like Scott Gilbert and Deborah Gordon. (See, for example, Latour, Schaffer and Gagliardi 2017) He dedicated his career in social research to running *toward* the sciences. Latour’s instincts about bridging the human-nature divide were to never mind the gap, to charge into the intersections where the social and natural worlds collide, to multiply the entanglements, to follow the knotted threads. In a general sense, these are useful methodological prescriptions. But the details of his political project have a tendency to get lost in translation.

Whatever the limitations and risks of deploying the language of ecological science, weighted as it is with suspect ideas about nature, Latour’s own attempt to redefine political ecology fails to offer a more attractive alternative. He is maddeningly vague about how to operationalize his verb “ecologize.” Not even a (necessary) glossary in *Politics of Nature* can help shed much light on what he intends with his usage of "political ecology," which he says is modeled on political economy, "but in opposition to it," and should be understood as "an umbrella term to designate what succeeds modernism." (Latour 2004a, 240-247) The ecocentrists and geographers are at least explicit about where they stand.

None of the approaches to political ecology discussed above has made much of an impact on political science. When these sources are referenced, it is usually by political theorists working on "green political thought," or "environmental political theory." As I discussed in section 2.2, there is hardly enough attention to ecology in any of these writings to warrant labeling them "political ecology."

Studies of comparative politics have often overlapped with research in anthropology, geography and history, through shared interests in the subjects of development and modernization. The references to political ecology in this comparative literature often take the form of environmental histories, like Robert Marks' *The Origins of the Modern World*. Marks' attention to the material conditions of development is noteworthy, but when he asserts that "ecology mattered" in establishing the global hegemony of Europeans, he seems to have in mind only the production and circulation of commodities. (Marks 2002, 17) These sorts of sweeping histories of "the rise of the West," are often accused of environmental determinism—as if the arc of world history can be boiled down to geography and the distribution of resources—and typically demonstrate little to no substantive engagement with ecological science.

One approach that has gained more of a foothold in disciplinary political science, especially in public policy research, is economist Elinor Ostrom's social-ecological systems (SES) framework. Ostrom's program has been buoyed by the endorsement of working field ecologists—scanning the thousands of cites in the SES literature reveals a plurality of articles on forests and fisheries and related work concerned with the conservation of various natural resources. To her credit, that interaction led Ostrom to internalize some core principles of ecological analysis, which informed the more radical elements of SES theory. Her writings on SES were particularly good at talking about how to study complex systems. “We should stop striving for simple answers to solve complex problems,” she writes, and then quotes Holling et al. (1998): “causes, while at times simple (when finally understood), are always multiple. They are non-linear in nature, cross-scale in time and in space, and have an evolutionary character This is true for both natural and social systems. In fact, they are one system, with critical feedbacks across temporal and spatial scales.” (Ostrom 2007, 15181) This view of causation has dramatic implications for both research practices and policy solutions. SES scholarship will have to welcome a diversity of methodologies, since “exclusive devotion to a particular research method threatens the capability of scientists to contribute to the development of the diversity of institutions needed to sustain the diversity of ecological settings over time.” (Ostrom 2007, 15185) Her research program also suggests that effective policy interventions must be adapted to local conditions. “Simple blueprint policies do not work.” (Ostrom 2009, 421) In language reminiscent of Scott’s *Seeing Like A State,* Ostrom criticizes scholars for a tendency “to develop simple theoretical models to analyze aspects of resource problems and to prescribe universal solutions” which have led to one-size-fits-all recommendations to impose particular policy solutions that frequently fail.” (Ostrom 2009, 419)

Instead of becoming “fixated on a low conceptual hill by trying to optimize specific variables while overlooking better solutions involving ignored variables,” Ostrom advocates the development of “diagnostic methods” capable of identifying how variables combine and interact across varying governance contexts. (Ostrom 2007, 15181) Such a model—and Ostrom has built her own to export—would organize relevant variables into classes “of relatively separable subsystems that are independent of each other in the accomplishment of many functions and development but eventually affect each other’s performance” and have “emergent properties” when combined. The framework she proposes sorts the components of social-ecological systems into four main subsystems: A resource system (such as a fishery), resource units (fish), users, and the governance system. Each of these subsystems can be further decomposed into numerous additional variables at deeper levels of analysis. For example, governance systems include organizations, constitutions, property rights, and monitoring and sanctioning processes, among other component parts. “How far down or up a conceptual hierarchy a researcher needs to proceed depends on the specific empirical or policy question under investigation.” (Ostrom 2007, 15182-15183) This suggestion about the adaptability of the framework to the specific questions or problems at hand is one of the more inviting characteristics of her model.

Ostrom’s take on studying complex systems is a markedly more ecological in spirit than the reductionist approaches to the subject popular in political science (see, for example, Miller and Page 2007). And yet her framework is simultaneously too general and too particularistic in ways that create tensions with the attempt to establish an ecologically-minded interdisciplinary research community. Ostrom believes a common framework is needed to facilitate interdisciplinary collaboration, and her framework is expressly designed for the comparative analysis of case studies around the globe. Her justification for adopting a sui generis classificatory scheme is that "the ecological and social sciences have developed independently and do not combine easily." (Ostrom 2009, 419) She provides no further explanation of that assertion. For the sake of this dissertation, I hope she is wrong. For all her talk about diversity of methods, at the end of the day, Ostrom was seeking to build standardized, transferable databases.

Much like Latour, Ostrom's engagement with ecology amounts to a relatively thin veneer built atop an existing research program, in this case, a framework she previously developed to study the governance of common-pool resources. The SES model appears largely designed for, and best suited for, addressing a question Ostrom pursued throughout her entire career: When will the users of a resource invest time and energy to avert 'a tragedy of the commons'?" (Ostrom 2009, 420) The basic bifurcation of the world into users and resources is already quite limiting. Many ecological thinkers, like Aldo Leopold, would reject the characterization of nonhuman nature as a collection of mere resources to be exploited more or less sustainably. The SES model is tuned less to explaining the complex dynamics of system change than to explaining how certain features of an SES structure incentives for human "users." This perspective comes more from economics than from ecology, and is built on rational choice assumptions about the agency and interests of human individuals.

Ostrom's framework may have important affinities with the ecological sciences in both spirit and practice, but the conceptual apparatus remains her own. The most sustained efforts I have encountered by social scientists to directly apply principles of ecology to the analysis of social change can be found in the literature on "organizational ecology," most closely associated with Glenn Carroll and Michael Hannan. Organizational ecology research focuses on "the vital rates of populations—rates of founding and mortality in particularity," working from the basic premise that "organizational change over time occurs through the selective replacement of some kinds of organizations in the population with other kinds as environmental circumstances change." (Carroll and Hannan 2015, 358) In addition to adopting this evolutionary model of organizational change, research on organizational ecology has made significant progress in defining organizational niches, and has particular strength in analyzing the population dynamics of organizations within specific business sectors. This demographic analysis has yielded several theorems, such as the density dependence of rates of organizational birth and death, that have direct parallels in wildlife biology. (S. Carroll 2016, 147)

Thus far, the organizational ecology framework has been used primarily to study West Coast industries like wineries, movie studios, record labels, and software developers. Carroll and Hannan do not discuss the relevance of their model for understanding political change. It has seen some limited application to international relations theory in work by Kenneth Abbott, Jessica Green, and Robert Keohane (2016), who have used organizational ecology to explain the proliferation of international organizations for climate governance. These authors do little to extend Carroll and Hannan's theory, beyond tweaking the latter's means of measuring population density, which they argue does not "fit world politics well." (Abbott et al. 2016, 258) They do argue the theory fits their case, and "should be highly transferable across issue-areas."

(Abbott et al. 2016, 273) According to these Abbott, Green and Keohane, existing IR theories give incomplete explanations of the growth patterns of such organizations "because they overemphasize agency at the expense of structure" and "fail to pay systemic attention to the organizational environment." (Abbott et al. 2016, 249-250) In spite of these shortcomings of more traditional approaches, the authors argue that "actor-centered and ecological approaches are complementary:

> Organizational ecology enhances our understanding of the constraints and opportunities presented by environmental and population-level variables. Actor-centric theories supply the micro-foundations for understanding organizational responses to those constraints and opportunities. Even here, however, organizational ecology makes important contributions, highlighting actor characteristics important in structuring and mediating the influence of organizational environments. (Abbott et al. 2016, 272-273)

This notion that ecological concepts can be grafted into longstanding disciplinary debates without friction seems overly optimistic, even for someone like me who is generally supportive of such efforts. If an ecological orientation departs, in many ways, from traditional norms of social scientific research, then to what extent do those incommensurabilities open possibilities for thinking about, and studying, politics differently?

2.4.2 Ecological Tools for Political Analysis

The preceding review of research on political ecology found only the thinnest of engagements with ecological science. The "ecology" in this literature only rarely refers to a method of inquiry and more often signals a normative commitment—to conserving natural resources or promoting environmental justice. This relative lack of integration is probably no accident, and reflects some underlying tensions between the social and ecological sciences. As Elinor Ostrom pointed out, the disciplines have distinctive intellectual heritages, and practitioners have internalized some fundamentally incompatible ideas about what constitutes a scientific explanation and how to conduct a scientific investigation.

Dominant paradigms slowly lose some of their givenness, and eventually adherents, as they grow increasingly brittle and ill-fitting with age, as anomalies accumulate to raise doubts about theories, as new problems appear that existing theories and methods are unequipped to address. Many of the multi-dimensional, boundary-crossing social issues of the twenty-first century—and global climate change is an exemplary case of this trend—pose just this sort of paradigm-weakening challenge to the postwar organization and commitments of American political science. While confronting the obsolescence of our research traditions is bound to be destabilizing, it also presents an opportunity to innovate and to breathe fresh life into stale debates. If the defining challenges of this era are ecological in character, then perhaps it is worth taking seriously what biologists have learned about how ecosystems function.

These challenges to the discipline are not meant to deny the leadership of individual scholars, or the increasing popularity of climate policy as a topic of political studies, but to highlight the absence of a coordinated and sustained research agenda. There has been little effort to institutionalize the study of climate politics, and many of the existing subdisciplinary silos frustrate efforts at integration, too often discouraging potentially productive collaborations and cross-pollinations with the abundance of ecological research being conducted outside the boundaries erected by disciplinary political science.

When I attempt to summarize some core principles of ecological research, I am of course offering an interpretation. In what should now be a familiar refrain of this chapter, there exists no unified, homogenous approach to ecological research; there are instead many ecological sciences—such as forestry, hydrology, botany, zoology, entomology, marine biology, evolutionary developmental biology, population ecology, community ecology, ecosystem ecology … and so on. Practitioners in these diverse fields employ a wide range of methodological tools and explanatory strategies.

Furthermore, the sort of anti-reductionist approach to ecology that I will be emphasizing below is somewhat out of fashion in the leading academic journals and departments. Modern ecology originated in the late nineteenth century as a primarily observational science, but in recent decades, scholarship in the field has taken a mathematical turn, and the majority of the research being produced today is grounded squarely within the positivist paradigm, utilizing its methods, adopting its standards, and sharing its objectives. John Dryzek has described the mainstream of academic ecology as "thoroughly reductionist and stochastic." (Dryzek 1990, 206) Nevertheless, there exist recognizably ecological theories and methods, which can be distinguished from the explanatory strategies of the physical sciences or even evolutionary biology. These ideas and approaches have been articulated in the writings of some of the field's most renowned thinkers, and even if these perspectives have been marginalized in the scholarly journals, they are still identifiable in the daily practices and assumptions of field ecologists.

The description of core tenets of ecology presented here has been assembled from a wide range of sources—including classic studies from the disciplinary canon, popular textbooks used to teach basic principles of ecology in universities, contemporary research on wildlife ecology, theoretical treatises by leading ecological thinkers, and firsthand observation of and communication with practitioners in the field. My survey of these sources has revealed numerous contributions to the science of ecology that have potential applications to the analysis of politics and society. Below, I outline some of what I have observed about some of the distinguishing features of ecological science, beginning with the general approach to explanation, and then focusing in on some specific research methods and theoretical concepts.

2.4.2.1 Ecological Explanation

The dominant methods of political scientists working in the United States today originated in the behavioral revolution of the 1950s, which placed new emphasis on quantification and mechanistic causal explanation. This positivist approach was most influentially captured in Gary King, Robert Keohane, and Sidney Verba's methodological handbook, *Designing Social Inquiry* (1994), which advocates maximizing "leverage" by limiting the number of study variables and increasing the number of data points collected on each variable, in the hopes of making causal inferences through the isolation of the underlying mechanisms that produce observed phenomena. The notion that social processes can be explained in terms of linear and mechanistic chains of causation was itself a philosophy of science imported from the natural sciences—in this case, classical physics—and its popularity is rooted in a longstanding desire to make the study of politics a proper science, rather than the primarily historical and theoretical discipline it was before the twentieth century. Many political scientists, it seems, hold out hope of discovering Laws of Politics approximating the universality, invariability and practical power of the Laws of Physics.

If only the laws of physics were themselves so unimpeachable. Environmental historian Carolyn Merchant traces the origins of the mechanistic philosophy to seventeenth-century experimental physicists like Galileo Galilei, Robert Boyle, and Francis Bacon, and offers a trenchant critique of the domineering, exploitative and patriarchal aims that informed their philosophies. Whether or not these associations apply to positivist social science today, it is certainly the case that the ontology and methods of the mechanistic sciences differ profoundly from those of the ecological sciences. “The mechanistic style of problem solving …pays little regard to the whole ecosystem of which people are only a part. The antithesis of holistic thinking, mechanism neglects the environmental consequences of synthetic products and the human consequences of artificial environments.” (Merchant 1990 [1980], p. 186) Biologist Daniel Botkin has been similarly critical of the mechanistic worldview, which he sees as a major factor in environmentally destructive practices, and profoundly ill-suited to the study of natural systems. “The biosphere is unlike the mechanical devices of our construction, and its analysis requires the development of new scientific approaches,” he argues. (Botkin 2012, 9)

As Merchant emphasizes, ecologists have historically taken a more holistic approach to their subjects of study than their counterparts in other natural science disciplines, which typically seek to break down the phenomena of interest into their component parts. Another way of saying this is that ecological explanations are basically additive, attempting to identify as many relevant variables as possible and give as complete an account as is feasible of the numerous interacting systems that contribute to overall ecosystem function. Mechanistic explanations, by contrast, are basically subtractive, attempting to control as many variables as possible so as to remove them from the equation and isolate the effects of whatever study variables one's theoretical model emphasizes. These attempts at isolating variables are, of course, a fiction, never achieved in practice, not even in the most pristine laboratories. Social scientists who use statistical methods are well aware of the ever-present dangers of interacting variables, and the difficulties of accounting for those interaction effects, which can lead to dreaded problems of endogeneity and omitted variables. I would contend that many social variables of interest to political scientists exhibit high degrees of endogeneity, and probably every theoretical model omits potentially relevant variables.

Ecology is a science of systems, composed of closely interconnected parts that are not easily decomposed, and may not function in isolation from one another. This systemic perspective has implications for both the scale of ecological studies and their units of analysis. Mechanistic models assume closed systems, but such self-contained and self-sufficient systems are always abstractions from reality; they are found nowhere in nature, and nowhere in politics. The linear models favored in positivist social science can only describe processes at one level of analysis at a time, whereas ecological analysis is fundamentally multi-scalar. As Eugene Odum wrote in an article outlining an agenda for the "new ecology," "functions and principles change as smaller units are integrated into a larger one. Therefore, structure and function at any one level explains only in part the structure and function at another level which itself must also be studied to complete the picture." (E. Odum 1964, 14) This is one principal of ecological science that political ecologists have embraced in their work:

> Political ecologists follow a mode of explanation that evaluates the influence of variables acting at a number of scales, each nested within another, with local decisions influenced by regional polices, which are in turn directed by global politics and economics. Research pursues decisions at many levels, from the very local, where individual land managers make complex decisions about cutting trees, plowing fields, buying pesticides, and hiring labor, to the international, where multilateral lending agencies shift their multi-billion-dollar priorities from building dams to planting trees or farming fish. Such explanation also tends to be highly (sometimes recklessly) integrative. (Robbins 2012, 20)

Working across multiple scales appears necessary to approximate a "complete picture" of my empirical case, the growth of the Danish wind sector. Events at all scales, from the hyper local to the global, have had dramatic consequences for the evolution of wind energy technology. From an ecological perspective, addressing just one of these levels at the expense of the others would paint a very incomplete picture of the processes at work in system evolution.

In ecological thought, the ecosystem rather than the individual organism is the basic unit of analysis. One popular textbook defines an ecosystem as "a self-contained ecological entity of both organisms and their complete biotic and abiotic environment. It is quite simply the smallest functional ecological unit: an independent self-contained and self-sufficient block." Within ecosystems, "No one organism lives in simple isolation … Each organism is part of a complete community of creatures, each interacting with each other as well as with their abiotic environment." (Putnam and Wratten 1984, 43)

Political science explanations have long favored the preferences and choices of individual actors, who are assumed to be independent, voluntaristic, and internally consistent. These are extremely unrealistic assumptions, whether the actor in question is an individual, an organization, or a state. Individualism doesn't make a lot of sense from a biological perspective, either, as Daniel Botkin points out:

> We are accustomed to thinking about life as a characteristic of individual organisms. Individuals are alive, but an individual cannot sustain life. Life is sustained only by a group of organisms of many species—not simply a horde or mob, but a certain kind of system composed of many individuals of different species—and their environment. Together they form a network of living and nonliving parts that can maintain the flow of energy and the cycling of elements that, in turn, support life. A system that can do this is not only rare but also peculiar compared to mechanical systems, peculiar from the perspective that we have become accustomed to in our methods of analyzing and constructing the physical trappings of our modern civilization. (Botkin 2012, 10)

A significant portion of professional ecologists do specialize in the study of particular species—or, more typically, in larger families and classes of related species. There are experts on birds, and bats, and fish, and marine mammals, and ants and spiders. But even single-species studies will describe the particular species of concern in terms of the ecological niche it occupies, its location in food webs, its predators and/or prey, and its symbionts. And when studying these species, the concern is never with understanding individual behaviors or outcomes. Instead, ecological explanations are interested in population-level trends, and with understanding the overall health of the population. An entire subfield, population ecology, is dedicated to charting, modeling, and theorizing these population dynamics. I should note that this is the branch of ecology that has most enthusiastically embraced quantitative methods, and frequently employs tools of statistical analysis and formal modeling that will be familiar to many political scientists.

This overlapping toolkit probably largely explains why this is the branch of ecology that has been most productively mined by sociologists, who have a long tradition of demographic analysis in their discipline. The organizational ecology literature defines a populations as "sets of organizations engaged in similar activities and with similar patterns of resource utilization." Carroll and Hannan borrow from ecology the insight that a shared "dependence on a common set of resources" is the distinguishing feature of a population, which leads them to the corollary that organizations within a population occupy a shared ecological niche. (Abbott et al. 2016, 257) From this conception of a population, organizational ecologists derive some of their more well-tested theoretical propositions, such as their resource-partitioning theorem—specialist firms proliferate and enjoy competitive advantages over generalists as industries mature and markets concentrate—and their density-dependence theorem—"as density increases, founding rates initially rise, reach a peak, and then decline." (Carroll and Hannan 2015, 361) The latter theorem has a direct analogue in wildlife ecology. Studies of animal populations in the Serengeti have found that "the rate of change in the population depended on its density … If the population starts out small in number, it can expand as rapidly as the animals can reproduce. But as the number of animals increases, space or food begins to run low. If the population has overshot the capacity of the habitat, it will contract; eventually it will level out to the maximum that can be supported on finite resources." (S. Carroll 2016, 147)

One core characteristic of ecological science that is apparent in this discussion of systems and populations is the centrality of relational thinking. ***Ecological explanations aim first at specifying relationships*.** In fact, this is one of the most common ways of defining the field today—ecology is "the study of relationships between organisms and the environment," according to a textbook widely used in undergraduate courses (Molles 2016, 1), or "the study of the relationships among living things and their environment," in Daniel Botkin's glossary. (Botkin 1990, 230) This relational mindset has significant consequences for the basic ontology of an ecological worldview. It is a dramatic departure from the Galilean and Cartesian sciences, which distinguish reality from mere appearance in terms of primary qualities presumed to inhere in objects themselves. Liberal political thought similarly relies on the assumption that individuals possess certain inherent characteristics, such as appetites, and reasoning capacities, and moral rights. Ecology presents a rather different picture of reality. Boundaries between organisms are more fluid; entities are defined by the ties that bind them. According to Arne Naess, ecological science is "concerned first of all with relationships between entities as an essential component of what these entities are in themselves." (Naess 1989, 36) I discussed above how Michel Foucault similarly theorized that individuation and identity formation should be understood as effects of the collective fields of forces in which moderns find themselves caught, although in Foucault's case he did not derive this insight from ecology. Naess, for his part, does think that the theories of the biological sciences have several important implications for human beings:

> (1) A human being is not a thing in an environment, but a juncture in a relational system without determined boundaries in time and space.
> (2) The relational system connects humans, as organic systems, with animals, plants, and ecosystems conventionally said to be within or outside the human organism.
> (3) Our statements concerning things and qualities, fractions and wholes cannot be made more precise without a transition to field and relational thinking. (Naess 1989, 79)

The insight that human beings cannot be easily separated from the organic and inorganic systems of which they are a part is a core premise of the account of technological politics I developed above, and may hint in the direction of how to develop an "ecological" politics. Naess' third proposition is an intriguing rejoinder to positivist philosophies of science that contend precision is enhanced by isolating variables to increase leverage.

If the subjects of inquiry are defined in terms of their locations and connections, then it makes no sense to shear away this context in the effort to understand them. ***Ecological explanations emphasize the decisive role of environmental context.*** This explanatory strategy has both methodological and policy implications. For biologists, the importance of context usually means they have to go into the field to observe the plants and animals of interest *in situ*. Work in political ecology has historically shared, as Dianne Rocheleau writes, this "unflinching commitment to empirical observation of biophysical and socio-economic phenomena in place." (Rocheleau 2008, 716) That commitment to place has been a driving force in my own research design. When I became interested in Denmark's global leadership in renewable energy innovation, it quickly became apparent to me that I would not understand the trajectory of Danish wind development if I did not have a broader understanding of the Danish historical, cultural, political, economic, and biophysical environment. As just one example of the significance of observing and experiencing this context firsthand, the account I give in this chapter of the development of the Tvindmill could not have been produced without riding the regional train to far-flung Ulfborg, and then riding the turbine's service elevator to the dank engine room high above the campus, without eating in the cafeteria, and conversing with the people who built the machine and the people who live with it every day. If I had instead relied on secondhand accounts and the available production data, I would have told a very different story about that project—thinner, less insightful, and in important ways, probably wrong. More details on my field methods can be found in Appendix A.

Understanding how contexts shape processes and outcomes also has consequences for the kinds of interventions analysts recommend. Policy research tends to favor simple, generalizable prescriptions that are relevant in a range of settings. With my project, I am often asked how the Denmark's history of wind development compares to similar national cases, such as Germany or the United Kingdom, or how the lessons of the Danish experience can be applied to the United States. The short answer is not easily. Of course, I do not mean to suggest that we can learn nothing from studying other policy environments, or that knowledge is fundamentally nontransferable. In chapters 5 and 6, I will detail some of the broader implications of the Danish case for policymaking around renewable energy development. My point is about how those knowledge claims are framed and applied. One lesson is baked into the adoption of an ecological perspective: policy mechanisms must be adapted to the local conditions of their use, or they run a high risk of unintended consequences. Knowing what strategies and tools will be effective in a given setting requires a detailed knowledge of that environment, which must be understood more broadly than the institutional setting and what scholars call the "policy community," and includes the sociocultural, technological, and biophysical environments in which a policy decision will be implemented.

Field ecologists have also learned through countless hands-on experiences that the best way to influence developments is not by targeting a specific species or community of interest, but to modify the environment on which they depend. Microbiologist Lynn Margulis, who pioneered the science of symbiogenesis, argued that "the most efficient way of getting rid of organisms, cockroaches, for example, is not to kill them one by one but to completely alter their habitat: to promote them, give them more habitat." (Margulis and Sagan 1997, 252) Thus, the success or failure of any given species cannot be understood in isolation from the conditions of its existence. I attempt to apply Margulis' insight in my analysis of Denmark's energy tradition, and document how Danes built and maintained habitats in which wind developments could prosper, and how development pathways evolved in responses to environmental changes. In chapter 3, I use this approach to show how Denmark's favorable wind turbine habitat produced competitive advantages that allowed its domestic technology to outcompete rivals in global markets.

Ecology may offer a different path to identifying similarities between wildly diverse cases, through ***a focus on processes, rather than outcomes***, attempting to capture the operation of functional units and their development over time. One of the classic puzzles of complexity theory has been explaining the herding of mammals, or the schooling of fish, or the flocking of birds, organized patterns of behavior that are apparently achieved without any centralized coordination of individuals. According to Deborah Gordon, a leading expert on the collective behavior of ant colonies, the key to understanding how coordination is achieved is not "to focus too much on analogies among outcomes: the school of fish turns or the herd of wildebeest moves across the prairie. Instead, it helps to think not so much about the outcome, but instead about the process that generates that outcome; every outcome is the result of some process. The question is how that process responds to, and affects, and adjusts to changing conditions." (Gordon 2017, 39)

As is clear from the preceding discussion, ***ecological systems are complex***, and ecologists are comfortable with this complexity. Individuals aggregate in populations, populations aggregate in communities, communities and their environments form ecosystems, and local ecosystems are linked in biomes. “At each stage … we see an increase in complexity,” Putnam and Wratten write in their textbook. “An ecosystem is more than just a collection of communities or of communities and their abiotic environment; a community is more than a simple assemblage of species. The whole is something far beyond the sum of its component parts, but is a complete new entity with characteristics and properties of its own.” (Putnam and Wratten 1984, 43)

Political scientists have become increasingly interested in complex systems during the past decade, but their preferred tools for studying these systems have been computational social network analysis and agent-based modeling, strategies that are essentially reductionist. Both methodologies rely on rationalist assumptions about individuals and positivist techniques of quantitative analysis. It seems when social scientists see complex systems, their instinct is to break them down into smaller parts, and seek the simple underlying mechanisms that produce the illusion of a complex structure.

But simplification is not the only way to handle complexity. In Arne Naess’ ecosophy, complexity is seen as something beneficial to be embraced, in that it allows for greater interconnectedness, diversity, and the emergence of higher-order functions. (Naess 1989, 202) One way to work with complexity is to rethink what constitutes an explanation, and how they are constructed. Dianne Rocheleau has observed this reevaluation of explanatory strategies gathering steam in the political ecology literature. “The center of gravity is moving from linear or simple vertical hierarchies (chains of explanation) to complex assemblages, webs of relation and ‘‘rooted networks.’’ (Rocheleau 2008, 724)

While reductionist strategies attempt to streamline explanations to a single variable or dimension, integrative methods move in the opposite direction, layering on context. Cultural ecologist Andrew Vayda "proposed that explanations of people–environment interactions follow a path of 'progressive contextualization,' where human–environment interactions are explained 'by placing them within progressively wider or denser contexts.'" (1983, quoted in Robbins 2012, 46) This approach has affinities with calls by the likes of Donna Haraway and Sandra Harding for the social sciences to produce "situated knowledges."

Elinor Ostrom recognizes that the nested tiers of interacting variables in socio-ecological systems pose a "challenge to the way many scholars think about theory and explanation," and that her colleagues who specialize in large-N regression analysis would be "initially horrified" at her long list of potential explanatory variables. (Ostrom 2007, 15186) But Ostrom remains torn between the competing demands for complexity and simplicity, and settles on suggesting that complex systems can be dissected into their components parts, and many subsystems are relatively decomposable, and can be studied in isolation from one another. That claim runs counter to most of what I have said above about ecological approaches to explanation.

Although I have criticized Ostrom's SES framework for its limited integration of ecological science, one of her favorite cases to reference—the regulation of Maine lobster fisheries—offers a good example of how to give an ecological explanation that is non-reductionist, attends to the peculiarities of the local context, and captures the complexity of a successful policy regime. Ostrom recounts how, in response to a collapse of lobster stocks in the early twentieth century, Maine lobstermen developed "ingenious rules and norms" which allowed them to "evolve an ever more valuable local fishery." The state government had made it illegal to harvest egg-bearing females in the nineteenth century, but that restriction was routinely violated. To discourage cheating, the state implemented a buyback program, and game wardens would clip a V-notch in the tails of reproductive-age females. In 1948, the law was updated to make it illegal to sell notched lobsters. So far, this is a very traditional policy explanation: policy problem spurs policy response, policy intervention solves problem. But Ostrom emphasizes that the state program would not have worked on its own, or in a different environmental context. Rather than merely complying with an effective regulatory regime, Maine lobstermen began voluntarily notching female lobsters themselves. "Common understanding and use of the norm grew over time and is now widely practiced," Ostrom writes. Fishing communities do their own compliance monitoring, and punish offenders by destroying their traps. The adoption of this "reciprocity norm" would not have been effective, Ostrom argues, in the absence of a complex of local factors. Self-enforcement worked, in part, because of the manner in which local harbor "gangs" are informally organized and divide fishing territory. These shoreline communities have roots many generations deep, with strong local leadership, and locals possess substantial knowledge about the fishery. Furthermore, biological characteristics of the lobster fishery—the slow growth and long lifespans of lobsters, their migration patterns, the ability of the notch mechanism to survive several molts—are essential to the policy working as intended. (Ostrom 2007, 15184-15185) From this sketch, a complicated and contingent picture emerges of how to craft an effective policy response. Is marking game a good policy for preventing poaching? From an ecological point of view, it depends on where you're located, and the type of game you're hunting.

2.4.2.2 Ecological Methods

Ecology is a practical science – short on grand theory, its most well-established theorems largely developed out of grounded observation. When I reached out to faculty members in the ecological sciences at my home institution, asking if they could recommend canonical texts in ecological theory, they struggled to give me citations. There is no organized subdiscipline of ecological thought in the same way there is a longstanding tradition of political theory. Almost all of the field's most familiar concepts—including the ecological niche, ecological succession, the ecological pyramid—originated from case studies of specific plant and animal populations in specific environmental contexts—California songbirds, Lake Michigan sand dunes, fox predation of lemmings in the Hudson Bay.

The core method of most wildlife ecologists remains hands-on field observation. The ecologists I know personally gather their data through techniques like fishing off the coasts of islands, setting traps in the deep woods and tagging their catch, walking grids to collect carcasses, or flying grids to monitor wildlife activity in a given area. These field observations are always closely connected to a particular local context, a habitat or a range. The ecologists are interested in methods for controlling the population of sea lampreys in the Great Lakes, or the diets of geese in Icelandic hayfields, or the foraging activities of bats on Martha's Vineyard. This attachment to place is indicative of a mode if inquiry that is starkly different from the antiseptic laboratory methods of experimentalists in the physical sciences. The techniques used for gathering data, the types of data collected, and the knowledge claims produced from this data are in many ways polar opposites.

Historian Carolyn Merchant has argued that an ideological drive to subdue and control nature was the animating force behind the ascendence of experimentalism, from a relatively novel scientific approach in 17th and 18th century Europe, to the standard by which scientific methods are defined and judged today. In Merchant's view, the rise of experimental techniques aligned with the mechanistic philosophy popular among early modern scholars, and encouraged the domination and destruction of the natural world under industrial capitalism. "The key feature of the modern experimental method—constraint of nature in the laboratory, dissection by hand and mind, and the penetration of hidden secrets," she writes, "legitimates the exploitation and 'rape' of nature for human good." (Merchant 1990 [1980], 171) To whatever degree readers accept Merchant's association of experimental science with gendered violence, field methods unambiguously do not "dissect" or "isolate" their subjects, and as a consequence sacrifice some of the control that is supposedly achieved in the laboratory. What is usually treated as a weakness of field methods, from the perspective of feminist ecology could instead be viewed as a strength.

I would not go so far as to claim that experimental and statistical techniques have no place in ecology. Certainly, many ecologists conduct experiments, and many use statistics to analyze the data they collect in the field. But ecological field methods do seem to have stronger affinities with the research strategies of qualitative social science. Both traditions are grounded in close, sustained observation, a deep attachment to local context, and a reliance on thick descriptions to communicate findings. The case history is the classic form of ecological analyses, and even as academic research in the field becomes increasingly quantitative in orientation, narrative histories remain common in the scholarly literature. When I was taught basic ecological techniques in the classroom, one of the first activities the class practiced was preparing life histories of marine creatures.

Narrative histories can be composed at a range of scales. A lot of the early research on ecological succession described the stages of development of an entire ecosystem, such as Henry Chandler Cowles' classic 1899 of sand dune communities. Many social science theories of industrial and technological change borrow this approach of categorizing developmental stages of system evolution—Thomas Hughes' sociotechnical systems theory is one example of such a model. In ecological research today, the method of narrating a "life history" is more commonly restricted to studies of populations of a single species, a strategy that researchers in organizational ecology have adapted to their interest in the life cycles of firms. According to Carroll and Hannan, "the prototypical OE research design examines the full life histories of organizational populations, because experience shows that early events can exert lasting consequences for population dynamics." (Carroll and Hannan 2015, 359) I might add that later-stage events can also have significant population-level impacts. Mature systems never fully settle into stable configurations, a weakness of many evolutionary social theories—and also of ecological succession theory—that I will address further in Chapter 5. In the organization ecology literature, the usual approach to constructing life histories is to first gather data on all individual organizations in the population, to avoid selection bias, to record detailed information about the circumstances of entries and exits of organizations from the population, and, finally, to use longitudinal statistical analysis to estimate the life expectancies of organizations with differing characteristics. (Carroll and Hannan 2015, 359) In Chapter 6, I employ a similar design to present longitudinal and spatial analyses of the growth and decline of different types of wind turbine developments. Drawing from government records, I have access to detailed data on virtually every turbine that has been connected to the Danish electric grid since the 1970s, including location coordinates and the dates of commissioning and decommissioning. I have classified these turbines according to who owns them, which allows me to measure rates of change in the fitness of competing development models, and correlate those changes in populations with changing environmental conditions.

2.4.2.3 Ecological Concepts

As the ecological sciences have institutionalized and expanded over the past century, the theorems and concepts the research community employs have proliferated. Any attempt to review the most important findings would inevitably be partial, though books like Rob Dunn's *A Natural History of the Future* (2021) and Sean B. Carroll's *The Serengeti Rules* (2016) make valiant attempts to give lay audiences a general overview of what ecologists have learned about the laws of nature. I suspect many ecological theories have potential applications to the analysis of social systems. In this section, I focus on just three prominent ecological concepts that I will attempt to put to use in the chapters that follow to analyze the evolution of the Danish energy system.

A Human Niche? Probably no term borrowed from ecology has had wider appeal to social scientists than the niche concept. It pops up in numerous academic subcultures, but is typically used in a loose and metaphorical sense, and rarely in a way that demonstrates anything more than a surface-level engagement with how natural scientists understand ecological niches.

A good example of this sort of appropriation without sustained engagement can be found in the Multi-Level Perspective (MLP) theory developed by European sociologists Arie Rip and Frank Geels. MLP theorists have been using their own version of the niche concept to model the evolution of technological systems since the 1990s. However, in their writings, a technological niche is framed almost exclusively as an early stage in the developmental process, similar in conception to a business incubator.

In ecology, the niche concept is used in three related but distinct senses. The original definition proposed by Joseph Grinnell in a 1917 essay was primarily structural, focusing on the habitat requirements for an organism's survival. Charles Elton later proposed a more functional concept of the niche in 1927's *Animal Ecology*, drawing from his analysis of food webs to emphasize "various interrelationships it has with other organisms around it, the role it plays in the operation of the community as a whole," such as predator-prey relationships, and other forms of competitive and symbiotic relationships. As Putnam and Wratten explain, the Eltonian niche concept describes both an organism's "address" and its "profession." (Putnam and Wratten 1984, 49) Several decades later, in 1957, G. Evelyn Hutchinson put a new spin on the niche that focused on the perspective of an individual species, rather than at the community or ecosystem level, and defined the niche in terms of the resources that species needed for survival. The Hutchinsonian formulation emphasized the competitive relationships between species seeking to occupy a niche, and led to the development of the niche exclusion theorem—the proposition that only one species can fill any given niche in an ecosystem.

Carroll and Hannan's organizational ecology theory deploys the niche concept in terms more clearly derived from the ecological sciences. In their formulation, "an organization's or a population's fundamental niche consists of the ranges of environmental parameters for which its growth rate (fitness) is nonnegative in the absence of competition," which is a close approximation of the Hutchinsonian definition.

The three niche concepts clearly overlap, and ecologists have made efforts to reconcile them with one another, but each has its own distinctive characteristics, at least in terms of emphasis, that have methodological consequences. The Grinnellian structural approach is more static, while the Eltonian and Hutchinsonian definitions may better capture system dynamics. The Grinnellian and Eltonian concepts are more holistic in considering the web of relations than compose a community or ecosystem, whereas the Hutchinsonian concept is better-suited to treating individuals or populations as the unit of analysis. When applied to social settings, these different valences of the concept may imply normative commitments, as well. If the Eltonian definition invites thinking about the ways all of a system's parts work together and contribute to maintaining the stability and health of the system as a whole, the Hutchinsonian view may be more appealing to those who see politics as a zero-sum competition for supremacy and survival. (see, for example, Ojiem et al. 2006, Gross and Winiwarter 2015).

I would propose that all three of these senses of an ecological niche have applications for situating political actors within their broader sociological contexts. In Chapter 3, I attempt to give a more Grinnellian and Eltonian structural-functionalist explanation of the formation of a niche in the Danish countryside that sustained the first generation of modern wind turbine development.

From Individuals to Communities? I have dedicated a lot of space in the preceding sections to critiquing the concept of the self-interested individual that is the atomic unit of so much political thought, and especially liberal democratic thought. Enlightenment thinkers like Hobbes and Rousseau assumed that in the absence of civil society, humans were solitary creatures, at least in principle, if not as a matter of historical fact. A lot of contemporary political science research treats the community or the society as a mere aggregation of individual preferences. Ecologists find no such isolated individuals or loosely-knit communities in nature. "No one organism lives in simple isolation, interacting, according to selfish physiological requirements, with its physical and chemical—abiotic—environment," Putnam and Wratten explain. "Each organism is part of a complete community of creatures, each interacting with each other as well as with their abiotic environment." A ecological community could be defined as "an assemblage of animal and plant species occurring together in a particular area," but this assemblage is not a happenstance occurrence of unrelated entities sharing the same space, like a junk drawer that collects spare odds and ends. Instead, the "essence" of a community is "that it is a functional unit, which can be described only in terms of its operation, never frozen as a flat species mosaic." (Putnam and Wratten 1984, 43-44)

It should be noted that the community is an intermediate unit of analysis in ecological science, and limited to the organic elements of an ecosystem. The only fully self-sufficient unit is the ecosystem itself, which is composed of both the biotic community and the abiotic environment. This distinction between living matter and the material environment does not map cleanly onto the political ecology of someone like Bruno Latour, who wants to treat material objects as full-fledged members of actor-networks. In ecological science, the distinction seems intended to focus analytic attention on the biological processes that are necessary for sustaining life. On this view, an offshore wind turbine would not be a part of an ecological community, but part of the material substrate, for example, on which a coral reef establishes itself. As a nonscientist, I confess to having doubts about the necessity of drawing such a hard line. Pretty much every biological process contains nonliving elements—the carbon dioxide the tree breathes in, the narrow range of temperatures in which buds will blossom, the nest of dead twigs in which the bird lays its eggs—and the very definition of life is contested among biologists. Ecologists are cognizant that the living and nonliving elements of ecosystems are deeply entangled; living creatures adapt to their environments, and in turn alter those environments.

The present question, however, is if the ecological conception of community can be of use in social analysis. The idea of community has been at the heart of democratic theory at least since Aristotle, as I documented in detail in section 2 of this chapter. But as important as the concept has been in the history of Western political thought, it has always been a thorny one. The Ancient Greek concept of political community was a highly exclusionary one. In modern thought, concepts like the “general will” and even the “will of the majority” have been associated with fears of censorship, conformity, and the domination of the individual by the collective. Communitarian thinkers from Aristotle to Dewey to MacIntyre have defined the concept in substantive terms, as bound by a shared tradition, shared values, or shared ends. The impossibility or undesirability of achieving such community scared liberal thinkers like Dahl away from the concept entirely; Habermas attempted to redefine it in procedural terms, but couldn't escape the need for some baseline agreement on principles of order. Habermas was himself deeply influenced by Dewey, who believed community could be formed, in principle, through processes of scientific inquiry and discursive communication, although Dewey saw little evidence that such a community existed in the United States in his time, and he felt the core challenge for a democracy was creating the conditions in which such a community could form. I am sorry to report that the outlook for communitarian democracy looks no rosier in America today.

But democratic theory has always defined community in terms of discourse. As the agonists and difference democrats have shown, in practice discursive procedures seem to only deepen the divisions between us. Could some of the obstacles to achieving democratic community be resolved if, instead, these communities were understood in an ecological sense, as functional units? All of us already find ourselves in communities of this sort with plenty of people and things we may not like, or ever talk to. How do humans literally build communities, in the colloquial sense of the term? In concrete and steel. Some of that work involves debating and deciding, but constructing and maintaining physical communities requires much more than talk. Communities are formed around public infrastructure like schools and drinking water systems, around industries and transportation and communication networks, around "natural resources" like harbors, fisheries, and navigable rivers. In my historical study, I document the formation of communities around the construction of wind turbines. To the extent all these non-discursive systems shape the life of the community, they have political weight.

Competition or cooperation? A common expression among legislators is that politics is the "art of compromise," though their voters might fairly wonder when this art is ever practiced. Excepting the Habermasians, who are always seeking consensus, political scientists seem to share the public's skepticism that political actors have much interest in finding ways to work together. The most influential political science frameworks today assume that politics is a basically competitive enterprise—competition over offices, competition over the distribution of resources, competition for supremacy in an anarchic world.

The central place of competition in so many social science theories is an old inheritance, with roots at least as far back as eighteenth- and nineteenth-century classical economics, later supercharged by the pervasive influence of Darwin, who left a clear imprint on the thinking of everyone from Karl Marx to William James to Friedrich Nietzsche. Social Darwinists like Herbert Spencer were at the peak of their popularity around the same time modern social science disciplines were taking shape. So one possible response to concerns about applying concepts derived from the natural sciences to the social world is that social scientists already do. Denying that heritage does not make it disappear.

But do we really live in a dog-eat-dog world? Evolutionary theory is also foundational to ecology, and natural selection is still considered one of the underlying mechanisms by which ecosystems change. The role of competition in ecosystem composition and function is central in many ecological theories, although some practitioners argue it is too central. My survey of the literature suggests that the question of whether natural processes are basically competitive or cooperative is hotly-debated among ecologists. The reality is that both can be found in nature, and the types of relationships scholars foreground is a matter of emphasis. Historically, a popular definition of ecology was the “science of the struggle for existence.” (see Cooper 2003, for example) But that understanding of natural systems is falling out of favor among a new generation of ecological thinkers, such as Scott Gilbert, one of the founders of the field of ecological developmental biology, or eco-devo, as opposed to the more traditional evo-devo. Gilbert is building on pioneering work on symbiogenesis by UMass Amherst microbiologist Lynn Margulis, who was also closely-involved in the development of the Gaia hypothesis, which posits that Earth’s systems self-regulate like a superorganism, though Margulis had no patience for the New-Agey associations of what, for her, was a serious scientific theory. “The view that Richard Dawkins proposed, where organisms are just survival machines for the genes that built them, is so twentieth-century. The environment and organisms have agency, as well as the genes,” Gilbert has written. “Mutualistic symbiosis—the ability of organisms of different species to cooperate for their mutual good—is the signature of life on this planet.” While competition is a part of life, it “cannot be separated from the numerous flavors of cooperation.” (Gilbert and Gilbert 2019, 35-36). Gilbert likes to point to facts like 50% of the human body being composed of bacterial cells. “We are never individuals in the old sense,” Gilbert states. “Each of us is not only an organism, we are also a biome, a collection of ecosystems.” The proper name for our bodies, he says, is “holobiont, the bodily consortium of several species.” (Gilbert and Gilbert 2019, 37)

Putnam and Wratten’s 1980s textbook lends support to Gilbert “flavors of cooperation” thesis. Organisms in an ecosystem may compete in a variety of ways, for habitat and other resources. Some of the fundamental relationships ecologists have spent a lot of time studying are feeding relationships. One would assume those relationships are essentially competitive, after all, one thing is eating another. But those traditional predator-prey relationships, or "holozoic" relationships, in technical terms, are only one type of feeding relationship found in nature. Ecologists also find commensal relationships among organisms where "both eat at the same table," mutualistic relationships where both parties gain from the association, and parasitic relationships where one party takes from the other. But even this latter category is not as exploitative a relationship as in popular usage of the term. As the authors point out, it does not advantage the parasite to kill its host. "A well-adapted parasite enjoys a secure relationship with a host upon which it inflicts the minimum of burdens" Putnam and Wratten write. "Indeed, it is often hard to distinguish so refined a parasitic relationship from commensal or even mutualistic associations." (Putnam and Wratten 1984, 44-45)

Gilbert is among a crop of new ecologists challenging dated assumptions that the law of nature is survival of the fittest. Forest ecologist Suzanne Simard has done groundbreaking research on how trees communicate with and assist one another in forests, findings that have been popularized by the likes of American novelist Richard Powers and German forester Peter Wohlleben. In Powers' lyrical retelling of this science, "trees fight no more than do the leaves on a single tree. It seems most of nature isn't red in tooth and claw, after all. For one, those species at the base of the living pyramid have neither teeth nor talons. But if trees share their storehouses, then every drop of red must float on a sea of green." (Powers 2019, 142) Here is how Wohlleben summarizes the cooperative nature of trees:

> Why are trees such social beings? Why do they share food with their own species and sometimes even go so far as to nourish their competitors? The reasons are the same as for human communities: there are advantages to working together. A tree is not a forest. On its own, a tree cannot establish a consistent local climate. It is at the mercy of the wind and the weather. But together, many trees create an ecosystem that moderates extremes of heat and cold, stores a great deal of water, and generates a great deal of humidity. And in this protected environment, trees can live to be very old. To get to this point, the community must remain intact no matter what. If every tree were looking out only for itself, then quite a few of them would never reach out old age … Every tree, therefore, is valuable to the community and worth keeping around for as long as possible.

In this passage we see a rationale offered for the benefits of cooperation between species, rather than competition—cooperation enhances evolutionary fitness. Organizational ecology research has similarly observed patterns of both competition and cooperation between human firms. While competition for niches exists, Carroll and Hannan suggest this competition among firms has significant limits. Organizations are expected to compete "if the presence of each reduces the spaces in which the others can sustain themselves," that is, "if and only if their fundamental niches intersect." This formally logical proposition helps organizational ecologists model expected population dynamics in industries. (Carroll and Hannan 2015, 360) But this literature has also found substantial evidence of collaboration both within and among organizations:

> Efficient organization requires trust among members, which takes time to build. Creating roles and routines, learning about the environment, and developing relationships with other organizations also take time. Once established, these patterns of relationships enhance survival chances." (Carroll and Hannan 2015, 359)

Again, it is dangerous to put too much stock in claims about what types of relationship are or are not "natural." My point here is that scientists, and even social scientists, find evidence of both competition and cooperation.

Philosopher Donna Haraway, who established her academic bona fides with groundbreaking research on primate intelligence and communication, has spent the latter part of her career trying to build a normative case for enhanced cooperation across species boundaries, using her relationship with her pet dog as a frequent example. The importance of that relationship is that her dog is decidedly other, and yet these two very different organisms are strongly bound by ties of mutual support and dependence. "I have a dog, a dog has me," Haraway told one interviewer. (Paulson 2019). Haraway described those bonds this way in her *Companion Species Manifesto*:

> Contrary to lots of dangerous and unethical projection in the Western world that makes domestic canines into furry children, dogs are not about oneself. Indeed, that is the beauty of dogs. They are not a projection, nor the realization of an intention, nor the telos of anything. They are dogs, i.e., a species in obligatory, constitutive, historical, protean relationship with human beings. The relationship is not especially nice; it is full of waste, cruelty, indifference, ignorance, and loss, as well as of joy, invention, labor, intelligence, and play. I want to learn how to narrate this cohistory and how to inherit the consequences of coevolution in natureculture. (Haraway 2003, 103)

Her aim, Haraway says, is to show "the implosion of nature and culture in the relentlessly historically specific, joint lives of dogs and people" and "to convince my readers that inhabitants of technoculture become who we are in the symbiogenetic tissues of naturecultures, in story and in fact." (Haraway 2016, 108) Her recent work has focused on the normative project of "making kin" with otherness. "Making kin seems to me the thing that we most need to be doing in a world that rips us apart from each other," she said in a recent interview. "By kin I mean those who have an enduring mutual, obligatory, non-optional, you-can't-just-cast-that-away-when-it-gets-inconvenient, enduring relatedness that carries consequences." (Paulson 2019)

I will reflect on some of the benefits of cooperation for renewable energy development and sustainability transitions in the concluding chapter of this dissertation. I would also propose that there is a pragmatic case for applying a cooperative model to the analysis of the Danish transition, since national governance has operated on a distinctive consensus-based approach for well over half a century. Models of electoral or interest group competition do a poor job of capturing the actual processes by which national policies get crafted in Denmark today.

2.4.2.4 Critiques of Political Ecology

The effort to adapt theories and methods derived from the study of natural systems to political events is audacious enough to merit some pause in consideration of its potential downsides. Several common objections are considered below.

Is this environmental determinism? A significant amount of social science that masquerades as "political ecology" is, on my reading, worryingly deterministic in its explanatory outlook. Such theories are more common in pop anthropology than they are among academics, who are usually more careful about hedging their claims. But the tendency to resort to explaining political events in terms of resource distribution, or climate, or geography can be difficult to resist. The key point to stress here is that deterministic explanations are not ecological explanations. The ecological approach is integrative, layering on intersecting causal factors, rather than attempting to reduce causal processes to a single driving mechanism.

It is also worth noting that ecologists can be as guilty of slipping into reductionism as social scientists, as is evident in some of the literature on human ecology.

Biologist Rob Dunn considers the “revolt” against determinism in the human sciences, and he agrees that such theories should be rejected if they “reinforced racist and colonial ideologies.” (Dunn 2021, 108) But that’s about the only negative word he has to say about the subject, seemingly implying that as long as we steer clear of drawing discriminatory conclusions, environmental determinism is just fine. He goes on to approvingly cite studies by Solomon Hsiang and colleagues that conclude, in “remarkably simple” terms, that “increasing temperatures above the temperatures associated with the optimum human niche lead to rising violence.” (Dunn 2021, 119) No self-respecting criminologist would accept such a simplistic explanation for rates of violence, which a vast body of research demonstrates is influenced by a combination of socioeconomic, cultural, political, technological and geographic factors. I’m sure the weather can have an impact, too. To truly understand the epidemic of gun violence in America, and the variance in rates of violence, all of these factors, and others I have not mentioned, need to be considered collectively. That’s what an ecological, rather than a merely environmental, explanation would look like.

As the above example illustrates, to take seriously environmental variables does not mean social variables can be ignored. I suspect concerns about admitting ecological thought into the study of politics stem primarily from fears that doing so would be tantamount to giving up what makes human beings unique. This is in part a moral concern about eroding the legal rationale for treating humans with dignity, and respecting their rights. It is also a disciplinary concern for political scientists, who worry about losing their monopoly over the distinctive domain of politics. There are numerous possible responses to such concerns. To the first, I would say, the rearguard action insisting on the radical separateness of human affairs is a lost cause, and one that harms humans in both the short and long terms more than it helps. I would also point to Donna Haraway's writings on bridging otherness cited above; to admit our relations with nonhumans is not to erase our differences. To the second concern, I would argue that political science is at far greater risk of obsolescence if it fails to learn the lessons of ecology. I am not advocating that we all become ecologists, or that we do not need research focused on political processes. As some of the clumsy prescriptions of human ecologists make clear, they could use our disciplinary expertise, too. It's a two-way street. Natural environments shape people, and people shape their environments. Politics *is* part of the environment. Adopting this view does not mean that human communities are just like ant colonies, or that politics is rooted in an instinctual desire to pass on one's genes, or any other such absurdity. One project for a progressive political ecology would be clarifying the parallels and connections between human and nonhuman systems, as well as identifying and explaining the distinctions between those spheres of activity. While that work is underway, I don't see how it is any more unrealistic to speak of political ecosystems than it is to presume humans are rational, self-interested individuals, whose preferences and actions are wholly independent and unconstrained.

A Return to Structural Functionalism? Ecological scientists often frame their concepts and explanations in structural and functional terms. As such, any attempt to apply ecological theories or methods to political analysis invites comparisons to the "bad old days" of structural functionalism in the social sciences, and opens itself to the familiar critiques of that paradigm—that such models suppose an unrealistic coherence and stability to social systems, that they are excessively rigid and static and thus cannot explain social change, that they normalize and naturalize the status quo, that they fail to capture the motives of individual actors. The behavioral revolution of the mid-twentieth century was in part motivated by these perceived inadequacies of the structuralist theories prominent at the time.

While moving social inquiry in an ecological direction would constitute a revival of functionalist approaches to explanation, none of the criticisms mentioned above are directly applicable to contemporary ecological theories, and were directed instead primarily at Talcott Parsons' sociological theories. Parsonian and ecological structural-functionalism have some broad similarities that mask important differences. For example, Parsons' system could be described as holistic, focusing on explaining social processes at the macro scale. An inability to account for microsocial processes was considered a major weakness of this approach. I have already described above how ecological analysis is interested in processes occurring at multiple scales, from the organism all the way up to the biome (and for Gaia theorists, even on a planetary scale), and at how processes intersect, combine, and interact across scales.

From an ecological point of view, systems are anything but static. Early twentieth-century models posited that ecosystems move through neatly-delineated stages of development toward stable equilibriums in a manner that seemed almost teleological; contemporary ecologists have largely abandoned these ecological succession theories in favor of a more fluid and dynamic picture that stresses the constancy of conflict and change (see, for example, Drury 1998). Ecosystems do not evolve in any preordained direction, and are always in flux. I would argue that ecological perspective is better-suited to capturing systemic change over time than many more traditional social scientific methods. Public opinion researchers, for example, are adamant that the survey data they collect captures only snapshots in time.

Ecologists do find many structural patterns and similarities across natural systems. For example, food chains generally have a pyramidal structure, with a large number of producers at the bottom of the food chain and only a few predators at the top. And on land, at least, the number of trophic levels in an ecological community "rarely exceeds 4 or 5: producers and three or four consumer levels." Putnam and Wratten explain how such patterns can recur in nature without being evidence of some sort of premeditated design:

> This is not of course to say that this unique structure is in some sense predetermined to the extent that the design rules are deterministic, and that the community develops to 'seek a preconceived structure.' Such a constancy of design would also result, and more probably does, by virtue of the fact that it produces a stable community—which thus persists: in short that only the stable communities survive, and there are certain common features that promote such stability. (Putnam and Wratten 1984, 57)

The flipside of the notion that stability enhances survivability is that the achievement and persistence of that stability is not a given. Ecological communities decline, decay and disappear. While some measure of stable relations among community members is probably necessary for healthy ecosystem functioning—it is the ability to achieve some degree of self-sufficient internal regulation that defines an ecosystem as a functional unit—those relationships are constantly being recalibrated, and may fall out of balance over time.

It would be similarly antiquarian to suggest analysts much choose between a perspective that gives agency to individuals and one that sees larger structural forces at work in society, as if no progress had been made in resolving the old agency-structure debate. Anthony Giddens made a compelling argument for the "duality of structure" as early as the 1970s—social structures shape individuals, who in turn reproduce social structures through their actions. This resolution of the apparent conflict between agential and structural theories is mirrored in the way ecologists think about the reciprocal relationships between organisms, communities, and ecosystems. Not only do analysts not have to choose between agent-based and structural models, ecological research has actually made substantial progress in conceptualizing how individuals are embedded in and interact with broader systems.

Perhaps the most pragmatic stance is that different theoretical frameworks have different strengths, and researchers should be guided by the specific problems they are studying to select the appropriate methods. This is usually the approach taken by field ecologists, some focusing on the behaviors of a single species, while others examine the characteristics of entire ecosystems. A major advantage of an ecological approach is the ability to observe system-level effects and the interactions of multiple systems and levels of analysis, making it possible to explain large-scale social phenomena that are difficult to understand merely in terms of the psychology or behavior of atomized individuals. So this more holistic perspective may be a better fit for the study of something as broad and sweeping as an energy transition. A functionalist perspective is also a logical fit for studying technological systems, and especially energy systems. An electrical network is of little use to anyone if it is not a functional unit, and stability is arguably the most prized feature in an electricity system. In chapters 3 and 6, I will explain how reliability was a key competitive advantage for early Danish wind technology, and how the integration of wind technology has actually helped enhanced the overall reliability of the Danish electric grid, despite fears it would do the opposite.

Is this scientism? There exist justified fears of inappropriately applying scientific theories outside the contexts they were developed and for purposes they were not intended, and of placing undue faith in the authority of scientific knowledge. Raised to the level of ideology, the latter practice is known as scientism: the belief that everything can ultimately be explained in scientific terms, and thus a rational society would be organized and managed according to scientific principles.

Natural scientists seem to default to this sort of policy rationalism almost unconsciously. I see that attitude lurking in the computer models of engineers plotting the renewable energy transition, as if solving for the most "efficient" policies will help set a society on that pathway. (13) Such approaches drastically oversimplify the challenges involved in an energy transition; not least of all in assuming that technical efficiency is a salient indicator of political efficacy. Ecologists have a similar proclivity for thinking they know what needs to be done, if only they could get people to listen. Sean B. Carroll jokes that the motto for the twenty-first century should be "Better Living through Ecology." Carroll describes a two-step process for addressing the ecological crisis: scientists make recommendations, then policymakers implement them. "Scientists must equip politicians with the information necessary for making good public policy," Carroll proposes. "I would add that another approach to securing the necessary political will is for scientists themselves to pursue public office." (Carroll 2016, 203, 210)

To the chagrin of scientists and philosophers, knowledge transmission has never worked this way, and as long as human societies exist, it never will. There are entire academic literatures on science policy and science communication that have more sophisticated proposals for facilitating exchanges between these domains.

Ecological science does not seem to struggle, as the social sciences do, in recognizing the tight coupling and interdependence of human and natural systems, which might be one reason ecologists are often attuned to the political implications of their work. Consider what biologist Rob Dunn recently wrote about how humans must adapt to a changing climate:

> We imagine a future in which we are the only living protagonists. We seek, collectively, to simplify the living world and channel it into our service, to circumscribe it so fully within our powers that it ceases to even be visible. We put up a levee between our civilization and the rest of life. That levee is a mistake, both because it is not possible to hold life at bay and because in trying to achieve such a scenario, we do so at our own expense … Our best bet for extending our stay on this planet is … to pay attention to the laws of life and work with them rather than against them. (Dunn 2021, 4, 250)

Green politics, as practiced today, is largely ignorant of these lessons of ecology. The solution, however, is not to simply "follow the science," as Dunn suggests.

Any application of any scientific theory to political projects should probably begin from a spirit of humility. Good scientists know what they don't know, which is almost always orders of magnitude greater than what they do know. They know that science is always changing, and usually even have pet theories about the major tenants of their fields that need to be challenged, or are likely to be disproven in the future. All of this is certainly true about ecology, a relatively young and rapidly evolving science.

And history furnishes plenty of examples of how easily, and how badly, things can go wrong when evolutionary and ecological theories have been misused to serve ideological ends. At one extreme would be the Malthusians and Social Darwinists who portray human societies as competitive struggles over scarce resources in which only the fittest survive; at the other extreme would be ecocentrists like Arne Naess and Murray Bookchin who claim nature is essentially cooperative and benign.

Bookchin's writings on social ecology provide an example of the perils of taking too literally analogies between (debatable) claims about the function of natural ecosystems and political organizations. Bookchin asserts that biological "first" nature evolves in the direction of greater flexibility and adaptability, and the human beings are an outcome of this evolutionary process. The "derivation of human from nonhuman nature" dictates that human societies ought to be constructed "along ecological lines," rejecting unnatural class hierarchies and embodying an "ethics of complementarity." (Bookchin 1997) For Bookchin, this analysis supports his conclusion that capitalism is a crime against nature, and small-scale anarcho-communism is a better representation of humanity's evolutionary potential. Such leaps of logic should be taken no more seriously than Thomas Hobbes' argument that human nature justifies absolute monarchy, and like those state of nature theorists, Bookchin ultimately ends up reproducing the same dichotomy of a morally autonomous society, which may choose to either embrace or ignore the dictates of evolution, and a clockwork, apolitical nature.

Neither the Social Darwinists' nor the Social Ecologists' characterization of the findings of the biological sciences stands up to much scrutiny. Furthermore, there is no reason that the adoption of any theoretical or methodological framework need to go to such dogmatic extremes, and attempts to reify theoretical constructs or to apply them without flexibility and humility should always be treated with suspicion, whether the source of those constructs is ecology, or economics, or mathematics, or any other discipline.

Suspicion about the growing influence of the sciences has been the default position of critical social theorists throughout the modern period—from Weber to Adorno to Habermas to Foucault, all were worried about the rationalization of society. Those fears have not subsided, and as environmental science became more socially prominent beginning in the 1960s, the science reporting that humanity's actions were putting the planet in peril became increasingly controversial.

On the French left, critical theorists like Pierre Lascoumes worried that the green movement had "evolved from a popular movement grounded in a critique of technological society" into a "technocratically dominated policy area." For Lascoumes, the arrival of "ecopower" was an ominous development, an extension and deepening of the administrative state's attempts at social control. (Whiteside 2003, 143) Lascoumes' conception of ecopower owes a clear debt to Foucault's work on disciplinary power, and I described above how this critique of the green movement percolated through the French academy, showing up in the writings of Bruno Latour.

The common fear that arose with awareness of environmental crisis was that these risks would be used to justify some sort of authoritarian intervention, restricting individual freedoms. One example often pointed to is Garrett Hardin's argument in his essay on the "tragedy of the commons" that all "social arrangements that produce responsibility are arrangements that create coercion." In fairness to Hardin, it is often left out that he adds these relationships should be "mutual coercion, mutually agreed upon by the majority of the people affected," which sounds sort of democratic? Hardin's critics doubt his democratic credentials, and with some reason. His vision grows darker when he applies it to a pressing issue of his day, population control. "Freedom to breed will bring ruin to all," Hardin concludes. (1968, 1247-1248) It is clear today that Hardin was wrong. Demographers are not nearly as panicked about population growth as they were in the 1970s, when books like the *Limits to Growth* stroked these concerns. Global population is projected to level off by mid-century, and no large-scale coercive measures proved necessary to address the problem. The most authoritarian tactics, like China's infamous one-child policy, are now perceived as overreaches with huge unintended side effects, while the most successful policies to slow population growth were arguably the most liberal democratic.

That the rise of ecological thinking should inspire conservative reactions is not surprising, the conservationist framing that still dominates in the environmental policy community is fundamentally geared toward preserving existing systems and arresting change. Environmentalism has had appeal on the right at least since the Nazis, whose ideology of "Blood and Soil" is sometimes characterized as embracing ecological themes. In American politics today, increasing acceptance of the reality of climate change is leading many factions on the right to experiment with ecological and conservationist ideas, from libertarians to evangelicals. The arguments that appeal to conservatives range from appeals to place and support for local economies, to self-reliance and independence from the state. "Independent, green, sustainable, frugal — those overlap," Kentucky Congressman Thomas Massie was quoted as saying in a recent profile. Massie, who is otherwise the kind of congressman who poses for Christmas photos with his kids holding Uzis and M-16s, lives off the grid powered by solar panels, and has become a poster boy for a new localist movement among Republicans. (Pogue 2023)

The important point here is that it cannot be assumed that embracing ecological thinking necessarily leads in a progressive or democratic direction. Apparently, most social theorists have expected the opposite. Historian Lynn White Jr. famously claimed that democracy was to blame for the ecological crisis, arguing that the modern "fusion of science and technology" with the concurrent "democratic revolutions which, by reducing social barriers, tended to assert a functional unity of brain and hand. Our ecologic crisis is the product of an emerging, entirely novel, democratic culture. The issue is whether a democratized world can survive its own implications." (White Jr. 1967, pgs. 1203-1204) But White is talking about the particular form of liberal, capitalist democracy, and his criticisms are directed more at the liberalization of society than at democratic institutions or practices. I have already discussed the limits of liberal democratic frameworks for addressing the climate crisis at length above, and I largely agree with White's assessment. If there is a political solution to this crisis to be found, we will have to look elsewhere.

The question that has occupied this chapter is whether there is democratic potential in an energy transition. The preceding discussion does not make those prospects sound very encouraging. The potential for eco-authoritarianism should not be dismissed, but what about ecological democracy? What might that look like? How might it be achieved?

In section 2 of this chapter, I discussed how political theorists like John Dryzek and Robyn Eckersley envision a society that prioritizes environmental values and goods, and in which citizens endeavor to live sustainably. This emphasis on sustainable outcomes, rather than sustainable practices and relationships with the nonhuman environment, I argued, represents an impoverished notion of what it could mean to practice ecological democracy. At the end of the day, what these authors are selling is liberal environmentalism, a status quo in Western countries that has been pilloried by the likes of Michael Shellenberger and Ted Nordhaus (2004) as technocratic, elitist, divisive and largely ineffective. The difficulties liberal democratic political systems have encountered in their attempts to build consensus around climate action give such critiques weight, and urgency.

Farther out on the left, anarchist thinkers like Murray Bookchin offer a more transformative vision of an ecological society. Despite having its own flaws as a prescriptive political theory, Bookchin's social ecology at least improves on the thinness of liberal approaches, conceiving of democracy as a whole way of life, premised on the elimination of hierarchy and domination, and committed to an ethic of cooperation and complementarity—not only with fellow humans, but concerned holistically with the flourishing of the ecosystems in which humans participate. Bookchin imagines this political culture being institutionalized in small-scale participatory democracy at the local level, which would largely manage their own affairs, with these local communities sending delegates larger bodies to decide issues that transcend community boundaries, in something of a soviet structure. Of course, Bookchin believed this anarcho-communism would evolve organically out of the failure of capitalist society, which is far from guaranteed, and at least within the context of a capitalist society, there is little evidence that such social experiments are scalable or sustainable, as the example of the Tvind Schools in Denmark attests.

Ecology offers no panaceas for democratic or sustainability activists. What the encounter with ecological science does offer social theory is an opportunity to move beyond the impasses in liberal environmentalism discussed throughout this chapter, by raising new possibilities about how and where to start looking for the solutions we seek. An ecological approach would be attuned first of all to how relationships are structured, across multiple trophic levels, from relationships between organisms, to relationship among populations and communities, and so on. A properly ecological political ecology would be integrative rather than reductionist, focusing attention on system organization and systemic change, taking interest in how the varied constituent parts interact to maintain system function. Concepts like the "political system" and the "political community" would have to be expanded significantly, to include nonhuman and even nonliving members.

An ecological democracy would be defined in terms of processes, again, possibly cascading from one level of analysis to another, and unspooling over time. If democracy is taken to refer primarily to the distribution of power, as proposed in section 2 of this chapter, then a political ecology would look for democratic potential by assessing the effects of system processes and functions on the distribution of power within that system, and the capacities of system participants to effectively exercise power through those processes and functions. From this perspective, analysts can avoid prejudging which types of systems and processes meet the requirements for democracy. No detailed list of democratic procedures, like Robert Dahl's score sheet for measuring polyarchies, is needed. Democracy could hypothetically take a wide range of forms in different contexts, and whether a particular system configuration delivers democratic results becomes a question for empirical observation. An ecological democracy is one that empowers its members and shares power widely.

As scholars of technological systems recognize, there are significant resonances between contemporary theory on technology and on ecosystems. Beyond sharing a systems approach, the central metaphors of networks or webs applies almost as well to biotic communities as it does to circuit boards. And the contempt social scientists have historically shown for the material world is not mirrored by ecologists, who typically do not view natural and technological systems as radically separate. Biologist Daniel Botkin has argued that one of the central lessons of ecology is that humans need to rethink our assumptions about our relationships with nature, which are an "outmoded" inheritance of the "industrial age." Botkin thinks that armed with an ecological perspective, technology can be part of the solution to our environmental problems. "We can find a way to combine technology with our concerns about our environment in a constructive and positive manner," he writes. (Botkin 1990, 6)

Ecology teaches that humans are both a part of ecosystems and modifiers of ecosystems. Technology can be understood as human beings' attempts to shape their environments, something many other species also do. In these processes, humans both employ and are brought into intimate contact with nonhuman materials, and interact with a range of intersecting systems—the environment, in other words, pushes back. As a result, the outcomes of these processes are never completely under human control, exploding the fantasy of the technical mastery of nature.

It is precisely this fear of attempted mastery or domination that has so often made social theorists leery of both technology and ecology. I am intrigued by Pierre

Lascoumes' formulation of "ecopower," but for him the advent of such a power was a dystopian prospect, embodied by an ever-more intrusive state. But are other expressions of "ecopower" possible? I would argue that what Lascoumes has in mind is not really ecological at all, but technocratic, and would represent a continuation and expansion of the instrumental rationalism and bureaucratic and disciplinary processes characteristic of the modern, liberal, industrial, capitalist state. It may certainly be possible to integrate concerns with sustainability and environmental protection into that logic, but the distinctively ecological worldview I have been describing in this section operates according to a very different logic. I want to reclaim the idea of "ecopower" to instead refer to technological practices modeled on this alternative logic, in contrast to the instrumentalism assumed to be the default mode of technological development. The presumed limitations of technology as a means of promoting democracy and environmental sustainability may, in fact, only be limitations of thinking about technology instrumentally. Whether or not a more ecologically-conscious approach to development yields democratic dividends becomes a matter for empirical investigation.

Denmark provides fertile ground for putting these questions to the test, thanks to the wide diversity of energy development models that have flourished there since the 1970s. The existence of an idealistic and dissident political element in the early history of the Danish wind energy system gives me an even more concrete handle for assessing the prospects of challenges to the technocratic status quo. What happened when actors seeking to initiate a radical social and political transformation collided with the entrenched interests, governance institutions, deep social structures, as well as the technical and natural constraints of the existing energy system? Were these upstarts rebuffed, or absorbed, or co-opted? Or was the established system infiltrated, destabilized, remade in some new form? Addressing these questions has important implications for how scholars understand the nature of the changes the energy system is undergoing as renewable sources are incorporated into the electricity mix. Is the change systemic, transformational, or revolutionary in the way the adoption of fossil fuels fundamentally rewove social fabrics in the nineteenth and twentieth centuries? Or is the integration of wind and solar into the electric grid merely a technical fix that fails to upset underlying political dynamics, more akin to the development of new technologies for the extraction of coal and natural gas: a leap forward in rationalizing those systems with significant economic and environmental consequences, but otherwise a continuation of a settled social logic and organization? The remainder of this dissertation represents my attempt to apply some of the tools of ecological inquiry—getting close to the ground, examining developments in context, taking a systems view, building integrative explanations, etc.—in the hope that this fresh perspective can yield new insights into these questions.

2.5 The Legacy of Tvind

On a sunny spring morning in 2015 hundreds of people crowded into the Tvind school gymnasium for a party. It was a birthday celebration, and not just any birthday—the windmill was turning forty. The guests sipped coffee and lunched from boxes of smørrebrød delivered by a local restaurant. A giant cake—molded and iced to look like the windmill, of course—was cut. The assembled crowd raised their voices to literally sing the windmill's praises, with custom lyrics written in its honor, arranged to the melodies of well-known folk songs.

Then came the speeches. A Vestas manager spoke of the windmill's technical innovations. Wind energy pioneer Preben Maegaard, a supporter from the beginning, held up the project as an example of what ordinary people could achieve working together. The Energy Minister, traveling abroad at the time, sent his regrets for missing the party and his congratulations. A member of the original construction crew, bespectacled and graying, took to the stage to reflect on the legacy of the windmill team's work. She described how she had made the three-hour drive from Copenhagen that morning, the entire trip passing beneath towering modern wind turbines that dot the fields alongside the highway, like overgrown white flowers sprouting up among the yellow rapeseed.

Perhaps those windmills lining her route were a sort of legacy? Those wind farms were not built by Tvind, and few were constructed following anything close to Tvind's cooperative and experimental methods. Today's turbines are sleek, quiet, highly-efficient products of space-age engineering and manufacturing. They resemble the bulky, steampunk aesthetic of Tvindkraft to about the extent Howard Hughes' Spruce Goose resembles Darth Vader's Imperial shuttle. But in a surprising number of less visible ways, they could trace their ancestry directly to the Tvindmill. Most aspects of the Tvind group's program for transforming society have been relegated to the dustbin of history. But the once impossible idea of powering communities by harnessing the ample, renewable supply of wind has become common sense in Denmark, and the cornerstone of the nation's long-term energy strategy. Once a curiosity, Danes have grown accustomed to the sight of windmills spinning on the horizon. Back in 1978, Tvindkraft had been one of the first turbines connected to the electric grid, and the media coverage of its construction popularized the idea of wind power for a generation of Danes. Now, turbines were everywhere.

Does this integration of wind energy into the physical and cultural landscape mean the Tvind teachers were successful in achieving their political goals? Certainly, things did not work out quite as Amdi Petersen and his disciples had envisioned. The wind industry has matured into a corporate and capitalist behemoth, and Danes have generally not adopted the Tvind model of communal living. Danish politics remained fundamentally liberal, a far cry from the Tvind vision of a radically democratic, ecologically-minded society. And yet it is undeniable the Danish public has become dramatically more environmentally-conscious and supportive of sustainable development than it had been forty years prior. How much credit does the Tvind model deserve for catalyzing these later developments? As the following chapters trace the history of the Danish wind sector from the 1970s until the present, I will keep an eye out for evidence of that influence.

The path for Tvind has been anything but straightforward. The organization and the Ulfborg campus today are shells of what they were during their 1970s heyday. Anna Hoas, who lives and teaches on campus, said that when she joined the Teachers Group in 1982, there were between 350-400 people in the collective. During the 1980s and 1990s, the organization expanded into international development, and Hoas estimated that the group now had around 3,000 members worldwide, but mostly in Angola and Mozambique. Only about 100 members remained in Denmark. (11)

The group's leader, Mogens Amdi Petersen, had been on the run and in hiding with his chief lieutenants since 1979, when he fled Denmark under suspicion of financial improprieties. Petersen is presumed to be hiding in Mexico, which does not have an extradition treaty with Denmark, at a sprawling, 1,000-acre compound on the Pacific coast of Baja California owned by the Teachers Group. Anna Hoas told me she has visited the compound, and characterized it as a retreat center the group uses for meetings and educational programming. (12) An Interpol Red Notice for Petersen remains in effect to this day.

With Tvind's leadership on the lam, the schools and associated charities suffered from an accumulation of negative attention. Teachers Groups members have started charitable organizations around the world, many of which specialize in the collection and resale of used clothing, a revenue stream that is supposed to fund development aid, mostly in sub-Saharan Africa. But complaints about these charities' practices have piled up on multiple continents. (13)

In 1996, the Danish Parliament passed an amendment to the law authorizing state funding of private schools, singling out Tvind and attempting to disqualify the organization from receiving public support. The country's supreme court eventually declared that law unconstitutional in 1999, but Hoas described those three years as a trying time, during which she received no salary, and many teachers had to seek other forms of employment, some turning to farming or running secondhand clothing stores. (14) Most of the schools Tvind had been operating closed, and today the only program still receiving state funding is a boarding school for at-risk college-aged youth. When I visited the Ulfborg campus in summer 2015, I met only a handful of students in residence.

Through all of this turmoil, the windmill just keeps turning. Today it has been left in the care of two retirees, Britta and Allan Jensen. Britta, who spent three months working on the construction team back in the 1970s, handles the books, and said she spends most of her time making phone calls on the hunt for spare parts. Allan manages the daily operations and maintenance. Occasionally, they have a student trainee or a volunteer helper, though the students are usually most helpful with low-skill labor like giving the tower a fresh coat of paint. Britta estimated that about five students lend a hand each year. For larger repairs, they turn to their friends in the wind industry, though the custom design of Tvindkraft still requires some creative problem-solving. Britta described one recent incident she said was typical of the challenges they encounter, involving a large disc brake that had worn so thin it was bending. They called out an employee of the nearby firm WindTech, which specializes in refurbishing turbines, who advised them to immediately shut down Tvindkraft and replace the brake. But it was the summer holidays, and any workshop in the area that could make a new disc was closed. With assistance from their friends at the Nordic Folkecenter for Renewable Energy, they eventually found a workshop that could grind down the old disc to a smaller diameter, and then they fitted the smaller disc with a huge pair of calipers salvaged for free from a Vestas turbine that had collapsed in a storm on the Farøe Islands. The new brake barely squeezed into the nacelle with only millimeters to spare, otherwise they would have had to remove the generator to install it. (15) This scrappy ethos has been in the Tvindmill's DNA from the beginning. A small crane used to lift parts up into the nacelle was salvaged from the Siemens scrapyard, and the company's former Chief Technology Officer, a fan of Tvind since boyhood, once approved sending over a spare anemometer. "We should go for a trip in the Siemens' scrap heaps sometime," Britta said, turning to Allan as we are discussing turbine maintenance. "They scrap a lot, you know. As soon as there's anything wrong … they scrap it." (16)

When I visited, Tvindkraft had a small crack in one rotor they were waiting to patch until they could find someone who would agree to do the repair for a discount (or for free). They had detected another crack in a bearing a decade earlier when it started making noise, but because the location of the bearing would have made I difficult to replace, they instead found a way to lighten the load on the damaged bearing, and kept using it. As mentioned at the beginning of this chapter, the Tvindmill has always been run gently, at less than half of its rated capacity, which greatly reduces the stress on its components, extending their life. A commercial wind farm operator would never make these sorts of compromises or take these sorts of risks. Tvindkraft lacks the electronic sensors installed on modern turbines, and used by the maintenance divisions at companies like Siemens to send a constant stream of data to headquarters and spot performance issues in real time. Allan built a new computerized control system for the windmill, an improvement on the original system rigged up by a DTU professor in the 1970s, but when I visited it still appeared to be running on a Compaq desktop that looked like a relic from the 1990s.

It is something of a miracle that Tvindkraft survived to celebrate its milestone 40th anniversary, when commercial operators typically budget a 20-year lifetime for their turbines. All three of the Tvindmill's groundbreaking fiberglass rotors had been replaced, the largest repair project that has been completed, but the main shaft, gearbox, and generator were all still the originals. Most commercial wind farm operators would probably not bother with the sorts of big-ticket repairs Tvind has undertaken, but would instead use the opportunity to replace an aging turbine with a newer, larger, more efficient one. That's just one example of the numerous ways these alternative development models differ.

A lot of the industry engineers I spoke to are gently dismissive of Tvind. It's a cool project of historical importance, they will concede, but something of a curiosity, and doesn't offer a model for constructing wind farms on the sort of scale the industry contemplates today. Even if it weren't a Frankensteinian agglomeration of scavenged parts, the technical characteristics of the turbine are obsolete—it's highly inefficient, with outdated components and irreplicable design features, maybe even unsafe. What these criticisms seem to miss is how much the design of modern turbines owes to Tvind's innovations, and the design process that produced those innovations. It bears repeating that the Tvind team succeeded in building an operational megawatt-scale turbine where so many other engineering teams—including NASA and Germany's leading experts—had failed. The fiberglass rotor design pioneered in the construction of Tvindkraft remains the standard blade concept on virtually every commercial turbine installed around the world today. In the case of Vestas, long a world leader in cutting-edge turbine design and performance, their first generation of commercial products, which established their reputation and helped the company survive when many other competitors were failing, relied on rotors fabricated using the molds purchased directly from Tvind. In addition to offering an early test of the influential blade concept, Tvindkraft also helped popularize a variety of other design features that have since been adopted in numerous other turbine designs, such as pitchable blades and the use of a synchronous generator. Tvind was awarded the European Solar Prize in 2008 for its contributions to renewable energy development. It's hard to think of any other wind turbine so decorated, with so many offshoots sprouting throughout the wind sector.

As significant as the windmill team's engineering achievements were, their work arguably had an even greater impact on the evolution of the technology as a highly-visible symbol of the feasibility of wind power, as a clearinghouse for collecting and disseminating technical knowledge about turbine construction, and through the social bonds that were forged during construction among a network of wind energy pioneers who would build on what they learned at Tvind in thousands of other development projects around the world. Many of the leading figures in the Danish wind industry can trace personal connections to Tvind. Vestas engineers still visit the Ulfborg campus for training exercises to study the Tvindmill. By these metrics, the windmill project has been an astounding success.

The continued operation of the windmill is meaningful for Tvind and its supporters in still more ways. The turbine is not a big moneymaker for Tvind—Britta Jensen said that in most years, the budget balances out, but in years in when they have larger-than-expected maintenance costs, they sometimes have to turn to the larger organization for help covering those expenses. Tindkraft is registered as a separate company and sells the electricity it generates back to the national grid at market price, as required by the state subsidy scheme. So the windmill does not power the campus directly, but one quirk of its custom design is that to overcome the limitations of its synchronous generator, and to smooth its power output to meet the requirements of the grid, the windmill team developed a novel system of dumping excess power output by turning it into heat, which is then sent to warm the school gymnasium and cafeteria. Britta estimated this arrangement can save the school between 20-30% on its energy bills in some years. (17)

This symbiotic relationship between the windmill and the school seems to have financial benefits for both parties, but there's an even deeper emotional and moral resonance to the relationship for members of the campus community. The windmill is a towering statement and demonstration of the of the school's commitment to sustainability. It not only supplies heat to the canteen; it supplies sustainable, carbon neutral heat. This matters quite a lot to people at Tvind, even if it's hard to put a price on. The windmill is a source of pride for the community, and a claim to fame. It raises the visibility of the broader organization and its mission, and continues to bring a steady stream of visitors to the far-flung campus to this day. Britta gave the example of the international musicians who come for summer concerts and rave about how much they love the windmill. "It is still a kind of beacon," Britta said. (18)

The gentle *whoosh* of the spinning rotor is even reassuring to campus residents, making the turbine a sort of familiar friend, an ever-present part of the local landscape that one gets accustomed to, and then misses when the turbine shuts down for inspections or repairs. "If it's a crap day, it makes me feel better," Anna Hoas said. "I love that noise, it's like birdsong." (19)

Bruno Latour once argued, in his book *Aramis, or the Love of Technology* (1996), that a concept for an innovative French public transportation system failed because it was unloved. Not enough constituencies were sufficiently invested in its success, it never became a "matter of concern" in the relevant networks and contexts. Tvindkraft offers a good case study of the opposite effect—the windmill is nothing if not beloved. And I would caution against writing off the analytic value of Latour's point as a squishy, unscientific sentiment. The ability of a technological innovation to cultivate love, in the sense Latour means, may be a key indicator of the sustainability and success of that model, and this insight may be of particular relevance in helping to understand and combat growing public opposition to wind developments, both in Denmark and abroad.

The radical political vision of Tvind's founder and his acolytes has not been fully embraced by the Danish public, but the ripple effects initiated and inspired by the windmill project have been profound. From the earliest days of the project, the Tvindmill brought together a diverse network of environmentally-concerned citizens and professionals who would have been unlikely to cross paths otherwise. Academics forged relationships with grassroots activists; do-it-yourself tinkerers from across Denmark met face-to-face and swapped information about how to build their own (much smaller) turbines at home. The success of the project helped establish western Denmark as a hub of wind energy innovation, a status the region maintains today, and fueled the debates over the nation's energy future.

The case of the Tvindmill, and its lasting influence on the Danish wind network, offers one example of how a substantively democratic politics might emerge from sustainability transitions, though it is not the sort of democracy the teachers and students imagined when they embarked on their construction project. Their vision of small scale, localized, direct participatory democracy has thus far failed to supplant the mass politics of the modern nation-state and global capitalism. That doesn't mean the project failed to democratize Danish society in any way. The Tvind team were crucial players in the germination of a network that over time has fundamentally reshaped the country's landscape, infrastructure, culture and politics, in directions that could hardly be anticipated at the time. That wind energy network has produced citizens with new political capabilities and resources. It has toppled old industries and built new ones. It has shifted the national culture and mainstreamed environmental values. It is in this sense that Tvind team can be understood as political innovators—they helped launch a process of development that allowed a novel arrangement of social, ecological and technological components to grow together and flourish, in the process upsetting established orders and empowering marginalized communities, first and foremost by giving the members of those communities new tools with which to act politically.

And, of course, the Tvindmill is still turning, still generating, now nearing its 50th birthday, making it the oldest operational wind turbine in the world. How long it can keep going is anyone's guess. Eventually, it will experience a mechanical failure that won't be feasible to fix. Britta thinks it's unlikely Tvind would attempt to build another windmill, since today it's no longer necessary, they could simply purchase a replacement. And yet there are no plans to decommission Tvindkraft. "Maybe it will not last as long as the Coliseum in Rome, but it has been standing there for 2,000 years," Britta said. "In 150 years' time, this area will be flooded." (20)

Figure 2.1. Tvindkraft rises above the Tvind Schools campus in Ulfborg, in western Jutland.

Notes

1. The account that follows of the Tvindmill construction is adapted from numerous sources. In addition to my own conversations with members of the Tvindmill construction team and school, I rely most directly on descriptions from Preben Maegaard and Andrew Jamison's contemporaneous accounts, as well as Tvind's own histories. Citations are provided for quotations and facts derived directly from one of these sources.

2. From personal communication with Anna Hoas, Ulfborg, Denmark, June 2015.

3. From personal communication with Britta and Allan Jensen, Ulfborg, Denmark, June 2015.

4. It should be noted that in some of his more influential texts, Wolin is concerned with defending his subfield of political theory from the dominant paradigm of positivist social science, which had increasingly marginalized the role of theory in the discipline. Within this context, Wolin's seemingly immodest proposal for an "epic political theory" can be seen as a way of enacting his concept of political vision.

5. Eckersley and Dryzek are both established names in the small but growing subfield of political science scholarship on "environmental political thought." Dryzek is the second-ranked scholar in Google's tally of citations in environmental politics, with more than 37,000 references and an h-index score of 72. Eckersley ranks among the 50 most-cited political theorists, with almost 7,000 references and an h-index score of 33.

6. Working against them are the "institutional practices" of corporations, regulatory agencies, and even the unions, which benefit the powerful. Change agents must confront appeals to traditional values like family, religion and loyalty deployed in support of the status quo, as well as the symbolic capital spent to label them "communists," "outsiders," or "troublemakers." They must fight for recognition in the elite-run media. Collectively and over time, these mechanisms of power instill a learned sense of defeatism in the population activists are trying to reach. In order to stand a chance of breaking through, the rebels must amass their own symbolic and organizational resources. (Gaventa 1980, 254-255)

7. I made my own contribution to this voluminous, if redundant, literature, authoring a conference paper as a graduate student that argued Foucault conjured the image of famed sex researcher Alfred Kinsey, and his eponymous 6-point scale for measuring sexual orientation, when he described modern scientists as having "entomologized" sexual deviance. While Foucault focuses his attention in *The History of Sexuality* on nineteenth-century psychiatrists like Richard von Krafft-Ebing, it is hard to ignore the parallels to the later classification work of Kinsey, who began his academic career collecting gall wasps and became one of the world's experts on the insects.

8. The accumulation of "social capital," a concept she borrows from the likes of Robert Putnam, is critical to Fountain's understanding of networks. Bruno Latour

similarly emphasized “cycles of credit” in his first formulation of actor-network theory in *Laboratory Life*. (1979) And when Fountain writes that “a fine mesh of institutional entanglements envelop and create structural inertia in large organizations,” she is describing a phenomenon very similar to what historian Thomas Hughes calls “technological momentum.” Fountain may not need to adopt a systems view to explain the evolution of federal bureaucracies in the Internet Age. The dependent variable in her study is institutional change, and not technological change, per se.

9. In the eyes of a critic, an album of orchestral music becomes “a self-regenerating ecosystem in nine movements.” (Pitchfork 2021) Restaurants should invest in the mental health of their employees since guest service will improve “if the whole restaurant ecosystem is working smoothly.” (Severson 2023) DEA wiretaps of Mexican meth trafficking reveal “a pulsing ecosystem of independent brokers, truckers, packagers, pilots, shrimp-boat captains, mechanics, and tire-shop owners.” (Quinones 2021)

10. In 2021, the libertarian Niskanen Center published an analysis of Congressional industrial policy that advocated “supporting domestic technology ecosystems” as a means of competing with China’s manufacturing muscle. (Hammond 2021) A pair of British military strategists, analyzing the war in the skies over Ukraine, claimed that the projection of air power is “dependent on an array of technologies that require highly trained personnel who can quickly set up what amounts to an airborne military ecosystem.” (O’Brien and Stringer 2022) A recent critique of the Democratic Party apparatus published in Politico described the party’s progressive base as “a flourishing ecosystem of student-run organizations ensures that the quad-to-campaign pipelines continue to pump out a steady flow of enthusiastic young party staffers.” (Ward 2021) Making progress on social injustices like racism, according to conservative columnist David Brooks, requires first understanding that “people change when they are put in new environments… Their embodied minds adapt to the environments in a million different ways we will never understand or be able to plan.” (Brooks 2020)

11. From personal communication with Anna Hoas, Ulfborg, Denmark, June 2015.

12. ibid.

13. A 2016 BBC investigation found that the Zimbabwe-based Development Aid from People to People had been funneling the salaries of the ir African staff back to Teachers Group accounts, reporting that led the UK’s Department for International Development to suspend the organization’s funding. (Meisel and Cox 2016) An in-depth investigation that same year by journalists at the online magazine Reveal detailed a range of allegations against Planet Aid, a U.S.-based charity with ties to Teachers Group leaders. The report cited a 2001 FBI investigation that concluded revenues from the sale of used clothes were being “laundered out of the Trust by paying high salaries to Tvind teachers in Africa” and then funneled to bank accounts in Switzerladn and the Cayman Islands controlled by Tvind leaders, who “divert the money for personal use. Little, to no

money goes to the charities." (Smith, Walters and Ngwira 2016) Planet Aid denies these allegations, points to a long track record of what they argue have been successful aid projects in developing countries, and continues to receive federal funding. The organization's 2021 tax return, posted on their web site, reported just shy of $30 million in revenue, almost all of which came from grants. The group paid $11 million in employee compensation, but gave out only $3 million in aid to programs in Belize, Botswana and Brazil. By far the group's biggest programming-related expenditure was $18.7 million to fund the secondhand clothing business, which they characterized on their tax return as a recycling program that reduced carbon emissions. The watchdog group CharityWatch gave Planet Aid an "F" rating. Goodwill Industries, by comparison, earned an "A." (Hoyer and O'Donnell 2012)

14. From personal communication with Anna Hoas, Ulfborg, Denmark, June 2015.

15. From personal communication with Britta and Allan Jensen, Ulfborg Denmark, June 2015.

16. ibid.

17. ibid.

18.

19. From personal communication with Anna Hoas, Ulfborg, Denmark, June 2015.

20. From personal communication with Britta Jensen, Ulfborg Denmark, June 2015.

CHAPTER 3

FRONTIERS: THE BIRTH OF THE MODERN WIND INDUSTRY

3.1 A Window Opens

“Right place, right time,” has an intuitive, common-sense appeal that allows it to pass as a satisfactory explanation for wide range of life's occurrences, from meeting a lover, to landing a job, to (in its negative formulation) falling victim to a freak accident. As willingly as most humans would admit to the importance of timing in their lives, it still raises suspicions of vagueness or insufficiency as a social scientific variable. It feels like a placeholder for something more tangible and descriptive, failing to take the proper form of scientific explanations. It does not specify a causal mechanism or agent, and in attributing the outcome to fortuitous circumstances, it suggests that those circumstances were beyond human control, as if the chain of events were merely an accident of history. Such a narrative would seem to strip humans of agency, putting them at the mercy of fate, and limiting their ability to identify patterns in, or otherwise make sense of, historical change.

Yet no less a political thinker than Niccolò Machiavelli held the ever-turning wheel of fortune to be an unavoidable condition of the human experience. Of course, he did not think of destiny as a confluence of random occurrences. Machiavelli was comfortable embodying Fortune with sentient (even gendered) qualities, but the existence of a supernatural being meddling in human affairs did not put men at her mercy. Rather, fate shapes the terrain of history, which individuals can read and navigate. It presents both risks and opportunities. If Fortune is tempestuous and unpredictable, prudent men will construct dams and dikes to channel her occasional floods away from ruin, or toward their advantage. According to Machiavelli, fate is continually opening windows of opportunity, but only individuals of great skill (virtù) are able to recognize and take advantage of those opportunities when they present themselves.

That twists of fate were inevitable, but also bendable, made sense amid the political upheaval on the Italian peninsula in the fifteenth century. This conviction is arguably no less familiar today in a global political economy that treats disruption, breakthrough, and creative destruction almost as if they were laws of nature. Scholars of business, technology and politics have all long sought to understand how innovators get ahead of the curve, how they see openings where others cannot, and make the most of those moments when others fail. This chapter engages such debates by examining how a global wind power revolution took root in rural Danish farming communities in the 1970s. Why then? Why there? Why them? Did Denmark just get lucky? Or are there lessons that can be learned from their experience about how to seed and incubate the future innovations that will be needed to complete the energy transition?

Since the early 1980s, Danish wind turbines have held a reputation as the best in the world. A substantial scholarly literature has arisen seeking to explain this unlikely triumph. The most common narrative attributes the success of Danish manufacturers to a confluence of external shocks and a distinctive technological development culture. This dissertation does not dispute the importance of either factor in the history of modern wind power, but contends that the emphasis on these elements is misleadingly reductive, and leaves critical questions unanswered. It is undeniable that several significant shocks were turning points in the early history of the wind industry, though not all of those events were unambiguously beneficial to the domestic wind sector in Denmark, and it's debatable to what extent those circumstances were truly external to that national context. Prior choices made by both policy and industry actors increased the wind community's vulnerability to those shocks, and also helped shield it from the fallout. The occurrence of a shock to a system and its aftermath for that system are not so much explanations as things to be explained. The local context largely determines whether a given event is experienced as a shock, and with what consequences. It is commonplace for energy systems around the world to experience periodic, recurring shocks. That fact alone does not explain why the Danish wind network was uniquely well-prepared to ride out the shocks of the 1970s and 1980s, and leverage them to grow. Similarly, reducing the decisive competitive advantage to a superior engineering culture does not, on its own, reveal much about how that culture arose in Denmark, and not in other countries, or how it was sustained there. Long before anyone in Denmark attempted exporting a wind turbine, the ground had been prepared to set those ventures up for success. And when wind entrepreneurs did take the plunge into turbine development, they did not do so in isolation, but as members of dense, multidimensional networks of relationships that shaped the outcomes of their actions. The main goal of this chapter is to describe the conditions surrounding and the relationships comprising that early wind community. When Danish innovators are reembedded in this context, a fuller picture emerges of precisely how their exploits incubated a powerhouse industry. Denmark in the 1970s was the right place at the right time for an energy transition to take off, but this chapter proposes that what colloquially gets called "timing" should be understood, in more technical and theoretical terms, not so much as a temporal concept but as a structural one. From an ecosystems point of view, what it refers to is the development of environmental conditions and community relationships that facilitate the appearance and maintenance of a niche. Evolutionary fitness is not some inherent property of an organism, but a relational property of a species to its environment. To understand how Danes built the world's first and most robust wind industry, what is needed is a description of the niche in which that early industry flourished. Danish wind entrepreneurs thrived not because they had a superior development model, in some universal sense, but because that model was a good fit for the context of its deployment.

Learning how to identify and leverage opportunities is particularly crucial for technological innovation. Almost any successful technology rests atop the rubble of discarded precursors, competitors and alternatives. Promising inventions wither into obsolescence for many reasons—they might fail to find the right audience or the right application; they might face entrenched competition or political opposition; they might need refinement through further rounds of development. For every Amazon.com there is a Pets.com, for every Skype an AT&T Picturephone, for every Tesla Roadster a Henney Kilowatt.

Innovation scholars have sought for decades to understand how opportunities for technological breakthroughs arise. One recent example of a sociotechnical systems perspective on this question can be found in the Multi-Level Perspective theory of Frank Geels, who posits that "windows of opportunity" open for new technologies when an established technological regime is destabilized in one way or another. Geels identifies at least five ways "tensions and mismatches" can be created among the various actors and groups networked in the dominant regime, opening windows for new challengers: selective pressure exerted by the surrounding social and material environment, negative externalities of the regime creating pushback, competition among regime firms, internal problems with the regime such as technological bottlenecks, and changes in user preferences. Windows eventually close when a new dominant regime restabilizes. This could also happen in a variety of ways. The challenger may make a breakthrough and quickly replace the old regime. Or the old regime may gradually weaken, creating ever more incentive to switch to a new technology, which eventually supplants it. Alternatively, the new technology may be integrated into the existing regime, reconfiguring it the process, resulting in a new hybrid form. (Geels 2004)

The development of the modern wind industry offers an empirical test of the applicability of this theory to a real-world technological regime change. This “windows of opportunity” theory offers more descriptive content and analytical heft than the fuzzy concept of “timing,” but is it adequate for understanding how wind turbines went from a niche curiosity to a mainstream energy technology?

Today, wind turbine manufacturing has grown into a titan of global industry—employing more than 85,000 people in the United States and 300,000 in Europe, and generating more than 100 billion USD in new investment in 2015. Both of these indices continue to trend upward exponentially, and the list of companies invested in wind energy includes a who's who of the global Fortune 500. (1) This flourishing worldwide enterprise can trace its roots to one of the sleepiest corners of Europe, the humble farming communities of the Jutland peninsula in Western Denmark. In the mid-1970s small prototype windmills began popping up around this sparsely-inhabited countryside. Within a decade, the region had rocketed to the forefront of global wind turbine production. Two Jutland-based firms, Vestas and Siemens (formerly Bonus), remain among the world's largest and most-respected turbine manufacturers today. And Jutland can still boast more wind turbines per capita than anywhere else on earth. (2) It's a somewhat pedestrian and surprising pedigree for an ascendent energy technology with ambitions to dominate the global electricity sector. Humans have been generating power from the wind for thousands of years, and yet doubts about the potential of wind turbines as a primary energy source persist to this day. So why did the technology take off at this specific time? And why in this seemingly unlikely place?

The fact that the success story of modern wind power begins in an out-of-the way corner of Denmark is doubly surprising when considering that concurrent development efforts were underway in Russia, Sweden, the United Kingdom, the Netherlands, and most notably in Germany and the United States. In this competition to be the first to develop a modern wind program, the Danes were seriously outgunned. The Germans and Americans leveraged their unmatched national research and development infrastructures, drawing on aerospace engineers and university faculties, in an effort to transfer space-age technological expertise to electricity production. From 1975 to 1988, the United States government, led by the National Aeronautics and Space Administration (NASA), spent more than $400 million on wind energy R&D. During the same time period, Germany spent more than $100 million. The Danes spent a comparatively paltry $19 million. (Heymann 1998) Yet the German and American research programs never produced a single commercially successful turbine. Danish experiments launched an entire industry. How did the Danes outcompete these better-equipped rivals?

The immediate answer to that riddle, agreed upon by several scholars who have investigated the issue, is that the Danish wind turbines outperformed their competitors in terms of reliability. (see Dykes 2013, Gipe 1995) The decisive proving grounds were the California deserts of the early 1980s, where the idea of supplying commercial electricity from a “wind farm” comprised of a large array of turbines was first put into practice. In the wake of the oil crises of the 1970s, U.S. President Jimmy Carter's administration began seeking ways to promote the development of alternative energy technologies. Carter famously installed solar panels on the White House roof. In 1978, a 10 percent federal tax credit went into effect for investments in renewable energy technology, followed in 1980 by an additional 15 percent tax credit for investments in projects completed by 1985. At the same time, Governor Jerry Brown of California in 1978 pushed through a 25 percent state tax credit for wind and solar projects built before 1986. These combined tax credits would cover 50 percent of the costs of developing a wind farm. Additionally, in 1978 Congress had passed the Public Utility Regulatory Policies Act (PURPA), which required utilities to buy the electricity independent producers fed into the grid at a price to be determined by state utility commissions. The California utility commission set an attractive rate of seven cents per kilowatt hour. Collectively, these incentives led to a rush of investment in wind projects in the desert passes around Altamont, Tehachapi, and Palm Springs, where cheap land was readily available. Often, the investors were professionals like doctors and dentists who benefited from the generous tax write-offs even if the turbines never produced a single kilowatt of electricity. From 1980-1985, thousands of turbines were purchased from dozens of fledgling manufacturers. In 1983, Danish turbines accounted for 12 percent of the California market. By the following year they had grabbed 29 percent of the market, and in 1985 a full 55 percent of the turbines installed in California were from Danish manufacturers. (Musgrove 2010)

The California bubble burst dramatically in 1986, resulting in a trying period for the wind industry. Many companies on both sides of the Atlantic did not survive. When Ronald Reagan was elected president in 1980, he had promptly ripped the solar panels off the White House roof and sunset the tax credits for renewable energy. When the federal subsidies expired at the end of 1985, the market contracted severely. The Danish manufacturers limped away from California bruised, but having established a reputation for producing the highest quality turbines in the world.

Those desert passes had been a challenging trial site, with high heat, dust, and strong, gusty winds that subjected wind turbine components to higher-than-expected fatigue. It didn't help that most of the turbines being installed were little more than prototypes, rushed into production to meet the soaring demand by undercapitalized startups with understaffed engineering and service departments. Many turbines simply broke in the desert, particularly the lightweight designs favored by American companies like ESI, Fayette, Enertech and American Windshark. Many of the damaged machines were never repaired. The sun-bleached carcasses dotting the ridgelines were visible to motorists passing on the adjacent highways, and contributed to public perception in the United States that wind energy was not a workable solution for electricity production, that the California experiment had failed. The one American manufacturer that emerged from California with a relatively good track record was U.S. Windpower, not because their turbines performed particularly well, but because they made the shrewd decision to locate their production facility near Altamont Pass in Livermore, allowing them to bring damaged turbines into their shop for repairs and quickly get them back into service. (3) U.S. Windpower was later sold, and after a series of mergers eventually morphed into what is today General Electric's wind division. Most of the other American manufacturers went bankrupt after 1985.

Many of those involved in the American wind development program will readily admit they misunderstood the nature of the engineering problem. The university and government experts who led the development of wind technology in the United States usually had backgrounds in aerospace engineering, and sought to design turbines for maximum aerodynamic efficiency. This goal meant making the turbines as lightweight as possible. In contrast, Danish turbines of that period weighed 2-4 times as much as American machines of a similar capacity, and resembled farm implements more than the space shuttle. (4) Those who saw these early Danish designs firsthand tend to describe them using similar imagery—as “tanks on top of poles” or “dreadnoughts of iron and steel.” (5) These bulky machines were so overbuilt they were terribly inefficient, but they were sturdy, and they failed much less frequently than the American designs.

American engineers slowly discovered that building a wind turbine was a far different challenge than engineering an airplane wing or a helicopter rotor. Airplanes and helicopters only have to operate a few hours at a time, with regular service between flights. Wind turbines must operate continuously for years, thousands of hours, with little or no maintenance, making reliability the chief concern.

Aerospace engineers had little experience with or understanding of the stresses on wind turbines. An airplane might encounter occasional turbulence flying at 20,000 feet, but at ground level the complexities of weather patterns, obstructions like trees and mountains, and varying topography made for incredibly dynamic, and turbulent, wind conditions. All of the turbine's interconnected moving parts added yet another layer of complication. There was no way for turbine designers of the 1970s to anticipate and calculate the loads on their turbines under such complex conditions—much of the meteorological science was still being developed. Wind engineers were mistakenly solving aerodynamics problems, and only later realized that the real challenges were aeroelastics problems and structural dynamics problems. (6) The resulting calculations proved inadequate, because they were based on assumptions that were wrong. It was only as advanced computer modeling programs evolved through the 1980s and 1990s that engineers were better able to simulate wind conditions and more accurately predict the loads on turbine components. “There was a lot of uncertainty that we weren't accounting for,” said industry veteran and research engineer Walt Musial, now offshore wind manager at the National Renewable Energy Laboratory in Golden, Colorado. “We didn't understand the design conditions, we didn't understand the environment we were putting them into. We were making assumptions that were bolder and more confident than what we really understood.” (7)

The American R&D program compounded its errors by attempting to accomplish too much, too fast—what longtime industry observer Paul Gipe has described as trying to “hit a home run,” rather than taking a more cautious, incremental approach to turbine development. The lion's share of the research funding went to developing large multi-MW machines in collaborations between NASA and industrial giants like General Electric, Westinghouse and Boeing. The “MOD”-series turbine designs that resulted from these public-private partnerships never reached the commercial phase. Only a competing effort to design small-scale windmills—carried out by ponytailed dreamers and college students at places like the University of Massachusetts Amherst, and the small turbine test center in Rocky Flats, Colorado—was successful in bringing products to market in time for the California boom. When the federal subsidies evaporated in the mid-1980s, the heavy industry partners all got out of wind business. There no longer appeared to be an economic case for their large-scale, centralized vision of wind energy production.

Government-led R&D in Germany made a similar mistake, attempting to build the world's largest turbine, dubbed the Growian. The machine was a miserable failure, and was dynamited after only 420 hours of operation. (Gipe 1995) Though German expertise made other contributions to the development of modern turbine technology, the effort to launch a multi-MW machine never recovered from the Growian fiasco. As in neighboring Denmark, the eventually successful German wind firms were started by small entrepreneurs outside the state and industrial apparatuses. Wind energy did not take off in Germany until the mid-1990s, a decade behind the Danes.

The race in the United States and Germany to leapfrog the small-scale turbine technology has been called a "breakthrough" strategy by Peter Karnøe, as opposed to an iterative approach. (Garud and Karnøe 2003) Historian Matthias Heymann labeled it "technological hubris." (Heymann 1998) Wind engineer James Manwell, who participated in building a small-scale turbine at the University of Massachusetts which served as the model for U.S. Windpower machines, considers that a fair criticism. "American engineers thought, hey, we've gone to the moon, we can design windmills," Manwell said. "There was a lot of hubris." (8)

It's clear that the Americans and Germans either lacked or failed to apply the relevant expertise that would have allowed them to build more reliable turbines. But the Danes were even more severely restricted in their knowledge of how to optimize an electricity-generating windmill. It would be a mistake to assume the Danes knew what they were doing, at least in terms of applying science to their designs. How, then, did they manage to build the most reliable turbines available?

The wind power pioneers in Denmark—and they were more often passionate hobbyists than bottom-line-oriented industrial concerns—had a good appreciation of what they did not know. Since they had only rough estimates of the loads their turbines would be subjected to, they adopted a precautionary approach, applying conservative rules of thumb in their design specifications, buttressing against uncertainty with additional steel. Their ad hoc development strategies were also highly pragmatic, building on real-world operating experience and embracing trial and error aimed at achieving incremental improvements.

This narrative about a peculiar Danish engineering culture triumphing over better-equipped rivals has been widely shared and is now generally accepted. Matthias Heymann was one of the first to describe a specific Danish "technological style"—a popular concept used across the technological systems literature to capture the unique ways in which different social groups respond to similar technical challenges. The concept of "style" demonstrates that the means of fulfilling particular technological functions are not predetermined, that there is more than one way to skin a cat. According to Heymann, style encompasses the "characteristic patterns of knowledge, actions, and artifacts" of a given development community. The Danes, he argues, employed a decentralized, "bottom-up" development strategy, as opposed to the "top-down" approach favored in the United States and Germany. (Heymann 1998) The wisdom of fostering a "bottom-up" development culture has since proliferated the energy policy literature (see, for example, Sovacool and Sawin 2010 or Kamp 2012).

There is a lot to recommend about innovation programs that encourage open sharing of information, incremental learning, and close-knit networks that connect suppliers to manufacturers, engineers to the production floor, and developers to the communities where the technologies are being deployed. All of these elements were crucial in the early development of Danish wind technology. And as a point of historical record, the "bottom-up" development pathway followed in Denmark was the only effort in the world that resulted in a durable wind industry in the 1970s and 1980s. Those entrepreneurs who embodied this development style can certainly be credited with choosing an appropriate method given they were working with limited resources under conditions of uncertainty. But the suggestion that any particular engineering style, or culture of the development community, was the decisive factor in the success of Danish technology is a misleadingly one-dimensional characterization of a complex and multifaceted reality. As a general explanation for what happened in the early stages of wind turbine development in Denmark, it has several deficiencies. The "bottom-up" narrative implies that the Danes had a conscious and coordinated strategy for turbine development. Preben Maegaard, who was among the first and most influential turbine designers, has written that no such directed strategy existed. (Maegaard 2013) Rather, the engineering networks that would eventually produce successful turbine designs took shape organically as a consequence of broader social conditions that encouraged this mode of development. The Danish way of building turbines was not so much an innovative strategy adopted by wind entrepreneurs as it was a reflection of rural Danish culture writ large.

The usual narrative also gives a false impression of the competence of Danish turbine designers, who suffered through numerous growing pains on their way to producing reliable machines. Early Danish turbines had a wide range of inefficiencies and design flaws. The list of discarded design features—from wood and steel blades, to stall-controlled rotors, to tip brakes, not to mention all that extra girth—grew with each new design iteration. Turbine failures were commonplace, and sometimes catastrophic. The industry magazine *Windpower Monthly*, which compiled monthly statistics on the performance of turbines installed in Denmark, reported that in the first month of 1986 alone 22% of turbines surveyed experienced problems. Two had complete breakdowns, 36 suffered serious damage, 103 had minor damage, and an additional 24 were out of service for unspecified reasons. (9) The reputational damage inflicted by reports of poor product performance ruined some small firms, but ultimately helped cull the herd, and strengthened the Danish wind sector as a whole. Danish manufacturers benefited from supportive local conditions that allowed them to learn from their mistakes, and for the industry to survive as they underwent this learning curve. The social environment in Denmark at the time cushioned pioneers from the impacts of failures, and propped up the industry as it improved its product.

Thus it would be incorrect to draw the conclusion from the Danes' success that their development program was somehow inherently superior to those of their competitors. Although the “bottom-up” approach worked in the Danish context of the time, that's no guarantee a similar approach would fare just as well in altered circumstances. Some American wind engineers believe they could have produced more reliable designs, if better support structures had been in place, particularly government backing. (10) What might have been different if Reagan had never been elected, and the California wind boom had continued another 3 or 5 or 10 years? What if rather than providing an investment tax credit, the U.S. government had pursued a production tax credit, pegged to the actual amount of electricity a turbine produced? What if the public had been more supportive of the California wind farms? All of these factors were beyond the direct control of the development community, yet they had a major influence on the decline of American wind power in the 1980s.

Many technological systems theories have accounted for the role of the selection environment in shaping system change. As mentioned above, Multi-Level Perspective theorists posit that environmental pressures are one of five mechanisms that create windows of opportunity for novel technologies. But the social and natural environment in Denmark did more than create opportunities for courageous and far-sighted entrepreneurs, it also created conditions that assisted these entrepreneurs in achieving their goals, a supportive niche in which the technology could develop.

In his classic study of early electrification, *Networks of Power*, historian Thomas Hughes demonstrates a clear appreciation for the impacts of environmental factors on system evolution, yet that layer fits uncomfortably into his theory. It is often simply passed over in discussion. Partly, this is a consequence of Hughes' primary aims, which lead him to focus his attention elsewhere. Among other opponents, Hughes was positioning himself against the still prominent technological determinism of his day. He was also proposing a new “sociotechnical systems” theory, which meant he needed to specify the characteristics of technological systems, and define their boundaries. He arrived at a definition that allowed space for humans to shape the paths of large-scale technological change, by limiting sociotechnical systems to the components under the control of managers. Presumably anything outside this boundary would have to be considered part of the environment, which would include both social and natural conditions. Though Hughes is aware of the influence external circumstances exert on technological development, he is far more interested in the internal dynamics of system evolution. Environmental shocks become a prominent part of the story late in Hughes' book, as crises like the First World War and the imperatives of global finance begin to exert differential pressures in Germany, Britain, and the United States. He deals with these always outside "contingencies" under the category of style. "Out of local conditions comes style. The local conditions external to the technology can be defined as cultural factors; the technology they shape, a cultural artifact," Hughes writes, but these "factors only partially shape technology through the mediating agency of individuals and groups." (Hughes 1983) His interest remains primarily in the choices of these human actors. The conditions system engineers confront force them to adapt, but the stories of these environmental influences remain in the background.

The aim of the current chapter is not to tear down this edifice sociotechnical systems theories have already constructed to account for the roles of environmental factors in system change. Indeed, numerous system actors have agency in trying to adapt to external circumstances. Sometimes, in these adaptive responses there may even form distinctive patterns or cultural "styles." And it's hard to dispute that environmental shocks or major realignments in social conditions can open up opportunities for new technologies to emerge. But even more layers can be added to what remains a relatively thin account of environmental influence, even selection, in the systems literature. The following sections detail the range of environmental factors that affected the outcome of the first generation of Danish wind development. This empirical evidence shows that the right local conditions are critical in nurturing a young technology, providing a supportive environment for it to flourish, creating a niche. Conveniently, this is also a type of environmental influence that human actors can attempt to shape, which raises policy implications for system governance. Ecologists know that niche relationships are a two-way street—organisms are not merely at the mercy of their environments, but also actively work to transform their habitats. One of the distinguishing characteristics of human communities is their capacity to alter their environments in pursuit of desired ends at unrivaled speeds and scales. One common name for this activity is “technology.”

The analysis in this chapter calls for a reevaluation of the niche concept as it has been presented in technological systems theory. A niche appeared in this particular time and place—Denmark, after 1973—partly because of broader global events, but also partly by design. With the benefit of hindsight, it's possible to draw the conclusion that the supportive social fabric swaddling the infant wind sector in Denmark made this the likeliest of places for the technology to succeed. It is time, then, to become observers of those environmental conditions, in an effort to better understand the circumstances in which a promising effort can flourish.

3.2 A Homegrown Champion

Ringkøbing Fjord offers the hamlets inland little protection from the strong and steady North Sea winds that buffet the exposed coast of Jutland. One of those hamlets is Lem, which is less a town than a loose association of nearby homes and farms. Most Danes have probably never heard of Lem, the only attraction of note being the small harbor on the fjord, around which are gathered a cluster of traditional summer cottages.

In 1978, this is where Birger Madsen settled with his young family. Fresh out of university and mandatory military service, he had just taken a job as the first engineer hired by a local manufacturing company. The small shop, called Vestas, had been in business for decades, producing a range of steel products, from window frames to dairy milk urns. Madsen had been hired to engineer hydraulic cranes for small trucks, at the time the company's biggest product category. (11) But a monumental shift was on the horizon. Madsen would soon be head of an entirely different department making an exciting new product, but one with which he had no experience. In just five years Vestas would be the most celebrated wind turbine manufacturer in the world.

Madsen and his wife were locals, and they had firsthand experience of the impacts of the 1973 oil crisis on their community. They lived through the Car Free Sundays and a cold winter when they and many of their neighbors would throw on an extra sweater rather than turn up the thermostat. It was a financial hardship—Birger's home heating bill had quadrupled—but it also had its perks for the Madsen's courtship, when relying on a motorbike for transportation and being snowed in meant an invitation to spend the night under the roof of the future in-laws. Energy was on everyone's mind. It was water cooler talk, coffee break conversation. Tips were shared around the office about how to save energy in your home. As a Christmas gift in 1976, Birger's wife bought him a copy of one of the first books published in Scandinavia with information on how to build a small windmill at home, a topic in which Birger had had an interest since his school days. It was around this time that Madsen and his boss' son, Finn Hansen, were beginning to have conversations about wind turbines. The interest for them, Madsen said, was partly ideological. Like many Danes who had experienced the oil crisis, they perceived their country as too dependent on Arab petro-states, and felt strongly about trying to make Denmark more energy independent. (12) Alternative energy seemed to them like a good opportunity, and Finn Hansen brought the idea to his father, who agreed to invest some money in exploring the possibility of manufacturing small turbines. The oil crisis and the resulting economic recession were continuing to drag down the market for agricultural machinery around Europe, and it had been a few lean years for the many small manufacturers in Denmark. Across the industry, companies were looking for new product lines. For the senior Hansen, wind was purely a business opportunity, and at first only an effort to determine whether a financial case could be made for it. (13)

In 1978 Birger and Finn, on behalf of their company, began tests on turbine concepts. The first design they tried was a Darrieus vertical-axis turbine, with its characteristic egg-beater shape. The turbine performed extremely poorly, and was rejected. (14) But a local blacksmith and high school student had been working on a design of their own in nearby Herborg, and when they found out from a friend that Vestas was testing turbines, they made a phone call to Madsen. Karl Erik Jørgensen and Henrik Stiesdal had only built a couple of their machines, which were typical of what would later be known as the Danish concept—three-blade, upwind, horizontal-axis. Vestas took measurements on the first machine completed, and Madsen found the results satisfactory, so an agreement was made to license the design for a few hundred thousand kroner, and a royalty payment to the inventors on each turbine sale. (15) This first acquisition would become the model for all Vestas turbines going forward.

What gave Vestas the confidence to enter production was a subsidy scheme approved by the national government in 1979, which took effect the first day of 1980, allowing individuals to recoup up to 30% of what they invested in a turbine project. (16) With this incentive, small windmills became an attractive investment, and Vestas had a sales pitch for the second generation of the Herborg machine, the company's first major product offering, the 55kW Vestas HVK-15. They would produce more than 1,000 of the 15-meter rotor series in the coming years, but at first they sold only dozens, entirely in Denmark, mostly to rural residents like school teachers or pig farmers. Vestas' solid reputation as a maker of agricultural equipment, “undoubtedly helped the sales of turbines to Danish farmers,” according to industry pioneer Erik Grove Nielsen. (17)

In those early years at Vestas, there was close contact between the small engineering department and the shop floor. Madsen also worked closely with researchers at the Danish Technological University and at Risø National Laboratory, which was tasked with certifying new turbine designs. This association with the national laboratory later made Danish turbines more attractive on the international market, since they came with a seal of quality from an independent testing facility. The back-and-forth between manufacturers and the national laboratory also allowed the Danish industry to converge around shared standards, encouraging an unusually close-knit development community in which knowledge circulated openly to the benefit of all.

In March 1980 Madsen was made head of the new wind division at Vestas, which started with only 16 employees. The company as a whole employed slightly more than 100 people. By 1985 the wind department would grow to 600, and Vestas would be poaching employees from machine shops around west Jutland. (18)

It could not have been a better time to start a wind company, with the California tax credits taking effect the same year Vestas began producing turbines. Within a year or two, news of what was happening in California had reached Denmark. In 1982 Madsen and a colleague, Per Krogsgaard, made their first visit to California to plant a flag for Vestas. They took a series of meetings with developers, financiers and American manufacturers. In San Francisco, the bankers were impressed that they had collected 15,000 full load hours of data on the performance of their turbines in Denmark. By September they had orders from three different wind farm developers. The following year, they shipped 300 turbines to California. One of the first customers was Zond, the largest of California's wind farm builders. Zond was happy with the turbines it received from Vestas, and for the next few years bought almost every turbine the company could produce. (19) In the rush to fulfill orders, the Vestas team decided to delay the introduction of their new 200 kW design. The expectation in the engineering department had always been that the size of their turbines would roughly double every few years, but the flood of sales left the factory in Lem with little spare capacity to complete R&D on the next generation of their technology.

The mid-1980s were a bonanza on the California market. There were more orders to go around than any of the manufacturers in the business could handle, and everyone feasted. More than a half dozen Danish firms made their names in California, including Bonus, Micon, and Nordtank.

Madsen accepted a promotion to head of new product development at Vestas, leaving the day-to-day oversight of turbine production and sales to a new crop of middle managers who had been hired in the expansion. He had also been elected the first president of the new trade association for turbine manufacturers in Denmark, and began dedicating a third of his hours to the work of promoting the industry to lawmakers in Copenhagen. Through the trade association, Madsen participated in government committees with utilities and regulators planning the nation's energy future. The wind industry was employing more and more Danes, and its public profile was rising, as a promising new national champion. And then, as quickly as the industry's stock had shot up, it fell back to earth.

Seemingly everyone had gotten caught up in the California wind rush, and when the bubble burst in 1986, few were prepared. Vestas had made the mistake of financing all of their projects internally and had not established good lines of credit. When the demand from California evaporated, they were caught flat-footed. The precipitating event that would lead Vestas into insolvency was an unlucky hitch in completing a contract that set off a chain reaction of consequences. A shipping company went bankrupt while one of their vessels was carrying 80 Vestas turbines bound for the United States, to fulfill Zond's final order of 1985. The shipment sat anchored outside of the port of Houston for two weeks, unable to dock. By the time the turbines were unloaded, it was too late to install them by the end of the year, which was the deadline for receiving federal subsidies. This delay led Merrill Lynch to back out of financing the project, as their loan to Zond had been contingent on the project receiving the subsidies. Without the capital, Zond was unable to pay Vestas for the turbines. The collapse of this deal threw both companies into crisis.

When Vestas didn't get paid for the turbines, they in turn could not pay their suppliers. The company went into receivership, and its assets were sold to a group of investors, mostly the owners of other small manufacturing shops around Denmark. The Hansens departed, and a new board of directors was formed. The American market contracted severely in 1986, and so did employment at Vestas. His new role in research made Madsen inessential, and he was one of the first to be let go in March. Many more would follow. Five hundred people would be fired from the Lem factory in the course of the year.

Should the Danish manufacturers have been better prepared for this sharp decline in the California market? Admittedly, it is hard for any company to ramp up to sharply and then suddenly throw on the brakes, and keep its balance. This is especially challenging for a small company that is expanding, and in a new line of business. But it had been common knowledge around the industry since 1980 that the tax credits in California would be ending. Madsen himself had published an editorial in September 1982 in the industry magazine warning of the credits' approaching expiration. (Nielsen 2001) But Madsen had a hard time explaining why steps were not taken inside Vestas to anticipate the coming market correction. “It was stupid,” he said. “I think we believed that there would be some market. And 1987 and 1988 were an absolute disaster for us.” The owners, Madsen admitted, probably could have done more to shore up the company's finances. He specifically cited securing lines of credit in advance as a step that should have been taken. (20)

Henrik Stiesdal, who was working part-time at Vestas while attending university, was also critical of the way Vestas management handled the end of the boom years in California. “The actual chapter 11 event was handled very clumsily,” Stiesdal said. Normally, in Chapter 11 “you make sure your small suppliers are taken care of, and you pay their bills, because they are more exposed than the big suppliers. And nobody had done that. So we owed money, and not big money, but like 80,000 kroner at the hotel and 100,000 kroner at the butcher.” Stiesdal grew disillusioned with the new management at Vestas, especially at the callous firing of Madsen and other employees, and decided to leave the company himself. (21)

What had been an auspicious chapter in the early history of Danish wind power ended with a thud. But it would not be the last chapter for Vestas. The company reemerged, under new ownership, thanks to the residual home market. Danes would be the primary investors in wind power in the second half of the 1980s, breathing new life into their domestic manufacturers. It was not the first time, or the last, that Danish society supported the industry at a critical moment.

3.3 Building on Tradition

No one who has visited Denmark for more than a few days fails to understand why wind power works there. Though blessed with few natural resources, to the extent bad weather can be considered a blessing, the nation is rich in clouds, rain, and wind. Rushing in from Copenhagen harbor, slicing across the sharp northern tip of Samsø island, whistling through the grassy dunes at Thy National Park, howling across the flat expanse of a freshly plowed field in western Zealand, the wind is a constant companion. Denmark's fragmented land mass is comprised of one long peninsula and two main islands, and a total of 74 inhabited islands. The archipelago has more than 7,000 kilometers of coastline. There is nowhere you can live in Denmark and be more than an hour's drive from the ocean. Most of the country is, to use the scientific terminology, flatter than a pancake. The highest point is only 170 meters above sea level. Much of the countryside has been deforested for farmland, and the terrain is dominated by gently rolling hills. The country's total wind resources, particularly strong on the west coast and offshore, could power the entire nation many times over if fully exploited. Danes have been harvesting this resource for more than one thousand years, first to fill the sails of the longships that carried the Vikings far beyond these shores. Learning to sail remains a deeply ingrained part of growing up in Denmark, and a popular pastime, today.

Danes have been entertaining the possibility that windmills could generate electric power for more than a century, and the first practical demonstration of the concept is usually credited to Poul la Cour, a scientist and teacher who performed experiments with electricity-generating windmills, as well as a variety of other electrical technologies such as battery storage, beginning in the 1890s. He instituted a rural folk high school in southern Jutland to provide practical education in science and engineering. For la Cour, this work was part of a larger progressive political vision to promote self-sufficiency and local democracy in rural communities. "At the passing of the first patent law in 1895, they made it part of the law that processes and agricultural technologies could not be patented. Inventions should not gild individuals but be at the disposal of the people," wrote wind pioneer Preben Maegaard. “Especially Poul La Cour turned this production philosophy into reality. He was no Bill Gates.” (Maegaard 2009) La Cour always understood his innovations, and his pedagogy, to be in service of his community, the rural farmers with whom he worked. This cooperative spirit was later embraced by Tvind and the rural windmill cooperatives that sprang up in the decades that followed. Although none of la Cour's wind energy experiments had a direct commercial impact, he established a foundation of meteorological, electrical and aerodynamic knowledge on which future advances in turbine technology would be built, and he trained a generation of electrical engineers.

One of the best-known graduates of la Cour's folk high school was Johannes Juul, who carried on his teacher's legacy in wind research during the postwar period. Juul worked for a utility company, but his passion was wind power. He convinced his employer, SEAS, to support his experiments with small turbines of his own design. In 1957, with financing from a Wind Power Committee established by the association of Danish utilities, he undertook his most ambitious project, the construction of the 200 kW Gedser mill, an early example of the “Danish” design concept, and at the time the largest operating turbine in the world. From 1957 to 1967, the turbine continuously fed power to the grid without requiring maintenance. (Musgrove 2010) Despite this borderline miraculous performance record, demonstrating for the first time that wind turbines could be a reliable source of utility-grade electricity generation, the Wind Power Committee concluded that the costs of producing wind power were not competitive with traditional coal-fired power plants. Against Juul's strong objections, they decided not to pursue additional investments in wind. (Thorndahl 2009) After sustaining minor damage to its gearbox, the Gedser mill stood frozen for another decade, until NASA paid to have it recommissioned for experimental operation in 1975. The measurements collected during these experiments laid the foundation for U.S. government-sponsored research on wind power. Grassroots wind entrepreneurs in Denmark also used the data gathered in the Gedser tests to set rules of thumb for the loads their turbines should withstand. (Dykes 2013)

One noticeable benefit of the genealogy just sketched is its continuity. The lessons of Denmark's early forays into wind power were never forgotten, with each new generation absorbing the learning of the past, and using that accumulated knowledge as a launching point for their own inventions. This retention and application of experience surely contributed to the steady gains made in Danish turbine performance in the 1970s, 1980s and 1990s.

3.4 Responding to Crisis

The shock of the 1973 Arab oil embargo was a decisive turning point in the history of modern wind power, generating interest in alternative energy technologies on both sides of the Atlantic. Fuel shortages hit Denmark especially hard. At the time, the country was dependent on imported oil for more than 92 percent of its energy production. (Maegaard 2009) During the height of the oil crisis in the winter of 1974, wind energy pioneer Preben Maegaard remembered:

> There was a real concern in this country on how we could get through the winter because people were relying on heating their houses by using oil. They had all thrown out their old stoves, and we lived in modern times where oil was available, and it was a complete shock that this supply of oil was suddenly interrupted. And when you live in a cold climate here where we have these cold winters, we really feared to freeze (…) The Minister of Trade appeared Saturday evenings in

> primetime and reported on the supplies of oil and how much was in storage (…) he would tell people to go to the forest and collect some wood, and he would say you should close some of your rooms (…) and only use one room to save energy." (quoted in Dykes 2013)

Fears that rural residents would freeze to death proved overblown, and many Danes feel a tinge of nostalgia when reflecting on these years, which, consistent with the national obsession with coziness (*hygge*), they remember as a time when the commercial pace of life slowed down and friends and family huddled close together. The driving bans imposed on Sundays and the darkened storefronts were considered larks, akin to the joy children feel when a snowstorm shutters the schools.

Danish families did feel pain in their pocketbooks, with the soaring costs of home heating. In 1973, the average family's electric bill increased by 400 DKK. (Svendsen 2015) Economic growth rates dipped temporarily from 1973-1974, and again when the second oil crisis hit in 1979, but overall the national economy continued its steady upward trajectory for the remaining three decades of the twentieth century.

Although the direct impacts may not have been catastrophic, the oil crisis was a wake-up call in Denmark. Energy became a prominent issue for the first time, both for the public and for policymakers. The feeling of helplessness during the oil crisis provoked a widespread sentiment that Denmark needed to become more energy independent.

One lasting consequence of the 1973 crisis was that in the aftermath the Danish government developed the first national energy policy, and began exploring alternatives to fossil fuels. These actions were a departure from the government's previously laissez faire attitude toward the energy markets. The Danish Energy Agency (Energistyrelsen) was created in 1976, and Energy became a cabinet-level ministry in 1979. Throughout the 1970s, government officials, academic researchers, and the large utility companies favored nuclear power as the alternative of choice for the nation's future, and plans were developed to build several reactors. The first small support programs for renewable energy research were also created during this period, but establishment actors did not consider new energy technologies like wind, solar and biomass serious contenders for large-scale implementation. The first national energy plan, published in 1976, projected marginal roles for renewable energy in the coming decades, and concluded wind power was an unproven technology in need of further research. If the central planners had prevailed, several nuclear power plants might have been built in Denmark in the 1970s and 1980s. But they were unprepared for the stiff resistance they would encounter from a recalcitrant public.

Under the leadership of nuclear physicist and national hero Niels Bohr, a nuclear research center was established outside Copenhagen in Risø in the late 1950s. Two test reactors were built on the small peninsula jutting out into Roskilde Fjord. In 1974, ELSAM, the association of utility companies in Western Denmark, proposed building a nuclear power plant in Jutland. “You can discuss as much as you want,” the director of ELSAM told local residents at a public meeting, “but atomic power you will get anyway.” (Jørgensen and Karnøe 1995)

Public opinion was opposed to nuclear power, at least partly as a legacy of campaigns against nuclear weapons, and partly due to the popularity of the environmental movement, with groups like the Danish chapter of Friends of the Earth being among the first to speak out against the nuclear plans. Erik Grove Nielsen, who would later become the primary blade supplier to Danish turbine manufacturers during the California wind rush, was involved with Friends of the Earth at the time. Nielsen, who was raised on a Jutland pig farm, described the attitudes of grassroots activists toward the nuclear lobby: "My grandfather was a Christian missionary in Nigeria. Thus fighting for an idea was nothing new to me," Nielsen wrote. "We did not agree on that idea, and we wanted to work for alternatives to nuclear power … We wanted to create new products for a greener planet, and we never asked if our goals were realistic." (Nielsen 2013)

This attitude was characteristic of the pragmatic political culture, prevalent in rural Denmark, that spurred idealistic hobbyists to successfully innovate a range of environmentally-friendly technologies in the 1970s. Danes like to think of themselves as more doers than dreamers. Idealism is almost always mixed with practical problem-solving. Perhaps because it is a small country with a strong agricultural heritage, Danish politics embody many of the virtues of Jeffersonian local democracy. Individual liberty and initiative are prized, as well as self-sufficiency and economy. These liberal traits are combined with strong commitments to social equality, loyalty, and responsibility to the community. Bragging, conspicuous displays of wealth, or otherwise acting superior to one's neighbors are met with frank disapproval, as are other violations of community norms. Individuals feel obligated to contribute their fair share to the maintenance of society, and expect their government, in return, to prioritize social welfare. Confronted with the crisis of the oil embargo, growing environmental consciousness, and fears about nuclear power, ordinary Danes decided to take matters into their own hands, and remake the state and utility energy establishment from the outside-in.

In 1974, environmental activists formed the Organization for Information about Atomic Power (OOA), which quickly grew into a nationwide social movement, and would play a critical role both in supporting renewable energy innovation and derailing the government's nuclear agenda. The success of the OOA in generating opposition to nuclear power can be attributed to two strategic decisions, according to scholars Ulrik Jørgensen and Peter Karnøe. First, the OOA avoided associating its message with leftist politics, and instead framed their arguments in terms of the popular "vision of a self-sufficient local community with the idyllic village as the typical motif." They drew on the language of the appropriate technology movement and associated nuclear energy with the centralization of political power, the growth of monopolies and regulation, technocracy, mass production, and a consumer society. While waging battle against centralized energy production in the arena of public opinion, the OOA simultaneously pursued institutional means of shaping policy, forming partnerships with other civil society organizations, convincing members of Parliament and political parties to support the cause, enlisting academics to publish reports, and placing members on the oversight committees for government energy programs. This ability of lay citizens to influence national policy by serving on one of numerous public committees is a distinctive feature of Danish government, with its traditions of transparency and public debate, and one the OOA effectively leveraged. (Jørgensen and Karnøe 1995)

All of this organizing turned the tide against nuclear power in the latter half of the decade. The first sign of the nuclear consensus unraveling came when OOA pressure resulted in the creation of a new requirement for Parliamentary approval of any plans for a nuclear power plant, taking the decision out of the hands of utility managers and the state bureaucracy and turning it into a political football. The meltdown at the Three Mile Island facility in Pennsylvania was the final straw that turned public opinion in Denmark against nuclear power for good. Though the Danish government never officially banned nuclear power, efforts to develop nuclear technology were quietly abandoned in the 1980s, and the test reactors at Risø were decommissioned. By the mid-1980s, contributions from nuclear energy had disappeared from projections in official energy plans. (Jørgensen and Karnøe 1995) According to former energy minister Rasmus Helveg Petersen, although government research and planning for nuclear power stations was considerably advanced, public pressure made it “politically impossible” to move forward with those plans. (22) With the nuclear option off the table after the 1970s, energy planners were forced to consider new alternative generation sources. Pursuing nuclear energy has remained politically toxic, though renewed fears about energy security after Russia’s invasion of Ukraine may be softening attitudes somewhat. As recently as 2007, three quarters of Danes opposed nuclear power. But a 2022 survey conducted by the country’s most prominent polling firm found 46% were in favor of building nuclear power plants in Denmark. (Surwillo 2022) Although nuclear is now being discussed more openly in parliament than it has been in decades, the current climate minister recently told reporters that reactors on Danish soil remain “simply a no-go.” (The Local 2023)

Technology researcher Peter Karnøe suggested that the Danish nuclear effort might have succeeded if it had moved forward more aggressively during a window of opportunity in the 1960s, but a series of setbacks like the need for an electrical cable connecting the island of Zealand to the Jutland peninsula and disagreement about the preferred reactor type delayed development, allowing the anti-nuclear movement to mobilize. (23) Other sources claim the utilities soured on nuclear as the costs of building reactors ballooned. But everyone gives enormous credit to the grassroots activism, led by the OOA, in making nuclear energy politically unpalatable.

3.5 Getting Organized

There is an oft-repeated joke in Denmark, one version of which goes something like this: Two strangers meet in a train car and strike up a conversation. By the time they arrive at their station, they have started an organization. The joke captures the Danish proclivity to join clubs and committees, but also a cooperative spirit of problem-solving that was an essential ingredient in the success of wind energy development.

By 1970, utility interest in wind power had dissipated, and the only people in Denmark actively experimenting with turbine technology were amateur hobbyists who had little or no technical expertise, and no background designing windmills. Enthusiasts relied on do-it-yourself manuals for building backyard turbines, like Swede Bengt Södergaard's *Vindkraftbogen* (the same book Birger Madsen had received as a Christmas gift). Many of the first prototypes were assembled in small machine shops, like the Herborg turbine built by blacksmith Karl Erik Jørgensen. These small, independent producers lacked a network to disseminate and improve their designs.

The OOA provided a critical assist with their organizational muscle. Some OOA members felt their anti-nuclear message needed to be supplemented with practical demonstrations of alternative technologies, so, naturally, they created a new spin-off group in 1975, the Organization for Renewable Energy (OVE). In the following years, OVE hosted information fairs around the country, providing a forum for renewable energy enthusiasts to meet and share the latest knowledge about developments in technology. The OVE gatherings brought together local residents, mostly rural homeowners who might be interested in installing a household windmill, or neighbors' associations, and the leaders of the pockets of grassroots efforts trying to build the first modern turbines, including the windmill group from Tvind and the Northwestern Jutland Institute for Renewable Energy (NIVE). NIVE organizer Preben Maegaard described attendance at a 1978 OVE meeting in the following terms:

> Professional associations, trade promotion officers, manufacturers, consumers' organisations, politicians and researchers as well as energy secretariats, consumers' foundations and associations and people who were building their own windmills, were among the participants. It is beyond doubt that this get-together was epoch-making for wind power. (Maegaard 2013)

The NIVE group were a little like their contemporaries in the garages of Silicon Valley, back in the days when Bill Gates and Steve Jobs were still friends. Though they were little known at the time, the members would become major figures in the new wind industry. A loosely-associated collective of inventors with big ideas and some talent from around Jutland, NIVE counted among its members Maegaard, one of the political visionaries of the young renewable energy movement, blade manufacturer Erik Grove Nielsen, and Henrik Stiesdal, the teenager who had engineered the first Vestas turbine, the first of many he would build at Vestas and later Bonus. The NIVE team decided to collaborate on a 22 kW turbine in 1976, on a design by Maegaard with input from Stiesdal and others, that became a classic and much-copied example of the Danish concept. The turbine embodied the sturdy characteristics that would be typical of the lumbering Danish workhorses throughout the 1980s—it was designed around the conservative rules of thumb derived from the Gedser Mill readings. The clunkiness, though, was intentional, engineering out of an abundance of caution, in the absence of firm knowledge about the kinds of loads the components would have to withstand. (24)

The manner in which the NIVE team worked is illustrative of what has since been labeled a "bottom-up" development style. Although by the late 1970s, many of the members were making their livings in wind energy businesses, instead of competing with one another, they pooled their talents and collaborated to advance the technology. Maegaard saw himself as continuing the tradition of Poul la Cour, and sought to empower rural residents to provide for their own energy needs. A genius of the NIVE design was that it was intended to be copied—the technical specifications were literally an open book. The team essentially gave away the intellectual property they created to all takers. The development effort was deeply embedded in the farming communities of western Jutland. The NIVE team worked in conjunction with, rather than in isolation from, their communities, and drew on those personal connections to spread their work. They cultivated relationships with a variety of local companies and blacksmiths, and entered into a partnership with the Danish Blacksmith's Association to publish manuals on how to build a "blacksmith's" turbine. Maegaard actually traveled around the country to small manufacturing firms and invited them to put the turbine design into production. The design spread widely and was incorporated by numerous small companies and several larger manufacturers, including Wind World and Nordex, throughout the 1980s. (Christensen 2013) The conservative design of the NIVE turbine was appealing to the small Danish manufacturers who were the main adopters, Maegaard explained, in part because of the personal relationships these companies had with their customers:

> These blacksmiths here were selling to their local clients, and if they lose confidence, it could be a disaster of course. So we would rather use too much

> material, make it too strong, than to lose confidence in the use of it. I think this was an important principle to have, because these wind turbines set the standard of high reliability. (quoted in Dykes 2013)

Those first generation Danish turbines were reliable, in part, because they had to be. They weren't being built with government dollars for some remote test site. They weren't being sold to doctors as tax avoidance schemes. They were being installed in the backyards of people who were counting on the machines to offset enough of their household heating budget to repay the bank loan. The sellers were typically on a first-name basis with their customers, and could expect to hear about it if the products underperformed. The importance of these personal relationships should not be overlooked. Jutland in the 1970s did not have a lot of booming urban centers. The agricultural economies of small-town Denmark relied on trust and fairness. There were a lot handshake deals. The first customer base for Danish wind turbines, and the customer base that remained when the California windfall evaporated, were rural residents, farmers and cooperatives. These early adopters helped the wind industry get off the ground, and were a valuable test audience, providing a constant stream of feedback to one another and to the manufacturers, which made possible quick responses to design flaws and the steady improvement of turbine technology.

This familiarity with the customer base was a huge boost to the firms that began manufacturing turbines in the early 1980s. The wind industry in Denmark grew directly out of the agricultural machinery industry. The history of Vestas recounted above is exceptional in its drama and in the eventual success of the brand, but many aspects of the Vestas' story were also typical of the firms that entered the wind market at this time. Agricultural machine shops were experiencing an industry-wide recession, and wind turbines looked like a promising product for companies trying to drum up new business, and one that would allow them to draw on their existing capacities. Nordtank built storage tanks for oil trucks, but the oil crisis eliminated the demand for new tanker trucks, so Nordtank got into the wind business. The company was able to draw on its experience welding and rolling steel to produce the first tubular steel towers, an innovation that would later be adopted as the standard around the industry, replacing the lattice towers common in 1980s. A third Danish firm, Danregn, sold irrigation equipment to farms. In 1981 they decide to build wind turbines under the name "Bonus." By this route, the agricultural and heavy machinery sectors formed the supply chain of early turbine parts in Denmark, which was partly responsible for the burly, rugged construction that became synonymous with Danish design. The first production line of Vestas turbines was constructed entirely from off-the-rack machine parts designed for other applications. Only the rotor blades were custom designed. Other custom components were slowly introduced through the years in close consultation with agricultural suppliers. And the fact that the first turbine manufacturers were established in the agricultural sector helped enormously with sales, as the brands were known and trusted by customers. This brand loyalty has allowed Danish manufacturers to thoroughly dominate their home turf. Despite liberal European trade policies that require level competition, no foreign manufacturer has ever sold a utility-scale turbine in Denmark.

The first adopters typically had one of two motives for purchasing a wind turbine. Some were political idealists, who saw wind power as a route to energy independence, local democracy, or environmental sustainability. The rest were concerned primarily with home economics, and rising electricity rates throughout the 1970s certainly made wind power look more attractive. Usually, some mixture of these two motives was involved. Birger Madsen remembered making sales presentations to community groups in those early years at Vestas. “I never heard at that time, anyone say, that 'I think it is a bad profit on the investment' … they had no interest in making a profit,” Madsen said. “If they could pay their energy bills, they were satisfied.” (25)

No buyers typified the unique character of the Danish wind market in the 1980s more than the local cooperatives established by groups of neighbors to collectively purchase a turbine. When a cooperative was formed, shares could be purchased for a few thousand kroner (a few hundred USD). A single turbine or a small cluster of turbines would then be raised, usually on the land of a local farmer, usually a shareholder, and managed by an elected board of directors. This method of energy development was uniquely Danish, though its success has led to many attempts to mimic the form in other countries. Forming a cooperative was not a radical experiment for these rural Danes. It came naturally to them; they had been creating cooperatives for more than century, either to share the burden of a large farm expense like a tractor, or to start a business selling agricultural products. Cooperative dairies and slaughterhouses and similar farm businesses have long been a staple of the Danish economy. The prominence of these community cooperatives has declined with the expansion of industrialization and demographic shifts that are pulling more residents to the cities, but many Danish businesses remain cooperatively-owned, including many local electric companies, and one of the nation's largest grocery-store brands.

Windmill cooperatives were a relatively uncomplicated financial proposition in the 1980s, as was small turbine installation generally, thanks to a banking culture that was comfortable making loans to private individuals on these largely unproven machines. Community banks—of which there were many around Denmark at the time—were used to financing cooperative ventures, and making loans to farmers. While securing bank financing was a major impediment in places like the United States, the small projects undertaken in Denmark were not considered a particularly novel or risky investment. According to Henrik Stiesdal, in those early years private citizens could often purchase a turbine without having to put any money down. He recalled one instance at Bonus in which they sold a man a 600 kW turbine, with the utility, bank loan, and turbine contracts all pre-drawn. The loan would be repaid within 7-8 years, and after that, the owner could make as much as DKK 1 million per year. “He didn't have to pay anything, we arranged everything, he just put his signature on three documents,” Stiesdal said. “That's kind of good money for the effort.” (26)

The ready availability of financing at this time was partly a consequence of the manageable scale of the turbines and wind farms being built. Today, wind farms cost millions and billions of dollars, and involve a tangled web of lawyers, lenders, accountants and insurers. But in the 1980s, a small turbine was within the reach of a private individual, and could be purchased by borrowing against an existing mortgage.

The first person to sell turbines commercially in Jutland was Christian Risaager, a carpenter who built his own machine at home, plugged it into the grid without permission, and watched his meter start running backwards. (Maegaard 2009) Risaager put his design into production in 1975 with assistance from local blacksmiths. The first one he sold, providentially, was to a journalist named Torgny Møller, who had recently purchased a home on a windy parcel of land near the coast. The Risaager turbine worked as advertised, and Møller became the wind industry's chief evangelist when he started the influential magazine *Naturlig Energi* (discussed further in Chapter 4).

Møller also played a leading role in establishing, with other wind enthusiasts, the Danish Windmill Owner's Association (Danmarks Vindmølleforening, DVF). "The importance of this association," Henrik Stiesdal later wrote, "for the development of wind energy cannot be overestimated." (Stiesdal 2013) At its height in the 1980s, the owner's association counted more than 150,000 Danish households as members. Among the many ways the owner's association helped solidify the burgeoning wind energy network, perhaps the most significant was that members submitted production data and accident reports on their turbines each month, and the results were published in *Naturlig Energi*. These independent consumer reports gave observers (including potential buyers) unbiased information about which turbine designs were performing well, and which were performing badly. The owner's association also communicated with the industry about member concerns, and was particularly influential in pressuring manufacturers to adopt safety features, such as redundant braking mechanisms that would prevent the turbine rotor from destroying itself (and possibly its owner) in the event of an accident.

The owner's association also formed a potent interest group. Together with the manufacturer's association, founded in 1981, and the Nordic Folkecenter for Renewable Energy, founded in 1983 by Preben Maegaard, the owner's association successfully lobbied for changes to national policy that were tailored to give the wind sector the support it needed at each stage of development. Throughout the 1980s, members of each of these organizations sat on government committees and actively participated in shaping energy policy. The associations also pressured members of Parliament directly through their memberships, in the press, and with standard lobbying practices. As the profile of the wind industry rose, government officials began to realize that not only was wind power a homegrown and environmentally-friendly alternative to fossil fuels, but also a growing industrial force, a job creator and an export opportunity. And a not-insubstantial portion of the population was directly invested in the technology. Policy tools to nurture this budding industry followed, but the initial push for those policies had come from the grassroots organizations.

3.6 State Intervention

Few sectors of the economy are more sensitive to shifts in government policy than energy markets. The Danish government cannot claim credit for launching the wind industry—that honor belongs to the rural entrepreneurs discussed above—but the Parliament and state bureaucracy in Copenhagen did eventually implement supportive conditions that allowed that young industry to flourish in the 1980s and beyond.

Prior to that point, state investment in wind technology had been sporadic, and focused on demonstration projects. Most of the government money allocated to wind research went to partnerships with the large utilities. The biggest ticket expenditures were attempts to construct multi-megawatt turbines, similar to the government-led research efforts underway in Germany and the United States. But just like in Germany and the United States, these investments in the Gedser Mill and in two large turbines near the town of Nibe, built in 1979, failed to create commercial interest.

But two state-sponsored programs did pay enormous dividends in the 1980s. The first was the creation of a small turbine testing center at Risø, the former nuclear laboratory. The government tasked Risø staff with developing certification standards for turbines, and made only Risø-certified turbines eligible for tax subsidies. Among the first turbines tested at Risø were the Riisager, Herborg, and NIVE machines. The performance and design characteristics of these turbines set the baseline standards by which all future Danish windmills would be evaluated, thus helping entrench the "Danish concept." The fact that all Danish turbines were expected to meet the criteria set by Risø contributed to the standardization of design around the industry, and the testing, which in the first years was free of charge, helped turbine engineers identify problem areas and refine their concepts. This arrangement was relatively informal—the design standards were not overly specific, and Risø staff did not share proprietary information about particular turbine designs with competing firms—but proved highly effective at disseminating general information about best practices. Through frequent communication with the manufacturers, Risø staffers were able to gently direct companies toward the state-of-the-art in turbine design, particularly on safety features. The involvement of Risø had a major impact on making Danish technology more consistent, and consistently reliable. The Risø seal of approval also gave manufacturers a leg up on the export market, helping them secure financing and contracts, as no other country had instituted comparable independent quality control.

Risø researchers made another important contribution in producing the first Danish Wind Atlas, and later a European Wind Atlas. At a time when the meteorological science of wind energy resources was still being developed, the Wind Atlas relied on simple calculations to help turbine developers determine the best locations to site their turbines. Today, more sophisticated site analysis tools are available, and the industry does most of its own testing and certification. But Risø, now administered by the Danish Technical University's wind engineering department, remains a test site for next-generation turbine concepts and a world-renowned center of research expertise.

The Risø certification program was introduced in concert with the first national subsidy program in 1979, which provided owners with grants to cover up to 30% of the costs of installing a wind turbine. (Gipe 1995, 30) This incentive ensured that there would be a market for the turbines Danish manufacturers were producing. Today, the Danish home market is of little more than symbolic importance to firms the size of Vestas and Siemens, which ship the majority of their turbines to larger markets around the globe, like the United States, Brazil, and China. But the stability of the home market, buoyed by that first investment subsidy, was a crucial incubator in the industry's early years, and allowed novice turbine builders to gain practical experience. American entrepreneurs enjoyed no such built-in safety net in the years before, or after, the California boom. Danish wind technology might have made its name in California, but first it had been nursed, and later was sustained, in the fields of Jutland. It's hard to imagine the Danish industry would have survived the 1980s, or even have been in a position to compete in Californa in the first place, without this supportive home market being fed by the government subsidy program. Although the investment subsidy would not last and longer-term policy support would be uneven, with the particulars of support schemes continuously shifting through the decades, as the industry recovered from the shock of the California bust, the nurturing home environment would help it chart a path of global ascendency.

4.7 Conclusion: From Development Styles to Developing Niches

The concept of style seduces with its ability to bracket all the caveats, the complications, the contingencies that tend to multiply the closer one looks at historical events. It would be so much easier if the success of Danish wind technology could be attributed to its distinctive style, and call it a day. It would save the effort of combing through so much history, from the oil crisis to the alphabet soup of the OOA and OVE and DVF, to Risø and Riisager, to the blacksmiths and Bonus. It would make for more direct answers to questions like how and why it happened here, and how Danish turbines were so reliable. Unfortunately, it is difficult to boil down this story into a buzzy catchphrase, and do justice to the variety of conditions and components that contributed to Danish success with wind power beginning in the late 1970s. It will not be enough to say the Danes pursued a “bottom-up” development strategy. Nor will it suffice to describe it as a “bricolage” approach, characterized by a dispersion of “embedded” agency through multiple actors in a network that proved superior to the American “breakthrough” strategy, as Peter Karnøe has proposed. (Garud and Karnøe 2003) These are both fine observations about characteristics of the Danish wind energy network during this period, but at best each presents just one piece of a larger puzzle. There's a risk that this focus on the intentional strategies of system engineers, which so much of the sociotechnical systems literature encourages, is liable to miss all of the surrounding conditions—the culture, the weather, the local economy, the political scene—that are so decisive in whether or not a new invention survives long enough to acquire a style. If technological style is understood in the sense Thomas Hughes used it, as the adaptations a technological system makes to its local context, then the peculiar characteristics a particular technology exhibits beg a prior question: what in the environment produced these adaptations? While the emphasis on style wraps technologies in a pretty package, it simultaneously strips them of the context needed to understand their evolution.

It's hard to give a succinct explanation for the success of Danish wind technology because that success was overdetermined. Many fortuitous or foresighted decisions were taken by wind system actors. Innovators came to the table with groundbreaking designs for new machines, and they had arrived at just the right time, in just right place. The table was set. Everything Danish wind entrepreneurs needed to expand and refine their technology was ready at hand—a familiar customer base, financing, spare industrial capacity, social movements drumming up political support, a government ready to listen and enact supportive policies. The better historical accounts tend to recognize that Denmark in the mid-1970s was almost the ideal environment for a renewable energy system to get off the ground. As social scientist Kristian Hvidtfelt Nielsen concluded in a publication of Poul la Cour's museum:

> Danish wind turbine technology succeeded because of favourable historical, political, and institutional conditions in Denmark, but also because the people were involved to a much larger extent than elsewhere, cooperating with and learning from each other. Undoubtedly, the small size of the country in terms of population and geography provided yet another advantageous circumstance as did its windiness. (Nielsen 2009)

Appeals to "advantageous circumstance" have the unsatisfying ring of pure chance, but that's misleading. One helpful aspect of the technological systems theories favored by the likes of Nielsen and Karnøe is that their network terminology allows for the "conditions" in which a technology develops to be understood in spatial, relational and structural terms, as interrconnected networks of actors, and networks of networks, all sewn together in a complex arrangement of interdependencies, what Hughes described as the "seamless web" of social systems. From this network perspective, the circumstances Nielsen is describing are the mostly social, but also material, infrastructure that had been built up surrounding the wind energy network, the configuration of the environment in which the developing wind system was embedded. If circumstances can be characterized in structural terms, then they no longer have to be entrusted to the realm of fate, of historical happenstance, beyond human understanding. They can be mapped, and maybe even molded.

Nielsen remarks on a noteworthy characteristic of the wind network interconnections in Denmark—the depth of community involvement, the amount of cooperation. This observation suggests that network growth can be measured not just in terms of its size—either its reach or the number of actors involved—but also by the degree of its embeddedness in its environment, the number and range of different connections to surrounding networks, and the strength of those connections. Symbiotic relationships, connections that are "win-win" for two or more parties, would be expected to add strength to the network. Negative externalities would make it more brittle, vulnerable, perhaps open it up to outside challenges. A technological network with a high density of internal connections might be more resilient to external shocks, but integration with other networks in the environment can have the same buffering effect, as well as a nurturing influence. This proposition has analogues in ecological science, such as the "diversity-stability" hypothesis, which predicts that ecosystems containing a greater number of species are better able to weather disasters such as fires, floods and droughts. (Dunn 2021, 153) The wind network in Denmark has historically possessed this kind of internal diversity and dense interconnection, and it has also been well-connected to the surrounding social landscape. An apt descriptor of the structure of the network in the early decades of development would be “close-knit.” It remains to be examined how well that configuration has been maintained over time.

Still, as intriguing as concepts of network density and environmental integration may be for thinking about system development, no one dimension of the Danish development history can be said to have been decisive in how the wind energy network evolved. The creation of a close-knit development community is no more sufficient to explain this evolution than the adoption of a superior approach to turbine engineering. Rather than trying to isolate causal variables, understanding the factors that contribute to the dynamics of network change is about piling on layers. The more of these factors that can be accounted for together, the more completely the picture comes into view. No real-world system is a closed system, so it's a quixotic errand to attempt to uncover the full universe of potentially interacting variables, but the more the major components can be described, the more fully the system dynamics can be appreciated.

This systemic point of view has implications for technology management, and for designing policies to encourage technological innovation. There can be no one-size-fits-all recipe for success; interventions are more likely to have the desired effects if they are tailored to the specific local context. So for the many nations currently attempting to integrate more renewable sources into their energy mix, it's not enough to simply copy what has worked in Denmark. Wind power has made significant inroads in Denmark in large part because the specific development path pursued has been a good fit with the local resources, needs, and culture. As an example of adapting development strategies to the opportunities presented and the limits imposed by the context of implementation, consider the two different pathways of early wind turbine experiments in Denmark. The government and utility-led efforts to build large, multi-MW turbines were doomed from the start. Government R&D programs around the world not only suffered from their own hubris, ignoring the substantial gaps in their knowledge of wind turbine engineering. There was also no way to square these marginal, distributed generation sources with the economic and organizational logics of utility managers, who were used to operating large, centralized coal plants. The "business case" for wind energy was never likely to make sense in that context. The humbler development effort that took shape in the countryside, on the other hand, was always attuned to the practicalities of local circumstances. The turbine designs reflected the lack of technical expertise, and the necessity of relying on the materials at hand. They took advantage of existing manufacturing capacities and business networks, and were aligned with the economic interests of rural homeowners, concerned primarily with supplying heat and electricity for domestic consumption. The first generation of turbines were uncomplicated enough that they could be operated, and in most cases maintained, by private individuals with no prior experience.

Another lesson from the early decades of wind turbine development is that simple policy mechanisms are less likely to make an impact than comprehensive, inclusive strategies. No government was able to create a sustainable wind sector by simply throwing money at the problem. When the California bubble burst, it revealed how thinly wind technology had been integrated into the American energy system. In Denmark, a much more robust support network was assembled around wind technology. By the mid-1980s already, wind power was becoming an entrenched part of rural Danish culture. The work of promoting a new energy technology cannot be an activity carried out solely by formal policy actors using formal policy tools. Policy goals are more easily achieved when they are crafted in coordination with industry and community actors. Establishing a new technological regime requires a multi-pronged approach, fostering networks of collaborators, seeking out symbiotic partnerships, building the infrastructure the system needs to function.

One perceived shortcoming of systems perspectives on technological change is that they ignore agency, making actors subject to abstract structural forces. It is true that some of the characteristics of technological networks, and some of the shocks that ripple through them, cannot be easily controlled. The Arab oil embargo and the California wind rush are two signposts in the history of wind energy that had far-reaching consequences, but originated deep in the environmental background, and were in no direct way occasioned by wind energy activities in Denmark. They were social phenomena—and thus cannot be discounted as mere “acts of God”—but events of the sort that Danish wind enthusiasts would have had great difficulty anticipating or in a significant way directing. These are classic examples of the sort of environmental turbulence to which technological networks are exposed, but which system managers cannot easily control. The complex interactions that occur within large technological systems, and between technologies and their environments, also make it all-but impossible to predict system dynamics with a high degree of accuracy.

These properties of technological systems do not, however, make humans powerless to shape them. It might not be possible to say for certain that any condition or set of conditions can guarantee that a technology will flourish, but outcomes become increasingly likely as support structures combine and overlap, as network connections accumulate. Although it's impossible to know exactly where and when lightning will strike, it can be determined where and when a lightning strike is likely to start a forest fire, and take steps to manage that ecosystem.

By 1980, the environment in Denmark was primed with kindling to ignite the expansion of wind power. Perhaps the simplest way to explain the success of Danish wind technology is to say that Denmark provided good turbine habitat. As Danish-American historian Andrew Jamison has concluded, compared to other Scandinavian nations in the 1970s, Denmark "provided more fertile ground in which a popular energy movement could grow." (Jamison 1977) This fertile ground included epistemic, organizational and cultural resources, as well as the constraints of geography and climate. Some of that habitat predated efforts to launch a wind industry in the 1970s. But system actors also played a role in adapting the technology to that habitat, and in expanding and fortifying that habitat. Wind turbines found a supportive niche in the Danish countryside, but that niche didn't simply appear out of nowhere, rather, it was purposefully created and maintained.

The concept of a technological niche is popular in the innovation studies literature, though there is no apparent consensus on how this somewhat slippery construct should be defined, and it is more frequently described in the reverse terms, as "niche technology." In contrast to mainstream or dominant technologies, niche technologies are in an early stage of development or have not been widely adopted; they are considered immature, not ready for primetime. Frank Geels describes niches in similar terms as "protected spaces," shielded from "mainstream market selection." (Geels 2004) The images he seems to have in mind are the classic business incubator, the research laboratory, or the startup company with seed capital. In the Multi-Level Perspective schema, niches are systems in their own right, composed of actors and rules structuring their interactions, but these institutional arrangements are less fully-formed than when a niche stabilizes into a regime. Niches are systems still in the process of formation, still undergoing developmental churn, and the implication is that they must be isolated from the surrounding environment in order to survive.

But this conception of niches as protected spaces does not adequately describe the development of wind technology in Denmark. Early-stage innovations were shaped in numerous ways by environmental conditions, even depended on the surrounding environment for support. It was precisely the large-scale wind turbines built as scientific experiments, and sheltered from the context of use, which failed to produce viable technology.

The niche concept can do more work in explaining the differences between successful and failed technologies if it is not treated as a special type of network, but, instead, used to describe the relationships between a technology and its environment. This definition of a niche is more properly ecological, and closer in spirit to what Joseph Grinnell intended when he originally proposed the niche concept to describe the complementarity between a species' traits and its habitat. (Grinnell 1917) The difference between the Grinnellian niche concept and Hughes' “technological style,” is primarily a matter of emphasis. Style, for Hughes, like a niche technology for Geels, describes a particular configuration of a technological system, rather than the fit between the system and its environment. What is needed is a recalibration of technological systems theory, to counterbalance the tendency to focus on internal system dynamics and the choices of system managers, and to bring more clearly into view the ways in which these decisions are responses to the environmental contexts in which they are made. That requires having a fairly detailed understanding of the environmental landscape, and studying technology *in situ*, not as an isolated system but in its association with its environment.

This approach may be more complicated, but one benefit is that it helps clarify why some technological innovations seem to be better-timed than others. Geels talks about windows of opportunity as arising from misalignments of components within the dominant technological regime. This perspective suggests that a niche technology will find opportunities to break out when a dominant regime is destabilized. While it's true that the oil crises of the 1970s shocked the energy establishments in many countries, that doesn't explain why wind technology prospered in Denmark, while the initial interest died out in countries like the United States. A more ecological point of view recognizes that it was not merely instability in the energy system—which was one condition among many—but the alignment of the broader socioecological environment that facilitated this transition. The seeds of a wind energy system were planted in fertile soil in Denmark. In the United States, no similar support infrastructure had yet been developed, and this is the sense in which it was not yet the “right time” for wind technology in America.

This reorientation of technological systems theory is not intended to deny the importance of agency in technological change. For one thing, it suggests that actors can, to some extent, create their own luck by laying the groundwork to encourage technological developments. It also recognizes that technological niches rarely develop without these kinds of purposeful efforts. The hardworking grassroots activists, community associations and entrepreneurs deserve enormous credit for kickstarting the renewable energy movement in Denmark. These were the people who demonstrated to Danish society that wind power was a viable energy option for their country, when few others believed in its potential.

The range of environmental influences on the history of wind energy development is widely varied—from resource availability, to social geography, to exogenous economic and political events like the California wind boom. Danish wind entrepreneurs did not create these circumstances, but they were well-positioned to benefit from them. And when the opportunity arose, they did not let it pass. Some brave people took big risks to transform an inspiring vision into a realized energy landscape. The next chapter takes a closer look at these pioneers.

Figure 3.1 Birger Madsen examines a second-generation Vestas nacelle at a warehouse in Lem, Denmark in 2015. In the background sits the main rotor shaft of Vestas' first production model, the HVK-10 "Herborg" turbine designed by Henrik Stiesdal and Karl Erik Jørgensen (see Chapter 4).

Figure 3.2 A collection of early Danish wind turbine designs at the Nordic Folkecenter for Renewable Energy in Hurup Thy, Denmark.

Notes

1. Employment statistics compiled by the American Wind Energy Association and the European Wind Energy Association, and published online at www.awea.org and www.ewea.org, respectively. Investment data from Bloomberg New Energy Finance 2016. A full list of the Global Fortune 500 is available online at www.fortune.com/global. Companies on the list with significant wind energy investments include the likes of, but are not limited to, General Electric, Siemens, Mitsubishi, Bank of America, HSBC, Goldman Sachs, TEPCO, EDF, Walmart and Unilever. It is almost *de rigueur* at present for any large manufacturer to offset some percentage of its carbon footprint by investing in a wind farm.

2. As of 2015, Denmark had the highest rate of electricity production from wind power per capita, at 42% of total electricity demand, and Jutland has the highest concentration of wind turbines in Denmark.

3. This explanation for U.S. Windpower's relative success was posited during personal communication with several sources who had direct experience in the California wind market during the 1980s, including Walt Musial, now director of offshore wind research at the National Renewable Energy Laboratory in Colorado.

4. A detailed comparison of the weights of various Danish and American turbine designs can be found in Heymann, 1998.

5. Descriptions from personal communication with Brian Kuhn, Aeronautica Windpower, August 2014, and from Gipe 1995, respectively.

6. From personal communication with James Manwell, Amherst, Massachusetts, August 2014.

7. From personal communication with Walt Musial, National Renewable Energy Laboratory, August 2014.

8. From personal communication with James Manwell, Amherst, Massachusetts, August 2014.

9. Niels Sønder, “Numerous Small Hitches in January,” *Windpower Monthly*, March 1986.

10. From personal communication with Mike Edds, Amherst, Massachusetts, June 2014.

11. From personal communication with Birger Madsen. Lem, Denmark, May 2015.

12. ibid.

13. ibid.

14. ibid.

15. ibid.

16. ibid.

17. From the “Vestas” section of Erik Grove Nielsen's early turbine catalog on his “Winds of Change” website, http://www.windsofchange.dk/WOC-danturb.php.

18. From personal communication with Birger Madsen. Lem, Denmark, May 2015.

19. From personal communication with Bob Zdebski, 2014.

20. From personal communication with Birger Madsen. Lem, Denmark, May 2015.

21. From personal communication with Henrik Stiesdal, Odense, Denmark, May 2015.

22. From personal communication with Rasmus Helveg Petersen, Copenhagen, Denmark, August 2015.

23. From personal communication with Peter Karnøe, Copenhagen, Denmark, June 2015.

24. From personal communication with Birger Madsen. Lem, Denmark, May 2015.

25. ibid.

26. From personal communication with Henrik Stiesdal, Odense, Denmark, June 2016.

CHAPTER 4

PIONEERS: THE WIND ENERGY NETWORK TAKES SHAPE

4.1 The Boy Genius and the Blacksmith

The weather was perfect that day for a long bicycle ride through the English Midlands—sunny, not too windy—as a young Henrik Stiesdal pedaled north from Lincolnshire toward Hull. After graduating high school in 1976, Stiesdal had nine months free before the beginning of his compulsory military service, so he had decided to spend some of that time exploring England on his bicycle, sleeping in youth hostels, meeting new people. Stiesdal's route that morning took him past several of the large coal-fired power plants dotting this industrialized landscape near the River Trent, their colossal cooling towers belching steam into the spotless sky. As Stiesdal passed beside one of these towers, the cloud of steam did not dissipate, but spread above his head like a gathering storm. Although he could still see blue farther out on the horizon, from about noon on he rode beneath this overcast sky.

"That was a sort of a turning moment, when I thought, this is not right. It is not proper," Stiesdal recalled, decades later. "This human-made thing creates a change in the local weather that's unpleasant and cold. In hindsight, it was a small thing, but for me there, it kind of sharpened my senses." (1)

When Stiesdal returned to the family farm near Herning, Denmark for Christmas that year, he relayed his experiences in England to his parents, and his father suggested they take a short drive to visit the Tvind School in Ulfborg, where a small army of idealists were constructing a huge windmill, garnering national headlines. Stiesdal said he found the visit to Tvind "fascinating;" he shared the group's antipathy toward nuclear energy and admired them for "doing their own thing." (2) During several visits with the Tvind activists he began collecting information on how to build his own windmill, including a copy of the recently-published handbook *Sol og Vind* (Sun and Wind) by Claus Nybroe and Carl Herforth, which became something of a bible to the grassroots renewable energy movement. (Stiesdal 2013, 268) Over the Christmas holiday, Stiesdal began tinkering in his father's workshop and cobbled together a small two-blade propeller by gluing and planing some spare wood boards, which he then mounted to a handheld metal shaft. When he pointed his homemade rotor into the wind, at first nothing happened. But after another half day of adjustments, suddenly "all hell broke loose." (3) Just holding the handle would heat his palms as the rotor spun wildly, up to 500 revolutions per minute. (Stiesdal 2013, 269)

"It was so powerful on a windy day, and that was very intoxicating. You got some very immediate, hands-on feeling out of that thing … it felt alive," Stiesdal said. (4) This experiment gave Stiesdal his first lesson in wind turbine aerodynamics, and the loads he could feel from the jerky side-to-side motion of his two-blade propeller was one of the experiences that would lead him to adopt a three-blade design in the coming years. A similar demonstration with handheld two- and three-blade rotors is still part of the factory tour at the Siemens wind turbine plant in Brande today.

In the spring of 1977, Stiesdal helped his father install a hot water heating system in a farm outbuilding, so they could expand their workshop and have a party room for his sister's upcoming wedding. The project taught him how to work with his hands, and supplied him with enough leftover water pipe and fittings to attempt building a second windmill, based on a design he read about in *Sol og Vind.* (Stiesdal 2013, 269) He mounted his 2-meter experimental sail wing rotor on a farm wagon and rolled it out into a field for testing. The experiment ended catastrophically when the rotor unscrewed itself from the shaft in heavy winds and thudded onto the wagon, which Stiesdal had just had time to dive beneath.

“I gradually got seduced by the tinkering, it got hold of me. I thought it great fun,” Stiesdal said. “Wind power was magic, in the sense that if you had a high school degree, at least if you had physics and math, like I did, then the physics of what went on was understandable, the math was understandable.” (5)

His design may have been fatally flawed, but from the crude calculations he had made, Stiesdal realized that even such a small rotor could supply more electricity than his family used on the farm. This revelation inspired him to get serious about building a “real” electricity-producing windmill, with a 10-meter rotor. He began scouring the junkyards in Herning and Copenhagen for parts, which he purchased at a flat rate of one Danish krone per kilogram. He welded together a lattice tower himself, working from an old city light pole. (6)

Stiesdal's hands-on education in wind turbine engineering was interrupted when he left for his military service in May, but he made what turned out to be a crucial connection when he offered to write an article on his experiments for the magazine of the Organization for Renewable Energy (OVE). That article led to an invitation to speak at an OVE Wind Workshop in early 1978. The workshop, held at a folk high school near Fredericia in Jutland, brought together many of the pioneers who were in the process of forming the first generation of Denmark's wind energy network. There Stiesdal met Preben Maegaard and Erik Grove-Nielsen, as well as Torgny Møller, a journalist who had purchased one of Christian Riisager's first turbines, and who at the meeting proposed the formation of the owner's association which would later be known as Danmarks Vindmølleforening (DVF). In these early years, catastrophic turbine failures from runaway rotors (something Stiesdal had personally experienced on the family farm) were a chief concern for home builders. So a turbine safety committee was formed, and Stiesdal volunteered to join, along with Maegaard and Grove-Nielsen, with whom he would later work designing the NIVE turbine. Stiesdal described learning from these older men on the safety committee as “instrumental” in helping him to see beyond the engineering challenges of wind turbines and consider the broader social and political issues with integrating this new energy source. (7)

As Stiesdal continued work on his own turbine design, he ran into a roadblock when he needed some large holes machined in a component, for which he lacked the necessary tools. The nearest place that could do the work for him was a small blacksmith's shop in Herborg run by a man named Karl Erik Jørgensen. Jørgensen had a reputation as an almost manic tinkerer. He had connected his workshop directly to his home, with entrances through the kitchen and bathroom. According to Stiesdal, Jørgensen once broke his pinky finger in a combine harvester, and when the local doctor advised he go to the hospital in Herning, Jørgensen self-amputated his finger rather than pause the work he had in progress. The finger had always been in the way, he argued. (Stiesdal 2013, 274)

Stiesdal and Jørgensen hit it off immediately. They shared an interest in wind power, and had complementary skill sets. Jørgensen was a talented craftsman, but lacked the formal education and theoretical knowledge Stiesdal had acquired. They struck a deal in which Stiesdal would help Jørgensen with a wind turbine design in exchange for the machining he needed done. Together they applied for a start-up grant the government was offering for energy projects through the Inventors' Bureau of the Danish Technological Institute. Peter Cordsen from the Inventors' Bureau came out to visit them and discuss their plans, and within two weeks they had a check in the mail for DKK 50,000. (8)

Construction of what became known as the Herborg turbine was completed by June 1978. Stiesdal provided the design work. Inspired in part by a magazine article he read in which the American wind pioneer Marcellus Jacobs had advocated for a 3-blade upwind rotor, Stiesdal went with a design that would become a classic of the Danish concept, the prototype for the entire Vestas line. Jørgensen did all the machining, either locating the necessary components or building them himself, and all of the assembly. Stiesdal's connection to the OVE safety committee, and the money from the Inventor's Bureau, allowed them to purchase cutting-edge fiberglass blades from Erik Grove-Nielsen, who had himself acquired the used molds from the Tvind team. (Grove-Nielsen 2013, 253) The Herborg machine initially performed well, but when the power went out during a storm that autumn, the rotor oversped, burning out the brake and throwing one blade almost 500 meters. (Stiesdal 2013, 276) In response to this failure, Grove-Nielsen designed aerodynamic tip brakes, which provided a redundant safety mechanism to prevent the turbine from destroying itself in the event of a grid outage. This dual mechanical and aerodynamic braking system became the standard among Danish turbines in the coming years, and played an important role in improving the reliability of the technology.

The success of the Herborg prototype motivated Jørgensen to put his design into production. Two more turbines were built in 1979 and sold to farmers in western Jutland. But Jørgensen lacked the business acumen to scale up his operation, and although Stiesdal had assisted with the marketing, sales, and installation of the first turbines, he had plans to leave for university in the fall. Through word of mouth, they heard about Vestas' experiments with wind energy—a friend of Preben Maegaard's had seen their test turbine from the air while flying over Lem. So they placed a call to Vestas, and by fall they had reached an agreement to license the Herborg design.

Sadly, Jørgensen never lived to see the full impact of his contribution to early turbine development in Denmark. He died of cancer in 1982. But Stiesdal's adventures in the wind business were just beginning. Before starting university, he took a trip to the United States, where he hitchhiked around the country and absorbed more knowledge from the American wind community. Stops on his tour included the small turbine test center at Rocky Flats, Colorado; meetings with engineering faculty at the University of Colorado in Boulder, Sandia National Laboratory in New Mexico, and the U.S. Windpower production facility in Livermore, California; and even a stay at small commune in Colorado being powered by a Jacobs turbine. (9) When he returned to Denmark to start university, he worked as a research assistant at Risø National Laboratory, which was just beginning its wind division. He also worked as an unpaid consultant for Vestas during his university years, and won a national competition sponsored by the Ministry of Commerce for his design of a variable speed, variable pitch turbine, which he sold to Vestas. In 1983, he started working for Vestas part-time on their next-generation, 150 and 225 kW designs.

Stiesdal had studied medicine at university, and originally intended to become a doctor, but he became disillusioned with what he described as the “hierarchical” and sexist hospital culture in Denmark at that time. “University seemed so one-dimensional compared to being in a professional company,” he said. “At university I felt I was with a carefully selected group of people like myself—same age, same scientific interest. Life was easy. At the job it had been all kinds of people, sharp and not so sharp; it had been blue collars, white collars; it had been real life. I simply came to miss that like hell.” (10)

Nonplussed with the new management at Vestas after the 1986 bankruptcy filing, he took a job with their chief competitor, Bonus, in 1987, where he eventually rose to become chief technology officer and right-hand man of CEO Palle Nørgaard. The pair would build Bonus into one of the world's largest wind companies over the next two decades, transforming turbine technology and Denmark's electricity system along the way.

Stiesdal had been present for, or had a direct hand in, nearly every major milestone in the early decades of Denmark’s wind adventure, and his career in the turbine business was still just beginning. At Bonus in the 1990s, he would lead construction of the first offshore wind farm in the world. When Bonus sold to Siemens in 2004, Stiesdal stayed on at the German industrial giant as CTO of the new wind division, where he developed their direct-drive turbine technology, among numerous other advances. But having grown up in the relatively informal and nonhierarchical cultures of small family-owned firms, Stiesdal never felt fully comfortable in the more buttoned-up world of corporate management. He remembered fondly the trusting relationship he had with Palle Nørgaard, whom he praised as treating everyone equally, from the man sweeping the shop floor to the Queen of Denmark. “I could easily have lived with Palle being my boss,” he said. “In Bonus it was always the substance that mattered. In Siemens it's also, how do other people see this? How will they interpret it? How does it place our department in the relative power game with other departments?” Stiesdal had little interest in budgets, or salary negotiations, or wearing ties, so in 2014 he retired early and opened a one-man consulting firm in the basement of his modest home in central Odense. (11) Today, like seemingly everything Stiesdal touches, the company that bears his name is growing dramatically, and he continues to push wind technology into the future, designing floating platforms for deep-sea turbines and systems to convert wind power to hydrogen.

Throughout the history of Denmark’s energy transition, it has more often been independent spirits like Stiesdal than establishment actors leading the way. Those innovators usually came from the rural outskirts of Danish society, in Herborg and Lem, in southern Fyn and northern Jutland. They were small craftsmen like Karl Erik Jørgerson, or backyard inventors like Christian Riisager, or social activists like the Tvind Schools.

The previous chapter argued that favorable environmental conditions in Denmark allowed for the emergence of wind energy in the late 1970s as a serious alternative to the existing fossil fuel electricity system, with a range of supportive natural, economic, cultural and political conditions nurturing early wind entrepreneurs. This chapter takes a closer look at the individuals and groups who took advantage of this moment to introduce novel technologies for supplying Denmark's energy demand. What motivated these people to experiment with wind energy? What were they aiming to accomplish? What did they hope the impacts of their activities would be? How were they able to put their ideas into practice? To what extent were they able to achieve their goals, what were the limitations of their strategies, and in what ways were their efforts frustrated?

An overarching agenda of this dissertation is to redirect attention away from the elite actors and institutions so often foregrounded in political science explanations, and toward the networks, relationships, and systemic processes implicated in large-scale sociopolitical changes. But this largely structural account is not intended to dismiss the importance of individual agency in system evolution. Recognizing that conditions are ripe for change is no guarantee of when, where, or by whom that potential will be realized, if at all. Someone still has to take the initiative. If human beings were powerless to influence the social, technological and natural environments they inhabit, the question of what can be accomplished by building a wind turbine would not have a very interesting answer. Thinkers like Hannah Arendt have argued that it is the capacity for action that allows humans to fully participate in political communities, that makes us free. Faith in that capacity seems, at least to me, to be a pretty essential tenet of democracy.

The remainder of this chapter focuses on some of the more significant participants in the first generation of wind development in Denmark, which began in earnest in 1980 and lasted until policy shifts in the 1990s helped open the wind business to new entrants. That later period is discussed in Chapter 5. The earliest turbines were built in the late 1970s by amateur tinkerers and idealists, and the technology they incubated was quickly picked up by local manufacturers, who put the designs into production and sold them mostly to farmers and cooperative associations of neighbors. The empirical accounts in this chapter provide details on how this early wind network was structured and fit into the larger domestic energy system, as well as insights into the reasons early adopters bought into the wind experiment and the consequences of their participation. The attention to these actors has several methodological benefits for the present study. They introduce to the narrative explicit, and explicitly political, motives, and make it possible to assess the strengths and weaknesses of wind development as a means of pursuing those goals. They also provide one of the major sources of internal variation within the case study. As I explained in Chapter 1, among the myriad components of energy systems, this study gives special consideration to the varieties of project developers, whose diverging ambitions and outcomes allow for comparisons of alternative energy transition pathways. A distinctive feature of the Danish history is the wide range of types of projects that have been built over the country's five-decades of experience with wind energy. Beginning in the 1990s, the first generation of grassroots wind developers were supplanted by private capital, which in tun later took a backseat to utility companies and other large institutional investors. These now-dominant players had largely sat on the sidelines during the crucial early decades when Denmark established its global lead in renewable energy development, and as I detail in the following section, were intensely skeptical of the grassroots excitement about wind energy. When competitors to the first generation of community-based models eventually appeared on the scene, they did so for their own reasons, and with their own favored development styles, both in response to broader trends in the energy landscape, and stimulating further system evolution. This periodicity in the character of Danish wind development makes it possible to ask why particular models appeared, thrived, and declined at particular times, and how alternative development styles interacted on this shared terrain. Accounting for these complex system dynamics troubles the traditional portrait of Denmark as a wind energy success story. Not all actors in the energy system embraced wind at the same time, with the same fervor, or for the same reasons, and different groups pursued wind development in their own ways, with wide-ranging results and implications. An ecological mindset encourages thinking about competitive fitness and evolutionary success from a relational perspective. Why are some species of development a better fit than others for particular moments, in particular environments? When analyzing how and why an effort at systemic change succeeds, it is critical not to forget to ask, success for whom? Success on what terms?

Denmark's wind energy pioneers were a diverse lot, coming from many different walks of life. But as the coming pages will make apparent, the leadership of this young energy network did share a broadly similar ideological orientation, in that they all saw wind energy not simply as a business, but as an environmental prerogative and a means of rethinking their society's modes of energy production and consumption. Ulrik Jørgensen and Peter Karnøe have argued that these "social visions" played an important role in "establishing the institutional setting for the Danish wind-turbine industry," and the political project of achieving an "alternative" society became embedded in this burgeoning sociotechnical network. (Jørgensen and Karnøe, 59) A teenage Henrik Stiesdal learned this larger social vision from Preben Maegaard in those farmhouse meetings of the OVE safety committee in the late 1970s. Needless to say, these were not the prevailing views in the board rooms of the electric companies at the time.

4.2 The Dozing Ancien Regime

The wind network that began to assemble in the late 1970s arose far from the nerve centers of the country's established energy system. The Danish electricity sector at the time was still dominated by conservative utility monopolies. In 1980, a total of just 18 central power plants burning coal and oil supplied the overwhelming majority of the country's electricity. (see Figure 4.1; Bulow 2010) The large industry associations running the grid were at best skeptical of wind energy's potential, and would not fully embrace it until after the new millennium.

Denmark was a relative latecomer in electrification on the Continent, and many small Jutland towns were still without electricity well into the twentieth century. Aarhus, the largest city on the Jutland peninsula, was electrified in 1917. When the regional cooperative that carried out this electrification project was first formed, as many as 1,000 area residents participated in the initial meetings. (Svendsen 2015) When electricity spread to rural Denmark, it was most often organized by local cooperatives—small community enterprises owned by their members. As the utility network grew and the power plants got larger, so did the companies. They developed large regional associations and formed their obligatory lobbying organizations. By the 1950s there were two major utility associations, representing the two halves of Denmark, ELSAM in the west and ELKRAFT in the east. The country remained on two independent electric grids until 2010, when an undersea cable was laid between Zealand and Funen, linking east and west. (12) Danish government had a history of pursuing laissez-faire policies toward the operation of the grid. Together with their industry association (then called the Association of Danish Utilities, DEF) the utility conglomerates successfully pressed their agenda in parliament, and also had an effective monopoly on electricity production. The fuel of the future, in the minds of the energy establishment, was nuclear, and wind was little more than an afterthought. In 1965, ELSAM projected that by 1990, nuclear reactors could meet a full 50% of electricity demand. (Nielsen 2001, 62) At the inauguration of Johannes Juul's Gedser mill, the president of DEF, Robert Henriksen asked “whether the time of interest for the use of wind power has not passed.” (Van Est 1999, 84)

Although utilities would from time to time perform wind experiments, such as the Gedser mill, or the Nibe turbines, there were few serious investments until the government forced their participation in a late 1980s compromise. As was discussed in the previous chapter, the utilities' Wind Power Committee concluded from their experiments that wind was not economically competitive with other fuel sources. The utilities believed wind could never be more than a marginal contributor to the electricity mix, so many utility managers simply never took it seriously. At other times, the utilities were more openly hostile to wind. The concerns, according to industry experts, had as much to do with perceived grid integration and efficiency problems as anything else, but also a prevailing dismissive attitude toward the wind community, which was considered small potatoes.

“They were minding their business of thermal power plants and gas and coal,” said Christina Aabo, head of wind energy R&D at DONG Energy. This “business as usual” approach, she said, was coupled with the belief that wind power “won't work, it's too small, it's not stable enough, turbines are unreliable. It's such a small thing that we don't even care to look at how it could be integrated into the grid.” (13)

Of course, there were deeper ideological rifts between the utility mindset and the grassroots wind community. To the utilities, the very idea of small-scale, distributed generation from independent local producers was anathema to their entire system of highly-centralized energy production and distribution, not to mention their business models. The distributed, intermittent wind producers were such a puzzling challenge to grid engineers at the time, and their ideas of how to efficiently run an electricity system, that the foreignness of these concepts may partly explain why many of them did not fully wrap their heads around wind energy for decades, if ever. (14)

"The leaders at that time of the electricity companies, they were convinced that putting wind turbines into the electrical system would make it impossible to run the power stations. I think that's why they did not like the wind turbines." said Per Svendsen, who has worked in the utility business for three decades and is head of communications at the utility nRGI in Aarhus. "You must remember, the leaders of the utilities at that time, all of the CEOs, they came from the technical world. That was the only way of thinking they had. It changed later on."

Much later on. If wind wasn't on the radar in the 1970s, through the 1980s, as turbines began to make a bigger mark on the grid, the relationship of the energy establishment to this upstart became thornier. To be fair to the utility companies, the growth of wind was causing them headaches, as costs from grid enhancement and connections, as well as lost profits, were mounting. In the coming pages and chapters, several examples of the occasional flare-ups between the wind community and the utility companies will be discussed, though usually they were able to reach a detente through compromise, until the collapse of negotiations in the early 1990s led to policy changes that permanently reshaped the wind power network. But a closer look at the developments of the 1990s will have to wait until Chapter 5.

The conclusion that must be drawn from the early history of wind development in Denmark is that the utilities were at best a peripheral player, by virtue of administering the grid. Aside from begrudgingly allowing private individuals to connect their small turbines to the grid, until the late 1980s utility companies had little hand in the growth of the domestic wind energy network. Their primary contribution was to sit firmly pat and resist incursions by wind energy entrepreneurs into their grid dominance.

4.3 Policy Support for Early Wind Development

In the 1970s, government mostly shared industry's dim view of wind power's potential. On energy policy, Denmark's multiparty parliament was split into what Rinie Van Est has labeled the “establishment” and “cooperative” coalitions. The emergence of five new parties in the 1973 elections had recalibrated parliamentary politics, forcing the formation of governing coalitions and ushering in a new era of compromise policymaking that persists to this day (see Chapter 5 for more discussion of Denmark’s coalitional political culture). Grassroots renewable energy organizations like the OOA, and later the turbine owner's association, were able to get the ears of the cooperative coalition, which began to make inroads in national policy in the 1980s. (Van Est 1999, 72, 139) It would take decades for a sustainability agenda to filter through all levels of Danish government. When the first national energy plan was formulated in 1976, the establishment coalition still held sway in parliament and the ministries. Writing in the mid-1990s, the former chairman of the owner's association characterized attitudes toward wind power across state agencies as ranging from dismissive to obstructionist:

> Not a single public authority will lift a finger to support the development of wind power. They only do what they are being pressed to do by the so-called "green majority" in Parliament. They have not been able to stop the development, but they have delayed it, and they have made it a tough fight for DV [the owner's association] and the turbine owners to get the turbines up and running. (Tranæs 1996)

The first energy plan, prepared in the wake of the oil crisis, called for little overall contribution from wind in its projections through the end of the century. It estimated that by 1995 two-thirds of the nation's electricity could be supplied by several nuclear stations, and anticipated only a 4% contribution from renewables. (Van Est 2001, 74) Coincidentally, that projection proved to be almost exactly the contribution of wind power in the early 1990s. It should not be concluded, however, from the correlation of these statistics that government was effectively steering the electricity sector in implementing its plans. By the 1990s, wind power was on an exponential growth curve that few had anticipated. By 2000 its contribution to national electricity consumption was up to 13%, and pushed close to 20% by 2005. (Energinet.dk) This growth was not what state officials had expected, but they did respond admirably to the successes of early wind developments in many ways, feeding the wind sector more resources as it expanded, and, crucially, building up the physical infrastructure, the taxation and incentive schemes, and the market conditions to allow the burgeoning wind community to thrive. Overall, Danish energy policy has undergone dramatic shifts since the 1970s, most notably in the national government asserting more centralized oversight and administration of the energy system—the oil crises were the beginning of the end of the laissez faire approach—and the gradual embrace of sustainability as a goal of energy planning. But into the early 1990s, wind energy policies were still largely hammered out through semi-formal compromises, in consultation with both the utilities and the grassroots community. Government programs to support wind development were continually adjusted as a product of these negotiations. In general, this approach to policymaking could be described as experimental, incremental, and inclusive.

Particularly in the 1970s, central planners showed little faith in wind power. But the collapse of the government and industry-backed nuclear option in the early 1980s left a big question mark looming over Denmark's energy future, and wind energy's boosters were ready to step into the gap. The 1976 national energy plan, prepared by the Ministry of Commerce, concluded that wind turbines were an unproven technology in need of further research and development. The immediate action plan called for reducing reliance on oil by switching more power plants to coal. Natural gas and nuclear were seen as the fuels of the future. (Nielsen 2001, 102) Government reports in the 1970s saw little role for small turbines, beyond offsetting household energy use, and projected the lion's share of wind's future contributions to the grid would come from several hundred megawatt-scale machines. Any more than a 10% contribution from wind turbines, it was believed at the time, would destabilize the grid. (Nielsen 2001, 108) Even this amount was an upper limit. The 1976 energy plan expected all renewable sources to contribute less than 5% to total energy demand by 1995.

These unambitious projections for renewable energy, and the largely conventional energy strategy outlined in the official energy plan, met with howls of disapproval from left-wing parties in parliament (Van Est 1999, 74), and provoked the OOA and OVE to fund eight academics to produce an alternative energy plan in 1976. This rival plan envisioned a nuclear-free future. It called instead for increased energy efficiency and co-generation, and for small wind turbines to provide 10% of home heating needs, and large turbines to generate an additional 10% of the nation's electricity by 1995. (Nielsen 2011, 105)

The alternative plan fueled a healthy national debate over Denmark's energy future, and its influence was visible when the government released a second official plan, prepared this time by the newly-created Ministry of Energy, in 1981. The new government plan presented four different options for energy development, including nuclear and renewable options. This change represented a decentering of nuclear power from the government's agenda, and increasingly serious consideration of renewables. In the “business-as-usual” option, the 1981 plan projected renewable sources would provide 3.3% of the nation's energy by 2000. The renewable energy option doubled this target, to 7-8%. (Nielsen 2001, 137) Several of the academics who had authored the alternative energy plan—including leading wind energy experts Frede Hvelplund, Niels Meyer and Bent Sørensen—responded to these new government proposals with their own updated plan in 1983. The second alternative energy plan questioned government projections on future energy consumption, and argued significant reductions could be achieved through energy efficiency and conservation. The 1983 alternative plan called for substantial contributions from renewable energy sources, in addition to coal, oil, and natural gas. The plan imagined that approximately 60,000 small wind turbines would be erected around the country, along with about 2,000 larger turbines. (Nielsen 2001, 138-139).

The alternative energy plan, authored by outside experts with close ties to the activist community, overestimated by an order of magnitude the number of turbines that would eventually be built around Denmark in the coming decades. Rapid advances in turbine capacity meant that so many thousands of small turbines would never be needed. But in spite of these overly optimistic projections, it was arguably the alternative planners who correctly foresaw the potential to build an energy system around renewable technologies and by promoting a culture of sustainability. The importance of grassroots organizations like the OOA and turbine owner's association in lobbying for government support cannot be ignored. Conversely, there is little support for the proposition that officials in Copenhagen were hip to wind from the beginning. Government initiatives did provide critical cushion and sustenance during the wind network's formative years, but these programs were usually implemented in response to citizen pressure, rather than leading out front.

One of the more foundational public investments—initially carried out by the utilities, but at the insistence of government—came in the form of grid upgrades needed to handle thousands of new distributed power stations (see Figure 4.1 for an illustration of the changing landscape of generation facilities). The vital role grid infrastructure plays in making renewable development possible has perhaps not received enough attention in the literature on Denmark's energy transition. The grid acts as the circulatory system of an electricity network. Renewable technologies, and wind turbines in particular, pose novel challenges for managing grids designed to disperse the steady, easily-regulated power produced by large centralized plants. The growing number of wind turbines being connected to the electricity system throughout the 1980s and 1990s required continuous work to reinforce transmission lines and reimagine grid management. As scholars of public policy know well, these types of large-scale infrastructure projects are incredibly expensive, and politically treacherous. Private businesses are often loathe, if they even possess the resources, to make such investments. The consequences of delaying grid modernization can be seen in the United States, where deteriorating, antiquated infrastructure is inhibiting the integration of renewable generation technologies. Many billions of dollars will have to be spent on grid improvements before distributed generators can make significant inroads in U.S. electricity markets. (15)

How were the Danes able to surmount this obstacle, and raise the money to modernize their electric grid? The gradual pace of wind power expansion, and especially the extremely small size of early turbines, made the task more manageable. The difficulties associated with integrating a 25 kW home turbine are modest compared to connecting today's gigawatt-scale offshore wind farms, which require their own dedicated substations and undersea cables. As a result, wind energy producers were able to gain a beachhead in the Danish electricity sector before costs and technical conflicts rose above the level of a mere annoyance to grid managers. Since wind enthusiasts were not taken seriously at first, establishment actors did not recognize the threat this new technology posed to business-as-usual practices. The pressure wind turbines placed on grid infrastructure and management multiplied with the scale of adoption. However, as the presence of wind power on the grid grew through the latter decades of the twentieth century, Danish grid operators were simultaneously able to relieve this pressure through growing national and international interconnections. These grid improvements were not accomplished overnight. Rather, a series of investments has been made over decades, keeping pace with newly arising needs. What began as a handful of isolated regional grids were slowly unified through the construction of new transmission backbones like the Great Belt Link from Funen to Zealand, completed in 2010. Construction costs for that project alone were estimated at DKK 1.37 billion. (Michelsen 2016, 13) In addition to multiple land-based interconnections from southern Jutland to Germany, since 1965 Denmark has built undersea cables to connect with its North Sea neighbors. Establishing these links also required the development of international electricity trading markets, which made it possible to sell excess wind across the border, or to buy electricity from neighboring countries on less windy days. A more detailed analysis of these grid and energy market developments and their significance for wind development can be found in Chapter 6.

The costs of these grid improvements, of course, were ultimately passed on to consumers. According to some sources, Danish households pay the highest electricity prices in Europe, with neighboring Germany a close second. (Eurostat) The lion's share of consumer electricity prices comes from several different taxes implemented in the decades since the oil crises. In 2015, the wholesale cost of electricity only accounted for 15% of a homeowner's electric bill. The remaining 85% covers a variety of taxes, included the standard value-added tax applied to most purchases, but also several dedicated streams of revenue for grid enhancements and renewable energy subsidies. (Energinet 2014) By 2009, the state transmission system operator's budget for grid reinforcements and expansions averaged nine figures annually. (Karas 2010)

While high electricity costs have become an issue in recent elections—opposition to the taxes has been led mostly by industrial customers, particularly greenhouses—electricity prices for individual households have remained remarkably stable since the 1970s. The ability of the Danish state to make enormous investments in renewable energy integration without dramatically increasing household electricity bills can be credited to the government's forward-thinking response to the energy crisis. While Ronald Reagan used falling oil prices in the 1980s to slash taxes in the United States, the Danes took the opposite approach. The government first introduced an electricity tax of 2 øre/kWh to consumer bills in 1977, as an energy conservation measure intended to tamp down consumption. After the second oil crisis, the tax was raised to 13 øre/kWh. (Van Est 1999, 87-88) In 1986 the electricity tax was increased again to 25 øre/kWh. (Nielson 2001, 331) At the same time, wholesale fuel prices were falling on the global market, cushioning consumers from the effects of the tax increases, and keeping household bills relatively flat.

The heavy taxation of electricity has proved an effective means of reducing household consumption. While maintaining one of the highest standards of living in the world, Danish citizens, accustomed to paying high prices for their electricity, have adapted their daily habits in myriad ways to avoid wasting energy. These cultural shifts include everything from installing off switches on wall outlets and air-drying laundry, to bicycling to work and shopping more frequently for fresh groceries. Energy efficient appliances, heating systems, and building materials have been widely adopted in Danish homes. Most buildings are heavily insulated, and thanks in part to the temperate climate, few buildings have air conditioning. Municipal governments and utility companies have also sought to encourage energy efficient renovations through a variety of incentives and information campaigns. For example, Danish homeowners can sell energy savings achieved through efficiency upgrades directly to the utility companies, which are required to meet annual usage reduction targets in their service areas. (Tjørring and Gausset 2016)

Since 1990, national energy consumption has decreased almost 8%, while the gross domestic product grew 41% during the same time period. (16)

The introduction of electricity taxes starting in 1977 created an indirect production subsidy for wind turbine owners, who they were exempted from paying the tax on any watts they generated and used themselves, but still had to pay taxes on electricity they purchased from the grid when the wind wasn't blowing. After 1984, the tax break for wind production was expanded, refunding owners' electricity taxes up to the full amount they generated. This exemption from electricity taxes was justified in parliament as a means of supporting the wind industry by ensuring a strong domestic market for their products. (Van Est 1999, 88)

In addition to spurring major strides in energy efficiency and reducing electric bills for renewable energy producers, the taxes also funded direct subsidies for wind development, which helped put purchasing a wind turbine within reach of families of ordinary means. As discussed in Chapter 3, the first 30% investment subsidy for wind installations was approved by parliament in summer 1979. The bill was intended primarily to boost domestic turbine manufacturers—"creating production opportunities for the Danish industry, in such a way that serious production could be achieved," the housing minister argued. In the end, all but the far-right parties voted in favor of the legislation. (Van Est 1999, 79)

In order to qualify for the subsidy, the turbine model being installed had to be certified by the Risø test center at the Technical University of Denmark (DTU), a hurdle that favored domestic manufacturers. The DTU faculty members who wrote the certification rules said they drew inspiration from similar requirements imposed on hearing aid manufacturers in the 1960s, which helped make that industry competitive on the export market by ensuring product quality. (Nielsen 2001, 120) Municipal governments were charged with taking applications from turbine owners and distributing the funds. The investment subsidy proved enormously popular, and only three weeks after taking effect the entire DKK 25 million earmarked for 1979 had been subscribed. Long waiting lists formed to install a turbine in many municipalities. (Nielsen 2001, 122)

In 1981, the owners' association—which had grown from 60 members at its founding in 1978 to 1,300 members—and manufacturers' association successfully lobbied parliament to include cooperative windmills in the program, at a reduced rate of 20% of the price of the turbine. (Nielsen 1999, 124) The investment credit was gradually reduced throughout the 1980s, in 5% increments, from the initial 30% down to 5% of the project cost, and was eliminated entirely after 1989. (Sawin 2001, 266)

The relatively small annual allocations, and their quick exhaustion, created a stop-and-go effect on domestic demand for turbines, swamping manufacturers with orders when new rounds of funding were approved, and then forcing them to lay off workers a few months later when government funds ran dry. After amendments to the subsidy program were announced in December 1985, Per Krogsgaard, managing director at Vestas, complained in the pages of *Naturlig Energi* that the changes would cost his firm 80 jobs. (Nielsen 2001, 219, 322) This early uncertainty about the availability of subsidies is just one of numerous examples of how policy instability rippled through the wind energy network, wobbling the industry and metering the growth of wind turbine deployment.

In the short term, these kinds of fluctuations can have a chilling effect on development, since investors crave policy certainty. Numerous studies have pointed to stable, long-term policy support as a crucial factor in the success of renewable energy development efforts around Europe, and in Denmark in particular. (for example, Toke et al. 2008, IRENA 2012, Meyer 2004b) But the commonly-held view that state subsidies for wind development were unusually consistent in Denmark, as the above examples demonstrate, is misleading. It is more appropriate to conclude that Danish renewable energy policy has been characterized more by its flexibility than its stability. As Erik van der Vleuten and Rob Raven have argued, in the study of energy regimes, stability and change should be viewed as "two sides of the same coin." (Van der Vleuten and Raven 2006, 3747) With respect to Danish wind policy, regular adjustments to subsidies have been the norm, not the exception. That policy flexibility has its advantages. Danish government policies were able to nimbly respond to technological developments, emergent market conditions, and stakeholder pressures. Wind energy governance has undergone a continuous process of policy learning—the Danes, as first movers, had nowhere else to look for guidance, and many of their policy efforts were understandably experimental. That history of policy learning and adaptation, and its implications for policymaking to encourage energy transitions, is examined in greater detail in the next chapter.

Although the continuation of institutional support was far from guaranteed in the 1980s, the programs implemented during that decade did make investing in a wind turbine financially attractive to many Danish families. The utilities agreed to pay turbine owners for the electricity they contributed to the grid, and shouldered most of the costs of grid connection and maintenance, while government subsidized wind producers on both the front and back ends. Government officials and utility managers deserve some credit for being more receptive to these measures than their counterparts in other countries, but they had also been effectively pressured by a robust and growing networks of grassroots wind power enthusiasts. (17) The fact that most of the turbines sold domestically were being purchased by rural community cooperatives helped make those public expenditures politically popular. According to political scientist Rinie van Est, the cooperative movement was “regarded as *folkelig*, in that it was connected to community-based self-reliance, and to the ideal of social cooperation. It was seen as coming from the people, and (thus) as being beneficial to the people.” (Van Est 1999, 80,)

The relative lack of political opposition to the generous subsidy schemes can be explained by several factors. The anti-nuclear movement and fledgling wind energy community were certainly vocal supporters, and activists like Preben Maegaard had the ear of policymakers. The social movement groups united around a shared disenchantment with technocratic society, and a commitment to direct, local democracy. (Van Est 1999, 135) But it was not just a narrow activist community that looked favorably on the experiments with wind power in the countryside. The raising of the Tvindmill had been a national sensation, and the public had a generally favorable impression of the community development model being practiced at the time, which aligned with Danish folk traditions and values. What van Est calls the “cooperative coalition” favoring small-scale development had institutional support from progressive parties in parliament, especially the social liberal party, Radikale Venstre, and the Socialist People’s Party.

Academics were another key constituency who supported the grassroots wind energy movement. Engineers and planners from the country's leading universities provided technical advice to early wind projects like the Tvindmill, established the small turbine testing center at Risø, and drafted the influential alternative energy plans in 1976 and 1983 in response to the government's official plans. University researchers also had a direct role in shaping legislation through the Steering Committee for Renewable Energy, established in 1982. Niels Meyer, an engineer at DTU who chaired the advisory committee, was an ally of Preben Maegaard, giving the Nordic Folkecenter for Renewable Energy's anti-establishment vision a voice in policy discussions throughout the 1980s and 1990s. The steering committee directed approximately 10% of its research and development budget to the Folkecenter, for work on their Blacksmith turbine concept, (Vasi 2011, 75) allowing them to grow their staff to 24 employees. The committee was disbanded two decades later, after a right-leaning government took power in 2001 and slashed funding for renewables. This abrupt shift in national policy provoked a budget crisis at the Folkecenter, which was forced to reduce its staff to only four people. (18) The Folkecenter had been a torchbearer for the "soft path" and "bottom-up" development model so closely associated with the rise of wind power in Denmark in the 1970s, but by the end of the century that folk vision had been supplanted by a new generation of wind actors.

Divisions over the path of renewable energy development had existed from the beginning, both within the wind network and the broader political culture. Already in the early 1980s, conservative politicians began to raise doubts about the price tag of wind energy subsidies, concerns that were amplified and began to drive policy in later decades.

The cooperative movement, turbine manufacturers, and the private investors who became increasingly prominent as wind installations boomed, frequently did not share the same priorities. There was not much love lost between the owner's association and the Folkecenter, putative allies in pushing for greater policy support for wind energy who often butted heads over specific provisions. Some of those rivalries amounted to clashes of personality and ideology. Maegaard, who could come off prickly and inflexible, rubbed a lot of people the wrong way. In my conversations with him, he did not hold back in his criticisms of many players in the Danish wind sector. They, in turn, were sharply critical of him (I am withholding names at the request of some of my interview subjects). Maegaard said that during his time on the renewable energy advisory committee, his strategy was to position himself far to the left of the other members, in the hopes of dragging them a little away from the center. His chief antagonist on the committee was the representative from the utility association, whom Maegaard said objected to everything he proposed. (19)

Utility interests clearly frowned on wind enthusiasts in the 1970s and early 1980s, or simply dismissed them. Early on, the energy establishment treated wind turbines as more of a curiosity, and a bit of an annoyance, than a threat, which probably explains why there wasn't more of an organized effort to thwart the government subsidy programs. Anne Højer Simonsen, a former senior official in both the energy agency and the climate and energy ministry, characterized those early subsidies as a "hobby project" of the left-wing parties, who were fans of the Folkecenter and Tvind. "It was not much money," Simonsen said. (20) Everyone I asked about the how the first subsidies passed the *Folketing* gave me basically that same response.

Members of parliament almost certainly did not anticipate how explosive the reaction would be to such attractive subsidies—no one ever expected the wind business to grow so big so fast. In 1981 alone, only the second year of the program, 300 wind turbines received subsidies. (Nielsen 2001, 218) It was only as the first generation of wind turbines proved themselves in operation that the national government began to recognize the importance of the domestic wind sector—first primarily as a matter of industrial policy—and to show it favorable treatment.

The mid-1980s saw dramatic examples of both compromise and conflict in the tug-of-war over state support for renewable energy. One ongoing bone of contention was the strict residency requirements to qualify for subsidies, which were relaxed throughout the 1980s. At first, owners were required to live within 3 km of where their turbine was erected, but later this was loosened to 5 km, then 10 km, then within the same or an adjacent municipality. Finally, in the 1990s the residency requirement was removed entirely. (Nielsen 2001, 320)

In May 1984, parliament backed a 10-year agreement between the utilities', turbine owners' and manufacturers' associations, which split the costs of grid connections, increased rates for utility payments to wind power producers, excused turbine owners from electricity taxes on the power they produced, and temporarily eliminated the residency requirement to qualify for subsidies. Cooperative organizers thought the 3 km rule was too strict, limiting the potential size of their membership. (Van Est 1999, 140) But with the rule change, cooperatives were no longer limited to the grassroots neighbors' associations that had dominated the first years of turbine development. Now, many observers had crunched the numbers and realized that with the combination of the generous investment subsidies, payments for the electricity sent to the grid, and electricity tax forgiveness, there was money to be made erecting windmills. Not only did the size of the cooperatives get bigger, so did the wind parks. Throughout much of the 1980s, the typical Danish wind installation consisted of a single turbine, or a small cluster of several turbines. Neighbor cooperatives rarely had the resources to put up an array of more than a half dozen or so machines. But with the new investment potential, particularly attractive to well-off individuals hoping to avoid taxes, the wind farm model pioneered in California was transplanted to Denmark. Emblematic of this new development style was the *Velling Mærsk* park, which in its initial phase brought together 450 shareholders to raise 35 turbines on farmland near Ringkøbing. Two later expansions brought the total number of turbines in the park to 75. While *Velling Mærsk was* technically a cooperative, and many of the shareholders were locals, the project was organized by Vestas. The company profited from supplying all the turbines for the project, and promised investors a 13.6% rate of return. (Nielsen 2001, 281) The development earned praise from wind energy expert Paul Gipe, who called it one of the world's most aesthetically-pleasing wind parks (Gipe 1995, his impression of the farm likely benefited in comparison to the slapdash manner in which many California wind farms had been sited). Not everyone was such a fan. The utilities had tolerated neighbor cooperatives, which were not perceived as much of a threat due to their small scale, but sharply opposed projects funded by what were derisively referred to as “panty investors”—a reference to an old practice of evading taxes by purchasing shares in shipping companies, including some that traded in lingerie. (Nielsen 2001, 277)

The opening created by the new regulations led to a rush of turbine speculation the following year—in 1984 a total of 7 MW of new wind capacity had been installed in Denmark; in 1985 that number more than tripled to 23 MW. (Van Est 1999, 88) But the boom would be brief. The utilities had begun secret negotiations with the government, and in December 1985 additional changes were announced. The investment subsidy was slashed to 15%; the residency requirement was reinstated, this time limiting ownership to within 10 km of the turbine; and qualifying investments were capped (including for cooperative shareholders) at 35% of an individual's own energy consumption. (Nielsen 2001, 321) In exchange for these limits on decentralized development, the utilities agreed to install 100 MW of wind energy by the end of the decade, more than had been built in the entire country to that point.

The sudden announcement of what looked to many like a backroom deal provoked outrage in the wind community. An anonymous letter that had been circulating among the turbine manufacturers was reprinted in *Naturlig Energi*, alongside responses from the energy minister, the country's largest utility, and Birger Madsen, then president of the manufacturer's association. The anonymous letter accused the energy minister, the utilities and Vestas of "horse trading," and claimed the new rules would give "electricity companies a monopoly over windfarms and the installation of large windmills." (Anonymous 1986) The energy minister and utility director flatly denied the charges, but Madsen considered the new rules "too restrictive" and vowed to share the industry's concerns with government officials. He urged patience until the market impact of the new regulations could be determined, but the manufacturer's association would "react strongly against” the changes if they proved, as many feared, to be damaging to the domestic wind business. (Madsen 1986)

The timing of the shake-up of the subsidy program proved disastrous for Danish turbine manufacturers. Similarly attractive subsidies in the United States, where Danish companies had shipped almost 3,500 turbines worth DKK $2 billion in 1985, were simultaneously expiring. (Van Est 1999, 88) The same month Madsen's editorial was published, he was out of a job at Vestas, and he stepped down as chairman of the manufacturer's association.

The turbine industry bore the brunt of the impacts in the years that followed, significantly reshuffling and contracting amid a rash of bankruptcies, an ironic outcome for a policy regime that had been pitched foremost as a program for industrial development and market stabilization. In the latter half of the decade, the surviving manufacturers would rely once again on their first customer base, the rural landowners and cooperatives, to stay afloat. The utilities had shown they possessed the purchasing power to rapidly upscale development, but dragged their feet fulfilling their pledge, and wouldn’t become reliable customers for another two decades.

Perhaps the most important takeaways from the utility sector's first forays into the wind sector were the knowledge and experienced gained. The early wind parks would lay the groundwork for the expansion of that model in the 1990s. The government, in a parallel way, used the experience of the 1980s to develop some of the world's first policy regimes for regulating and encouraging distributed, renewable generation. This baseline of knowledge, expertise, and institutional capacity made possible the flowering of the wind sector in the 1990s. Wind power was viewed as a promising technology of the future, but it had not yet been assimilated into the dominant electricity regime.

Seismic shifts in government and industry attitudes toward this disruptive technology were on the horizon. A powerful minister named Svend Auken would soon lead a transformational campaign to cement wind energy at the forefront of Danish society. And the popularity of wind power was only bolstered by the early returns, which had been exceedingly positive. But it was not government ministers or corporate bosses who deserved the credit for first anticipating this future, or taking the decisive actions that proved wind power had more than potential. That credit belongs to the early adopters—the tinkerers and dreamers, then the farmers and the cooperatives—who put their social visions into practice in the fields of rural Denmark. The remainder of this chapter will be dedicated to the stories of these people who were on the scene first, the people who did take wind seriously, who did see its potential to be a significant contributor to the electricity mix. If politics is the art of the possible, it is significant that at a time when institutional forces in the electricity industry and government had little faith in the potential of wind power, ordinary citizens already believed enough in what this technology could do that they were sinking their money and their shovels into planting windmills around the countryside. What did these humble people see that the power brokers in Aarhus and Copenhagen were missing?

4.4 Inventors and Early Adopters

Thousands of tourists every year visit the national park in Mols, a gorgeous, windswept nature preserve on the Jutland coast north of Aarhus. Strolling on the seawall path alongside the ruins of 14th century Kalø castle, visitors can hardly avoid noticing the single large turbine across the narrow bay, gently rotating in the breeze. The 600 kW machine belongs to Torgny Møller, and sits in his backyard; it is the third generation of windmills on this exact site. (21)

There are many famous early wind turbines in Denmark, lauded as the first in one respect or another. Among the most mythologized are the inspirational Tvind turbine, the Herborg team's designs for Vestas, and Preben Maegaard's practical blacksmith design—remarkably, all of these actors were in close contact at the time, all were assisting each other in one manner or another, and all drew on the engineering principles established by Johannes Juul with his Gedser Mill. But of all these famous windmills, arguably none had as great an impact on the popularization of the home turbine concept, and the proliferation of the first turbines around Denmark, as the first one Torgny Møller raised in his backyard.

When Møller purchased the 22 kW machine designed and built by Christian Riisager in 1976, there were about 50 small home turbines around Denmark, all generating heat, not electricity. (Maegaard 2013) Like many Danes, Riisager grew up around farms, and since boyhood he had been fascinated by the not uncommon sight of mechanical windmills powering farm equipment. Always mechanically inclined, he was trained and made his living as a carpenter; he was a practiced home tinkerer, and he even had experience servicing an old farm windmill. (Jensen 2014, 13) In the early 1970s, Riisager and his family were living in a country house just south of Herning, along the road to Brande. At a time when environmental consciousness was growing around Denmark, and the oil crisis loomed just ahead, Riisager decided to put some of his ideas for renewable energy to the test in his backyard. His first project was a water wheel for a small stream, which supplied electricity to their home for several years. But he had even bigger plans. He started tinkering with windmill designs in 1972. (Jensen 2014, 13) His son, a Navy pilot who read English, helped him translate some wind engineering studies—the reports they consulted were most likely Johannes Juul's research published in the proceedings of a United Nations committee on distributed wind energy systems, which, incidentally, was the very same technical information relied on by the likes of the NIVE team. (Maegaard 2013, 198) Riisager had a workshop for his carpentry business, where in 1975 he began building his first electrical turbine, a 15 kW prototype. (22) As a Gedser-inspired turbine, it is not surprising Riisager's design embodied many characteristics of the classic "Danish concept," but with several distinctive features, like the unique broad rotor shape. Fittingly, the carpenter's early rotors were made of wood, and, along with the Gedser Mill and Tvindkraft, his were some of the only modern turbines to rotate counter-clockwise. (Grove-Nielsen 2006) Like many pioneering Danish turbines, the components were cobbled together from standard machine parts. The main drive shaft and gearbox were repurposed from an old British Centurion tank. (Jensen 2014, 14) The design proved sturdy and effective, but Riisager's most revolutionary innovation was a mischievous spark of an idea. The nation was in the midst of an energy crisis, and short of supply. What if he connected his turbine to the grid, and began feeding in electricity? He decided to ask for forgiveness rather than permission.

In fall 1975 Riisager tapped into the grid for the first time. Famously, the family was stunned as they watched their electric meter start running backwards. And to their delight, nothing caught fire. Over the next few days they made the rounds of their neighbors, asking if anyone had noticed any problems with their electric service. Everything seemed to be working fine. After the successful experiment, Riisager called the local utility and told them what he had done. The local authorities didn't seem overly concerned with the project, so they hammered out the first informal agreement on grid interconnection standards, agreeing to pay Riisager the value of one kWh of steam power for each kWh he fed to the grid. (Nielsen 2001, 127)

Riisager's experiment began to get attention in the media, and one of the people who noticed the coverage was journalist Torgny Møller, a reporter for the left-leaning Copenhagen newspaper *Information*. Møller had decided to escape the fast-paced life of the capital, and moved with his young family to a thatched-roof farmhouse on an exposed promontory of the Mols peninsula, where he opened the first satellite bureau of *Information*, as the sole correspondent. Møller was an established investigative journalist, who at a young age had won the Carving Award, the "Danish Pulitzer," and specialized in environmental, business and labor reporting. While he was not as expressly ideological as many other wind network actors who were more directly involved in environmental activism, his enthusiasm for the potential of small-scale wind was magnetic, and his tireless organizing and skill as a communicator made him an important standard bearer for the renewable energy movement in Denmark. (23)

At least initially, though, Møller's interest in wind had been more a matter of necessity than ideology. When the winter winds blowing in from the Kattegat began to buffet their old farmhouse, the Møller family quickly discovered a more immediate and practical reason to give serious consideration to innovative energy solutions. The old farmhouse was enormously costly to heat, burning through 40,000 kWh of electricity a year. After that teeth-chattering first winter in Mols, Møller was looking for anything that could help reduce his electric bill. Riisager, for his part, had never planned on getting into the wind manufacturing business. But when Møller and Carsten Fritzner, a teacher from Thy, on the northwest coast, inquired separately about whether he could build turbines for them, Riisager decided to take a shot at designing an updated model of the machine he had installed in his own backyard. (Jensen 2014, 16) The first 22 kW commercial turbine was installed on Møller's property in 1976. Riisager translated the immediate interest in his machines into a business he ran with his wife, Boe. Enlisting the help of local tradesmen, to whom they contracted out the assembly work, they manufactured a total of 82 turbines by 1982. (Energimuseet) By the end of the decade, the Riisager design had become one of the most recognizable around the Danish countryside. In May 1979 he sold that design to a new startup manufacturing company, Wind Matic, in Herning. Several dozen Wind Matic machines with the characteristic Riisager profile were installed around Denmark, and several hundred in the California deserts. (Grove-Nielsen 2006) But like many small manufacturers, the company went bankrupt in the late 1980s. Riisager got involved with a few other wind projects later in life, including in the Faroe Islands, but never matched the success of his first machines.

His initial 22 kW windmills, on the other hand, had been overnight sensations. The public perceived the machines to be "technological miracles," according to Preben Maegaard, and they cheered the grassroots, do-it-yourself ethos of Riisager's business model, which followed the:

> good old Jutlandish custom of including the blacksmiths, the local entrepreneur and the electrician, [who] had actually found the solution to the country's future energy supply by paying out from their own pockets. That was the kind of things

> that Danes liked to hear. It fitted perfectly with their ingrained scepticism towards experts and big capital. (Maegaard 2013, 201)

The acclaim that grew for the Riisager turbines was in no small part generated through the efforts of Møller, who was perfectly situated to become wind energy's voice crying out in the wilderness. The Møller family's turbine was working out wonderfully for them. They had paid only DKK 50,000 (about $7,500 USD) for the windmill, and it produced more than 30 MWh annually—seven times the average family's electricity consumption. (Maegaard 2013, 201) Møller calculated that he made a 13.3% return in the first year alone, and that that he would pay off his initial investment in five years. (Nielsen 2001, 127)

It was clear to Møller that he had made a good investment, and he was not shy about sharing that conclusion from his perch as a national newspaper correspondent. In a series of articles for *Information*, and a Danish-language book, he regularly reported on his own experiences with his windmill. (24) For many Danes, these stories were the first they had heard of a small-scale electricity-generating wind turbine. The relatable, real-life example, communicated by a trusted writer, and paired with detailed production and financial data convinced many readers of the practicality of a home windmill. Within a year of being installed, the three Riisager turbines drew a constant stream of curious day-trippers, who wanted not only to see the machines up close, but also to chat with the owners about how they could build or buy their own. Riisager's home became a stop on weekend bus tours to Tvind, organized by the OOA. (Jensen 2014, 13) Fritzner had to deal with trespassers, who on one occasion he caught breaking into his turbine in the dead of night, presumably intent on reverse engineering its inner workings. (Maegaard 2013,

199) At his seaside home, Møller entertained visitors from all around Scandinavia, and later from all over the world. (25)

The impacts of Møller's efforts extended beyond popularizing the concept of home electricity production. Christian Riisager may have been the first to connect a modern turbine to the grid, but Torgny Møller was the first to ask for, and to receive, permission to do so. This was not a simple task. When his initial application to the utility to connect his turbine was denied, Møller did what came naturally to him, and loudly objected in the newspapers. “He battled,” said Møller's longtime English-language editor, Lynn Harrison:

> At some point or another, the poor local electricity company decided, “oh for goodness sake, let him connect it to the grid, the whole thing will fall apart, it will be a disaster, that will be the end of the story, and we'll get rid of all these headlines” ... He got permission to connect it to the grid. And of course, as they say, the rest is history. It wasn't a disaster, his meter did run backwards when it was windy, the lights stayed on, and he ran equipment … It all worked. (26)

This victory for Møller not only proved wind's feasibility as a distributed generator of grid-quality electricity, it laid down one of the first legal arrangements for how wind power would be regulated and paid for on the grid, a baseline that would be built on in the years to come. Møller arranged one of the world's first power purchase agreements with a utility company, signing a contract with the local utility out of Aarhus, ARKE. The company agreed to pay him the deferred costs of the fuel they otherwise would have burned. In return, Møller had to ensure that his turbine met certain technical specifications. In 1976, the utilities' association formalized this style of agreement with a provisional proposal for rules on connecting small wind turbines and compensating the owners. One provision stated that the utilities were supposed to pay the costs of installing new lines to connect the turbines—a cost estimated as high as DKK 80,000 for a small turbine—but many owners began complaining to *Naturlig Energi* that their local utilities had been disregarding this guidance, and charging them large connection fees. (Nielsen 2001, 129) This friction between turbine owners and the utilities would make periodic reappearances. But however tensely the feeling-out period proceeded, relationships and ground rules were being established. Ultimately, this back-and-forth between the owners and utilities germinated into some of the Danish wind sector's most deeply-rooted institutional actors.

One of the first large organizations to form, in 1978, Danske Vindkraftværker (known today as Danmarks Vindmølleforening, DVF) grew from a grassroots network of the early turbine owners into a potent political interest group and consumer watchdog. The club began with Møller, and 11 others, gathered around his dining room table. (Holm 2009, 6) The newsletter he self-published for the organization quickly evolved into *Naturlig Energi*, the first and most important industry magazine, which he edits to this day. Each year the owner's association grew, to 60 members, then 400, then 1300. (Nielsen 2001, 129) By the 1990s the association counted more than 10,000 members, representing about 50,000 families. (Gipe 1995) These estimates suggest that at its peak, about 2% of Danes belonged to the organization. This presence in so many Danish homes made the owner's association a powerful lobbying force, and a key constituent in energy policy debates throughout the 1980s.

Naturlig Energi became the magazine of record for Danish wind power. Møller and Harrison, who edited the English-language sister publication, *Windpower Monthly*, established a reputation for independence, often irking big industry players and advertisers. But their hard-charging journalistic style unarguably benefited the industry in the long run. The light they shone on both industry failures and achievements not only kept industry actors on both sides of the Atlantic well-informed of the latest developments, but also regularly demanded improvements in turbine design and policy support (and frequently got them), and through the naked scrutiny to which they subjected manufacturers, forced real competition and spurred turbine innovation. None of the magazine's projects better represents this effect than the first ownership surveys. Torgny Møller had a list of his association membership's addresses, so he came up with an elegantly simple little idea. He mailed them all cards, printed with a form asking them a series of questions about their turbines, which he asked them to voluntarily complete and return. The cards came pouring in, and Møller accumulated the first hard numbers on how Danish turbines were performing. In handling the data he remained true to habit—he published it every month in the pages of *Naturlig Energi*. This unvarnished look at the records of Danish turbines let everyone know which models were making the most watts, and thus would make owners the most money. The early data gathering effort, with its radical transparency, informed the decisions of turbine buyers and provided critical feedback for turbine innovation. It was certainly an amateur effort in the early years, and records for the early 1980s are noticeably incomplete. But while the representativeness of the sample is unknown, it nevertheless paints an illuminating, impressionistic portrait of the kinds of people who were buying turbines, and where they were raising them. Møller successfully scaled up the data collection effort in just a few short years, with funding from the government, and by the mid-1980s records became increasingly accurate. Some years later, the Danish government deemed the task had grown too large for Møller, and gave the contract for maintaining the national turbine registry to a consulting firm. That decades-long data-gathering effort, initiated by Møller, produced the fascinatingly comprehensive database analyzed throughout this dissertation (see Appendix A for more details on data analysis methods).

A few companies began to rise to the top of the standings in the contests over kilowatts being printed in the pages of *Naturlig Energi*, and names like Vestas and Bonus grew more popular on the recommendations of owners, most of whom reported satisfying results overall. While the seeds of the modern industry came mostly from this pro-business trajectory, the more radical grassroots energy movement was still developing in parallel. The grassroots community of environmental activists and independent-minded property owners had political standard bearers like the Tvind collective, had captured the public imagination with the likes of the Riisager turbine, and had Preben Maegaard promoting a practical workhorse, his blacksmith turbine.

Maegaard had been the early leader of the team that designed the NIVE turbine—built in response to the success of the Riisager brand, and on the very same technical specifications from Juul's Gedser Mill. (Dykes 2013, 129) The NIVE design—a protoypical example of the “Danish concept”— proliferated through the industry, mainly in the form of Stiesdal's Herborg version, sold to Vestas. But Maegaard was busy in the 1980s pursuing his own, more politically radical, agenda behind a similarly configured NIVE descendant. Maegaard was committed to the appropriate technology vision of a small-scale, distributed energy system characterized by citizen involvement and local control. He had ties throughout the grassroots community, and had been an early supporter of Tvind. In the early 1980s, he formed his own brick and mortar organization to work on the practical demonstration and diffusion of these small-scale technologies around Jutland, the Nordic Folkecenter for Renewable Energy. The Folkecenter's hilly campus overlooking a narrow fjord in Thisted, complete with energy efficient demonstration houses and even a working biodome, became a focal point for energy and environmental activism in Jutland. Given Maegaard's past experience, his team's expertise in wind power was always their shop's biggest strength. For years, the Folkecenter enjoyed success with their small blacksmith turbine design. Maegaard still speaks with pride of the relative inefficiencies of the Folkecenter's heavy turbines, which he claims were highly reliable, because they were intentionally over-dimensioned—in his words, “built to last.” (27) At the organization's peak, Maegaard employed a staff of about two dozen engineers, working mostly on wind power problems, until cuts to their state funding in 2000 led to widespread layoffs. (28) During these decades, Maegaard was ever-present in the debates over wind policy described earlier in this chapter, participating in key negotiations, mailing letters, sitting on committees. He acquired more than a few enemies along the way. The Folkecenter was often a thorn in the side of government and industry actors, and Maegaard is still regarded with anything from wry suspicion to bald distaste in those circles today. Through the 1980s, accusations flew both ways, including of stealing each other's engineering breakthroughs. (29) The Folkecenter built blacksmith turbines around Jutland in the 1980s, but ultimately the design failed to catch on widely enough, and was surpassed by the rising domestic manufacturers, like Vestas, Bonus, Nordtank and Micon. It is clear from speaking with him that Maegaard prized his role as a turbine engineer, but the Folkecenter may have had a broader impact as an institutional force intervening in policy discussions, educating the public, and promoting local engagement in renewable energy production. Folkecenter staff have been a constant presence on the Danish wind scene, evangelizing the gospel of community wind, and they continue to participate in groundbreaking projects to this day, like the headline-garnering Hvide Sande cooperative. (30)

By the mid-1980s, the ambitions of wind pioneers like Maegaard, Møller, and Riisager had materialized in a thriving wind network. With growing interest from all sectors of society, wind power was already looking like the future "national champion" technology it would soon become. Many Danes grew excited about the prospect of making clean energy, or merely the prospect of making a little money. Owning a first-generation turbine may have carried a little risk, but with a predictable payback schedule, easy financing and lucrative returns, it was an intriguing investment opportunity and within reach of families of average means. The barriers to entry were lowered substantially with the rise of a new category of buyers—or rather, the revival of an old type of ownership in this new technological landscape—who needed only a few thousand kroner to purchase a share in windmill.

4.5 The Community Cooperatives

While early adopters like Torgny Møller and the Tvind school in Ulfborg were critical evangelists for wind power, providing inspiration and proof of concept, no actors created a larger footprint in restructuring of the Danish electricity sector in the 1980s than the local windmill guilds (*vindemøllelaug*) that began cropping up organically around the countryside. The phenomenon of cooperative wind development in Denmark has received so much scholarly attention—it is a prevailing theme and explanatory variable in research on turbine innovation and public acceptance of wind power—that it is somewhat surprising no overarching narrative has been attached to the emergence of this movement. This relative silence in the historical record is no doubt in part an effect of the grassroots nature in which the cooperative model grew. There is no leading actor or organization—no genius inventor or statesman—to point to and credit with the explosion of wind cooperatives in the mid-1980s. Rather, the leading actors were many dispersed individuals and families in rural pockets of the country, albeit often inspired by and in communication with one another, but ultimately making independent decisions around their kitchen tables, guided mostly by straightforward domestic interests. Frequently, the individuals who joined cooperatives were simply looking for a way to reduce household electric bills, which had skyrocketed in the aftermath of the energy crises, or were attracted to the tax-free investment opportunity. But especially in the early years, many cooperatives were formed with idealistic motives of environmental stewardship and community self-reliance. (Gipe 1995)

The cultural background of rural independence and strong local communities discussed in Chapter 3 provided fertile soil for the growth of cooperatives, supplying the requisite social knowledge and familiarity. The windmill cooperative may have been a new species of social technology, but it descended directly from a well-established model of rural subsistence. In addition to cultivating community spirit—already deeply ingrained in the national culture of joining and conforming to social norms—this experience with agricultural cooperatives had prepared Danes for the logistical, legal and financial challenges of administering these self-starting and self-governing organizations.

The first windmill guilds were formed by small groups of neighbors; a local farmer usually provided the land on which to erect the turbine. This hyper-local character of cooperative development was codified with the introduction of strict residency requirements to qualify for subsidies in the mid-1980s, but as discussed above, those restrictions were slowly relaxed over time. The size of cooperatives has varied widely in the intervening decades—they can be as small as a dozen members, but more recently there have been examples of cooperatives forming to build much larger projects, such as the Middelgrunden offshore wind farm in Copenhagen, which has more than 8,000 shareholders (see Chapter 6). Most cooperatives count between a couple dozen and a few hundred members. An inherent limitation of an organizational model that solicits membership primarily by knocking on the doors of middle-class homeowners within the community, cooperatives have historically been unable to raise the kind of capital needed to finance large wind farms, and instead have typically built small- or medium-sized arrays. In the 1980s, cooperative wind developments usually consisted of 1-6 turbines. It should be noted, however, that the scale of cooperative development reflected not only financial and regulatory constraints, but also concern with the "appropriateness" of the technology, with matching generation capacity to community needs, and with the landscape impacts of development. It cannot be mere coincidence that cooperative projects are so frequently praised for their considerate siting and the harmonious manner in which the arrays blend with their surroundings, while the mammoth turbines favored by private and utility developers today tend to dwarf everything else on the horizon, provoking locals to vent their irritation with the visual impacts.

As manufacturers have produced ever larger turbines, the average size of windmill guilds has grown in step with the rising costs of development, since most cooperatives have sought to keep the price of shares affordable for families of modest means—typically a few thousand kroner (a few hundred USD) per share.

Cooperatives have no special legal standing in Denmark, they are registered as partnerships (I/S, *Interessentskab*), in which the members are fully liable. Thus, Danish law does not shield members from the risks of their shared investments, but windmill cooperatives have historically enjoyed other tax advantages. As part of the subsidy schemes introduced to encourage renewable development in the 1980s, profits from cooperatively-owned windmills were exempted from income tax, so long as an individual's total shares did not exceed a specified percentage above their household electricity consumption. This limit was included to discourage wealthy individuals from buying a large numbers of shares in windmill projects as a tax avoidance scheme. (31) Given that the income tax rate in Denmark is around 50%, the tax exemption effectively doubled the value of every krone invested in a cooperative windmill, making participation a more attractive proposition. (Gipe 1995) However, joining a cooperative was, and remains, far from a highly lucrative investment activity. The rates of return for Danish wind projects vary widely, depending on a range of factors, including the size of the project, the windiness of the site, the current subsidies and market prices for electricity, and operations and maintenance costs. Some cooperative projects have outperformed projections, bringing in consistent profits; others have struggled to break even. By and large, most cooperatives report positive results for their members, though very few people, if any, have gotten rich purchasing shares in cooperatives. In most instances, the returns are stable, but relatively small. Buying shares in a cooperative is also not usually a good way to make a quick buck; membership is a long-term investment. The average turbine project budgets for a lifetime of 20 years—the period of time for which it is eligible for state subsidies—though many individual turbines have operated for much longer than that. It is common for cooperative members to finance their shares with a bank loan, which requires little or no upfront investment. If a cooperative member chooses to pay cash for their shares, they can generally turn a profit a year or two earlier than members who take financing. Cooperatives typically see no profits for the first 8-10 years, the period during which the initial investment in purchasing and installing the turbine (or turbines) is repaid. Once the loans have been repaid, and assuming the turbine is performing efficiently, shareholders can expect an annual dividend, typically in the amount of a few thousand kroner per share, depending on how windy of a year it was. From 1986-1996, the Tændpibe cooperative at Velling *Mærsk produced a steady 10-14% annual return for its 480 members, a*ccording to Per Krogsgaard, a principal at industry analyst BTM Consult and one the cooperative's founders. But Krogsgaard attributed the project's financial success largely to a good insurance policy, which had covered numerous repairs, and said that government bonds offered a similar rate of return, without the risks associated with a wind project. Another, smaller, Ringkøbing cooperative, Vognkær Møllelaug, produced a 6.2% return in 1995, according to founder Bøje Jensen, a local doctor. (Gipe 1995)

Compared to other models of energy development, Danish cooperatives are noteworthy for their transparency and their democratic organizational structure. Unlike the big corporate players in the wind business, who jealously guard financial and performance data on turbines they own as “business confidential,” cooperatives freely circulate this information among their members, and today many cooperatives even make it available to the general public online. This culture of information gathering and sharing was instrumental in the improvement of turbine technology and the dissemination of the cooperative model in the 1980s. Many cooperatives were started by a small group of highly-motivated individuals who did most of the legwork in getting the project off the ground and enlisting other members. So it is frequently not the case that all cooperative members are equally engaged in project management, but all members get the same vote in cooperative governance, regardless of the number of shares they own. The members elect a board of directors, who are responsible for the day-to-day administration of the project, but major decisions are usually made collectively, with the input of the full membership. These votes are often held at annual shareholder's meetings, though more frequent assemblies can be called if time-sensitive issues arise.

By the late 1990s, there were more than 2,000 cooperative windmills in Denmark. (32) They began appearing in official records as early as 1980—according to the owner's association the first cooperative was established that year in a small village south of Aarhus. (Tranæs 1996) As early as 1985 cooperatives were already among the leading financiers of turbine projects. A decade later, two-thirds of the wind capacity online in Denmark had been built either by a cooperative or a local individual. (Gipe 1995) A year later, in 1996, the owner's association reported 54,844 Danes belonged to turbine guilds. (Tranaes 1996) At the time, that was more than 1% of the country's population. Cooperative wind power was no niche curiosity.

How did owning shares in a windmill become so popular with the Danish public in a relatively short period of time? Certainly a range of cultural and environmental conditions—in particular, the shocks of the oil crises and their effects on home heating bills—encouraged the growth of this model. Interest in windmills was bolstered by the population's growing environmental consciousness, and frequent media coverage romanticized pathbreaking wind projects. The owner's association played a critical role in organizing early adopters, disseminating information, and representing cooperative interests in policy debates. Government pressure forced recalcitrant utilities to connect these distributed generators to the grid. Attractive investment subsidies and tax breaks made the projects economically viable. But these were still risky investments on an unproven technology—risks establishment actors were loathe to take. It is unlikely many cooperative shareholders had illusions of reaping windfall profits. Why, then, were so many ordinary people willing to take a leap of faith on these homegrown, amateur enterprises? If not riches, what did they expect to get out of direct participation in the electricity business? To gain greater perspective on the motives and experiences of the individuals who joined these unlikely collective ventures, it will be helpful to look more closely at a typical case.

Thisted Kommune on the northwest coast of Jutland is as experienced with wind power as any county in Denmark. Hundreds of mills have been raised in this heavily agricultural municipality since 1980. Many of these aging turbines still line the roads heading north from the railroad hub at Struer to the county seat. Folded among the rolling fields, they appear almost as a species of native flora, rising gently to greet passing motorists, then vanishing around the next bend in the road. One such turbine belonged to Jane Kruse, who today works with the Nordic Folkecenter for Renewable Energy, and about 50 of her closest friends and neighbors. (33)

Kruse was a young teacher leaving in the small village of Kallerup, and a veteran of the grassroots social movement that had successfully stopped government and industry plans to build nuclear reactors in Denmark. In early 1987, she and four of her neighbors began talking about putting up a windmill. Their next stop was to talk to four local farmers about renting their land, and then to the local utility. The electric company was supportive, and even recommended a site where the turbine could be cheaply connected to the grid. The property owner agreed to host the turbine, and wanted his family to join the cooperative themselves. So with the necessary approvals secured, the project leaders were ready to form a windmill cooperative, which they named Hornstrup Mark.

Kruse knocked on doors around her area, inviting all the locals to participate. About 30 people came to the first informational meeting, in which neighbors were invited to buy shares, at a price of DKK 3100 each (less than $500 USD). 392 shares were offered, based on estimates of the turbine's expected production, and individuals could buy up to nine shares. Twelve families signed up at that first meeting, and Kruse was elected chairwoman. Eventually, 49 of her neighbors would join the cooperative. On average, they purchased about a half dozen shares each. Eight different regional banks jumped in to offer the members loans to pay for their shares, which Kruse said about 80% of the members ended up taking. The total cost of the project, which would benefit from a 10% government investment subsidy, was DKK 1.2 million. With the capital pledged, the board members—all volunteers—next took meetings with a handful of different turbine manufacturers. They settled on the Vestas V25, at 200 kW the largest and most advanced wind turbine on the market at the time. The turbine was installed in early 1988, and thanks to the introduction on the V25 of cutting-edge components like pitch-regulated blades and an electronic control system, the machine consistently and significantly outperformed expectations. The payback time on the turbine was a little less than four years for shareholders who paid cash, and a little less than five years for shareholders who took a bank loan. After the turbine was paid for, shareholders received a dividend of a few thousand kroner annually, not a lot of money, but enough to cover small purchases like Christmas presents, which was what many families did with the money. The profits also paid for a party at the annual shareholders' meeting, which was eagerly anticipated by many members of the cooperative, and became a neighborhood tradition. Kruse counts these gatherings, and the community she built around them and with her fellow board members, as her fondest memories of her time running the cooperative.

Nearly twenty years later, a farmer interested in building a large new project elsewhere inquired about purchasing the Hornstrup Mark cooperative's windmill. In the interim, a repowering law had been adopted requiring the builders of new turbines to decommission an equivalent amount of the smaller, older windmills that now dotted the Danish countryside. Throughout the 1990s and 2000s investors bought up and took down thousands of these old windmills. The farmer's initial offer was rejected, but when he came back with a price of DKK 950,000—almost the full amount they had invested two decades earlier—a soul-searching meeting of the cooperative members resulted in a decision to sell. Tensions were high. “It was not a good evening,” Kruse recalled. With the turbine aging and the likelihood of major repairs growing, the money was too good to refuse, but many cooperative members seemed to have a keen sense of what they were losing by selling.

In spite of the significant amount of unpaid work involved, Kruse clearly cherishes her time with the cooperative, claiming she benefited in numerous ways from the experience. At home, she had a clear view of the windmill from her kitchen window, and whenever she noticed the rotor had stopped turning, she would ride out to the turbine on her bicycle and reset the controls herself, recording the outage in the logbook. This sort of technical ease with operating the windmill is just one of the types of “know-how” Kruse says she gained through the project. She also traveled the country sharing her knowledge of how to start and run a cooperative, wrote newspaper editorials, grew comfortable speaking in business settings, and learned how to manage the cooperatives' books. In addition to these skills developed through her participation, Kruse also said she learned discipline and responsibility from the project, and also enjoyed the feeling of “saying yes to something,” of being a part of something larger than herself that was beneficial to her community and the environment. Not to mention the turbine turned a profit every year.

On Kruse's telling, the cooperative was a positive experience for everyone involved, with few significant problems or drawbacks she could recall. The reasons for the cooperative's eventual dissolution had to do with the age of the turbine, the upcoming expiration of government subsidies, which would reduce the machine's profitability, and the white-hot market at the time for used turbines for the purpose of repowering. It had little to do with exhaustion of interest among the members. This apparent satisfaction with the experience raises the question of why Kruse and her neighbors did not simply form a new cooperative, after selling their old turbine. According to Kruse, they investigated that option, but by 2005 it had become impossible to find a location to site a new turbine project. She couldn't even get a quote on what it would cost to purchase land. The reasons behind this sudden land shortage—in one of the most out-of-the-way corners of Denmark—and additional factors that have precipitated the decline of the cooperative model will be addressed in the following chapters.

4.6 Conclusion: A Wind Energy Community

The 1980s were a transformational decade for the energy sector in Denmark, launching an overhaul of the electricity system that would accelerate through the end of the decade and beyond, and setting the tiny Nordic nation on a trajectory of green development for which it would gain worldwide renown. Initially a curiosity, the wind energy network that took root during this early period quickly became a competitive force in the Danish electricity system. This innovative and rapidly-expanding technology emerged from some unlikely places—not out of the research labs of the elite universities, or the factories of industrial giants, or the political and cultural center of the distant capital city, but along the scenic coastlines adjacent national parks in Mols and Thy, the blink-and-you-miss-them backyards and family farms on the outskirts of Herning, the isolated campus of an alternative high school run by a radical leftist teachers' collective.

The achievements of a colorful cast of underdog wind developers—students, farmers, environmental activists, neighbor cooperatives—are all the more impressive for their deficits of political and financial capital, of expertise, of access and authority enjoyed by the establishment actors who mostly stayed on the sidelines of this promising new trend. It's a winning story, a triumph for the common people. But it is only the first chapter of Denmark's ongoing experiment in powering a modern nation with the wind, and an outdated narrative, increasingly distant from the present realities of the domestic wind business. It has become something of a fairy tale, retold by the green energy lobbyists, now based in Copenhagen. It is a history that Danish turbine manufacturers, now multinational corporate giants with a reach far beyond their humble beginnings, like to claim as their own. But if the wind energy network that has become a dominant force in Danish politics, industry, and public consciousness bears little resemblance to the scruffy network of amateurs that cropped up in the 1980s, what is the value of repeating these well-documented origin stories, as the preceding chapters have done in somewhat exhaustive detail? Is it nothing more than propaganda? Nostalgia for the heady days on the frontiers? What can this early history, however remote from contemporary circumstances, reveal about the character and causes of Denmark's energy transition?

This dissertation has taken a close interest in observing the patterns of technology development through the course of an energy transition, and repeatedly returned to the question of what specific models of energy development can accomplish for the planet, for society, and for democracy. The preceding chapter followed key actors in the wind energy network of the 1980s, and discussed some of their most significant interactions with one another throughout that decade. This configuration of the Danish wind network, with its characteristic technological styles, species of developers, and patterns of relationships, can be thought of as a community, in an ecological sense. In drawing a finely-grained portrait of that community, the hope has been to understand something about how it was structured and functioned, how it emerged, how it was maintained, and the how its growth impacted the energy system and Danish society more broadly. What did these development models actually achieve? Could their efforts be called a success, and if so, in what ways? Would the community survive?

The most obvious legacy of these foundational efforts has been the exponential growth of wind energy in Denmark, which has remade the electric grid in a single generation. But the wind sector has evolved in ways that few predicted in the 1970s, and in directions that departed from the intentions of many early adopters. For some, the growth of wind energy has surpassed their wildest dreams. For others, the initial vision has been betrayed, and an opportunity to transform Danish society and politics is withering away. It should not be forgotten what the grassroots development models were unable to achieve—they were at their peak in the 1980s, and declined noticeably in the decades that followed. These *folkelig* approaches to wind development did entrench themselves firmly in the Danish countryside and the national psyche, and persist to this day in diminished forms, but it has never been harder to build turbines using the old models. They blazed a path for the future growth of the sector, and in the process were overtaken by new rivals. Was the grassroots era of wind development just an early developmental phase out of which the energy transition naturally passed? Was anything of note lost in the process?

Whatever its other strengths and limitations, the wind development model pursued in Denmark beginning in the 1970s produced a stable, and growing, renewable energy system. It is noteworthy that this had not yet been accomplished anywhere else in the world. Danes had been experimenting with wind turbines since the late nineteenth century; large industrial concerns and utilities had produced prototypes in the past, but these efforts were never able to build or sustain momentum. In the 1980s that changed, as the technology began to break through into the mainstream, successfully challenging the fossil-fueled status quo, and initiating the transition to a sustainable society—the first renewably-powered electricity system of its kind, the most comprehensive to date, and an effort that is still proceeding, now with significant momentum. These are not small feats of infrastructure development, organization building, and electrical engineering for high school students and pig farmers and neighborhood associations.

But historians of technology caution against just-so stories, and inferring from a technology's success that it possessed some aura of inevitability. The counterfactual questions can be asked: Could it have been otherwise? In the absence of the grassroots community, could some other pool of developers have achieved the same, or greater, results? Would the energy transition have proceeded anyway, in one way or another?

It would be foolish to suggest there is only one effictive or recommended means of carrying out a renewable energy transition, and the specific drivers and characteristics of technological evolution are highly context dependent. It is possible to chart alternative pathways in numerous countries, including in Germany, China, and the United States, (34) although wind energy would not gain a foothold in those countries for a decade or more after Danish development had begun in earnest. It is even possible to imagine alternative models for how wind energy might have taken off within Denmark. The utility conglomerates, with their technical expertise, financial resources and monopoly control of the grid, certainly had the means to pursue wind development in the 1980s, yet they actively resisted doing so.

If there are alternative pathways, options, choices, in how to develop sustainable energy systems, it's worth considering what has been tried, what has worked, what hasn't.

The Danish case offers a rich trove of experience that may not be directly replicable elsewhere, but still serves as a template for inspiration and refinement. Not all components of an energy system can be replicated exactly in changed circumstances, but nuanced knowledge of how different ingredients interact—their chemistry—along with illustration of how these ingredients have been successfully combined in the past—"best practices"—can inform efforts in other places or times. The last two chapters have attempted to do this descriptive work in some detail. In summary, the following pages assess some of the distinctive characteristics of the wind network that had solidified in Denmark by the end of the 1980s, and the chapter closes with some brief reflections on the broader political significance of this network's composition.

In 1975 there were no windmills producing electricity in Denmark. The nation was almost entirely reliant on energy from a handful of central power stations, which themselves depended on imported fossil fuels. By 1990 there were more than 2,600 wind turbines connected to the grid, with a total capacity of almost 325 MW. Collectively they supplied a little more than 2% of the nation's electric power. (Sawin 1996, 288) The rapid and accelerating growth in installed capacity throughout the decade is depicted in Figure 4.6.

The first generation of turbines sprouted across the countryside, often in single units or in small clusters, rarely of more than a half dozen machines. Large wind parks, common in the United States, were almost unheard of in Denmark until the utilities got involved in wind development in the late 1980s. More recently, the wind farm of dozens or hundreds of turbines has become the preferred model for offshore developments, and onshore arrays of several dozen turbines have become more common. But the average size of onshore arrays remains smaller in Denmark than in other countries, and sprawling onshore wind farms are still relatively rare, in large part due to the absence of suitably large plots of unoccupied land on which to build them.

The generating capacity of the first Danish turbines was trifling by today's standards, but already on an exponential growth curve, averaging only about 35 kW in 1980, then doubling to 70 kW five years later, and nearly tripling again to more than 200 kW by 1990. (Figure 4.3) These small turbines were far less intrusive than today's behemoths, with average hub heights growing from 15 meters in 1980 to 28 meters in 1990—still only about as tall as a mature oak tree. (Figure 4.5) Hub heights of today's state-of-the-art 3.6 MW onshore turbines can reach above 160 meters, roughly as tall as a 50-story skyscraper. (35) The visual and landscape impacts of wind turbines have increased dramatically from the 1980s to the present.

The companies manufacturing small turbines in the 1980s were entirely Danish-owned, often run out of local machine shops or by sole proprietors. Dozens of these micro- to medium-sized firms produced turbines for the home market, with names like Wind Matic, DWT, Kongsted, Kuriant, Nordex and Wincon. By the end of the decade, after several rounds of bankruptcies, mergers, moves, and rebrandings, a handful of leading manufacturers had emerged—Vestas, Bonus, Nordtank and Micon. The fight for market share would intensify in the 1990s, until eventually only two competitors remained.

Denmark's wind power plants were owned mostly by local individuals, either on their own land or by participating in community cooperatives. With the exception of a brief bonanza in 1985, legal restrictions mostly prevented speculators from cornering the market, and legacy institutions remained skeptical of the new technology. The utilities were similarly reluctant get behind wind power, with almost no presence in the market until 1987, and even then begrudgingly investing the bare minimum they had agreed to at the behest of the politicians. Still, utility wind parks became a significant presence by the end of the 1980s, demonstrating the speed with which these companies could initiate a large-scale transition, if they felt so inclined.

While the wind network had become well-organized by the end of the decade, and was increasingly professionalizing, at the ground level it remained highly decentralized. The more than 2,600 turbines feeding power to the grid were controlled by almost 700 independent entities, more than 70% of whom owned just a single turbine. No turbine in operation had a capacity of more than 750 kW. (36) This was a radical departure from the composition of the electricity system only a decade earlier, when the utility conglomerates operated less than two dozen central power stations, including several with capacities of more than 1,000 MW. (Danish Energy Agency 2017)

As several thousand small-scale generating stations proliferated around Denmark in the 1980s, the grid system had to adapt to this new distribution of electricity production. That meant ongoing investments in infrastructure, running cables to connect new wind capacity, and reinforcing sections of the existing grid to carry the increased loads. As the footprint of wind power expanded, grid balancing grew increasingly tricky, and Denmark became more reliant on interconnections with neighboring nations. In addition to the physical infrastructure required to support wind power generation, the administration of this network necessitated the acquisition of new knowledge and the creation of new technical and legal frameworks—grid connection standards for turbines, contracts for payment between the utilities and turbine owners, procedures for monitoring wind power production, and, if necessary, curtailing excess generation. These schemes defined new relationships among electricity producers and consumers, and structured new economies, as many Danish households that had previously been electricity customers now became suppliers.

As a consequence of all the experience gained in the 1980s, a lot of knowledge began to accumulate—of how to engineer, operate, finance and permit wind turbines. This knowledge percolated through unusually open and collaborative social networks, leading to rapid advances in turbine performance and accelerating the dissemination of new practices. Denmark gained a worldwide reputation for its wind energy expertise. Companies that only a few years earlier had been selling farm machinery increasingly concentrated on turbine manufacturing, training the skilled workforce needed to produce these increasingly sophisticated machines. The first-generation turbine models were built mostly from off-the-rack parts designed for other applications, but over the course of the decade a dedicated supply chain began to take shape in Denmark, fabricating specialized turbine components. Meanwhile, government agencies learned how to regulate this new technology, which was disrupting the established electricity system. University faculties assisted in these efforts, developing the means for measuring the nation's wind resources, and certification criteria for new turbine designs. Research centers were established, as were undergraduate programs to train the next generation of wind engineers.

Just as important as all of this knowledge gained was the institutional capacity that developed to store and transmit it. In addition to the creation of state entities like the new Energy ministry and the Risø test center in the late 1970s, industry actors successfully advocated for their interests through their professional association, and arguably no organization had a greater impact in growing the wind network than the owner's association, which gave private citizens the confidence and the practical tools to safely invest in the new technology.

But ultimately much depended on the choices of those lay citizens. Individuals are not prisoners of their circumstances, and can actively shape them. This chapter has taken a special interest in trying to understand what distinguished the pioneers who took the leap into wind power from the many other actors, some of them better-positioned, who hesitated. The chapter began with the story of a small-town teenager taking a gap year, who, armed only with his father's tools and some engineering magazines and indefatigable curiosity, bested NASA engineers at turbine design. Is the myth of the heroic inventor alive and well in this dissertation? Hopefully, the empirical analysis presented here sheds a little more light on the sources of the innovators' powers.

By identifying and analyzing the participants in the Danish electricity system, and the range of distinctive approaches to wind development, this study makes it possible to ask comparative questions about why some particular actors chose to develop and exercise their capacities, while others with the opportunity did not. At first glance, it might seem it was the establishment actors, the utilities and the government researchers, who were best positioned to push wind power forward. But these were the very actors who proved unable, initially, to see the technology's potential. Instead, it was the Henrik Stiesdals, the Torgny Møllers, the Jane Kruses who were the first converts. On traditional measures of political and economic power, these people would not seem likely to lead a technological revolution. What advantages did these outsiders possess that the better-resourced energy establishment lacked?

That the wind network emerged from the periphery of Danish society appears to confirm Henrik Lund's claim that radical technological change cannot originate from within existing institutions, since these radical challenges necessarily imply institutional change. According to Lund, institutional actors are inherently conservative, and will use their power to protect their privileged positions. Furthermore, the alternative technologies advanced by radical actors “do not form part of the imagination or perception of existing organizations.” (Lund 2014) This inability to conceive of wind power as an alternative to traditional generation sources is abundantly clear in the Danish case. It accurately characterizes the attitude of the utilities in the 1980s, when they simply could not take wind power seriously. It remains true into the present. The success of the sustainability movement in Denmark has remade establishment energy institutions, which have had no choice but to accept wind power as a core component of their businesses, but in a variety of ways these organizations are still resisting the distributed and intermittent characteristics of the technology. The dominant actors on the electric grid seem constitutionally incapable of fully embracing a radical restructuring of their traditional approaches to producing and disseminating watts. They are continually pulled toward highly centralized, hierarchical network structures, a tendency that recurred, and arguably only grew more pronounced, in later decades, as I detail in Chapter 6.

The people who launched the wind power revolution had a very different set of capacities, needs and interests. They were often people for whom the existing electricity system wasn't well-suited. Sometimes their complaints with the status quo were idealistic and political, sometimes they were practical and economic. More often, they were a mix of these factors. It is no accident that the first wind networks cropped up in rural Denmark, where early adopters drew on community values of cooperating for subsistence, and a do-it-yourself approach to problem solving. When the solutions they were looking for didn't exist, they scoured the junkyards and fired up their welders. This was not an unusual strategy in Danish farm culture. Many of the first turbine builders had access to tools and materials at home workshops; many were already skilled craftsmen with the requisite know-how. When they lacked experience with machinery, as in the case of Henrik Stiesdal or the Tvind school, they had no hesitation learning by doing. There were few possessive and competitive Thomas Edison-types in the early wind network. More often, they shared their experiences openly and collaborated willingly. These were people who were more interested in seeing their efforts succeed than claiming credit or making money; they were motivated by a shared vision of an alternative society. Unlike the utilities and government agencies, they had very little or no interest in preserving the status quo. They wanted to see a change. Building a wind turbine was an action within reach that, however small, was symbolic of a political stance. The wind energy entrepreneurs' relative lack of resources and social power proved to be advantages, in that these limitations made them more open to negotiation and cooperation, more willing to adapt, and less desirous of controlling the outcome. As a result, they actually had fewer constraints on the range of actions they were willing to consider and attempt when it came to the practical work of network building, with all its contingencies and indeterminacy. This freedom to experiment and perspective from the margins of the energy system and Danish society afforded them a vision and facilitated a social praxis that would have been difficult that would have been difficult to achieve from within established institutions, with all their formal rules and procedures and calcified cultures. The power of the amateur hobbyists was partly an effect of the comparative openness and flexibility of their networks, the wide diversity of the experiences from which they took in information, their free and frequent communication, their rootedness in their local contexts, their reliance on one another. In these respects, the capacity for innovation they possessed could be described as a sort of "ecopower," in contrast to the technocratic power of the government institutions and the utility companies.

The wind pioneers understood the value of putting their ideas into action, and, crucially, they found the courage to take that risk. Actors in privileged positions of power often have too much at stake in maintaining their standing, making them less willing to shoulder such risks, and less able to see threats to the order over which they preside, since they tend to be shielded from the impacts of changing circumstances.

This lack of vision—the creation of blinders that make certain risks and consequences invisible—is an effect of the organization of power, which hides and obscures, sometimes intentionally, sometimes by necessity, sometimes accidentally. Other scholars have described similar (in)capacities in terms of "legibility" or "translation." Translation is the rarely spontaneous, usually difficult, process of taking discrete entities from the social and natural environment and bringing them into alignment—getting them to work together, putting them in conversation, finding a shared point of view. Thus, following the work of actor-network theorists like Michel Callon, Kristian Hvidtfelt Nielsen has characterized the first generation of the wind system's development in Denmark as "the translation of wind power into more and more diverse areas, taking place by means of the association of heterogeneous entities." (Nielsen 2001, 427) This stepwise process of "translation" is similar to the way James C. Scott talks about making practices "legible" in *Seeing Like A State*. Scott accuses high modernist industrial societies of favoring an especially narrow sort of legibility, a "tunnel vision" that simplifies real-world phenomena, making possible a "high degree of schematic knowledge, control, and manipulation." These shorthands are extremely powerful tools, so long as the circumstances in which they are applied remain within narrowly-defined parameters, which they pretty much never do. That is why many of these modernist attempts to discipline and dominate nature have been unable to achieve their ends, or at least not without severe unintended consequences. (Scott 1998)

The processes of rationalization that Scott targets represent an opposite movement of vision—a narrowing rather than a widening—from the processes of translation discussed in technological systems theory. The latter are concerned with establishing relationships and contexts, rather than stripping them away to isolate mechanisms of control. It is this widening technique that built the wind energy network in Denmark.

This example offers a new vantage point for considering the evolution of technologies. Innovation appears as a necessarily collaborative process of finding common interests and complementary capacities, rather than the weeding out of winners and losers among competing visions. Innovations do not come about in flashes of genius or even strokes of good luck, but through the slow, steady work of alliance building and translation. The basic challenge for innovators is not bringing recalcitrant system components under control, but adopting a pragmatic and experimental approach, often relying on trial and error, to finding combinations that work. The resulting alliances may be temporary, and circumstances are always changing, making flexibility critical to long-term survival. This pragmatic approach to system building may lack the supposed immutability and global reach of the forces of rationalization, but, somewhat counterintuitively, its adaptability may be the very thing that enhances its stability in the long run. The creative and additive power of generating new forms may be better-suited to addressing the complex challenges of contemporary societies than the zero-sum power of reducing those problems to manageable formulas.

I would not venture that the Danish model of wind development is the only or best means of executing an energy transition, though, at this moment, it’s hard to say who would have a better argument. The development community described in this chapter had virtues that are worth taking seriously, not least of all for those hoping to find political democracy in processes of technological change. But one of the unavoidable outcomes of looking closely at the history of the Denmark’s energy transition is the realization that wind technology and the renewable energy community have always been, and remain, in constant flux. Technological development is much more fluid and much less punctuated than schematic theories can capture. However useful, even necessary, these categorizations may be for narrative and analytic purposes, they will always be somewhat artificial. As the following chapters will argue, complex sociotechnical systems are highly dynamic, and rarely settle into equilibria for long. New forms bloom continuously.

Even as windmill cooperatives were rising to prominence in the 1980s, this development model was already sowing the seeds of its successors. One of the individuals who would leverage experience and inspiration from the cooperative model to push wind development in new directions was Peter Møller. In the mid-1980s, Møller watched from the window of his family's home as a turbine rose in a nearby farmer's field. He began thinking, why couldn't he do that himself? According to his son, Jakob Greth, Møller was motivated by a desire to do something good for the environment, and if he could make a little money at it, that would be twice as good. So he organized about 15 of his neighbors and together they raised around one million kroner and purchased a 55 kW Vestas turbine. The financial returns on the project were positive, so Møller thought, why not build even more? He parlayed his experience managing the cooperative into a new career, working first for turbine manufacturer Danish Wind Power, and then for Nordtank, and later opening his own consulting firm. He traveled the country seeking out development opportunities and advising new investors, mostly cooperatives. All told, over three decades he participated in more than 100 projects. When restrictions on investment were relaxed in the 1990s, he formed two new businesses, PMN Holding and JP Wind Ltd, to invest his own money, eventually acquiring ownership of a dozen turbines around Denmark and three more in the United Kingdom. After his death, his son took over management of the businesses, which provide the family with a steady income from the turbines in operation. (37)

By the 1990s, wind energy consulting and investment firms like Møller's became so adept at cornering the market that they began to threaten the cooperative developments on which many of them had cut their teeth. The idealism that had initially motivated the likes of Henrik Stiesdal—and Peter Møller—to experiment with wind power and the environmental activism that provided political and organizational support for the early entrepreneurs would take a back seat to market logics and profit motives, as Danish wind power became more of a business, and less of a movement. The following chapter investigates how this transformation of the wind network occurred, and with what consequences for the progress of the energy transition. Wind power in the 1990s would grow exponentially, moving from the fringes to the center of the national economy and government energy plans. The wind system was getting bigger, but did bigger also mean better, stronger, sturdier? The wind community gained new members and new capacities as it infiltrated the board rooms and the halls of parliament, but at the same time, it became increasingly apparent that some of the distinctive elements that had made Danish wind power unique, and uniquely successful, were falling by the wayside.

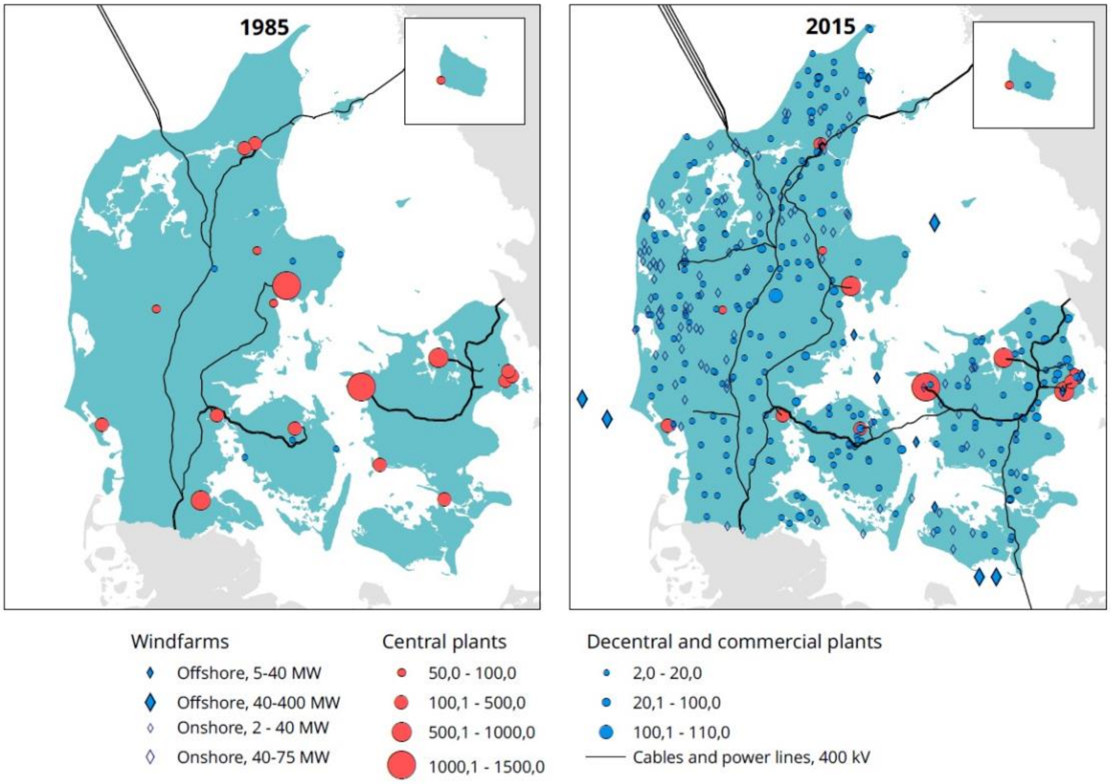

Figure 4.1. Large power plants in Denmark in 1985 and 2015. Note that only wind installations larger than 2 MW are pictured, which excludes thousands of smaller mills erected since 1980. Source: Danish Energy Agency 2017.

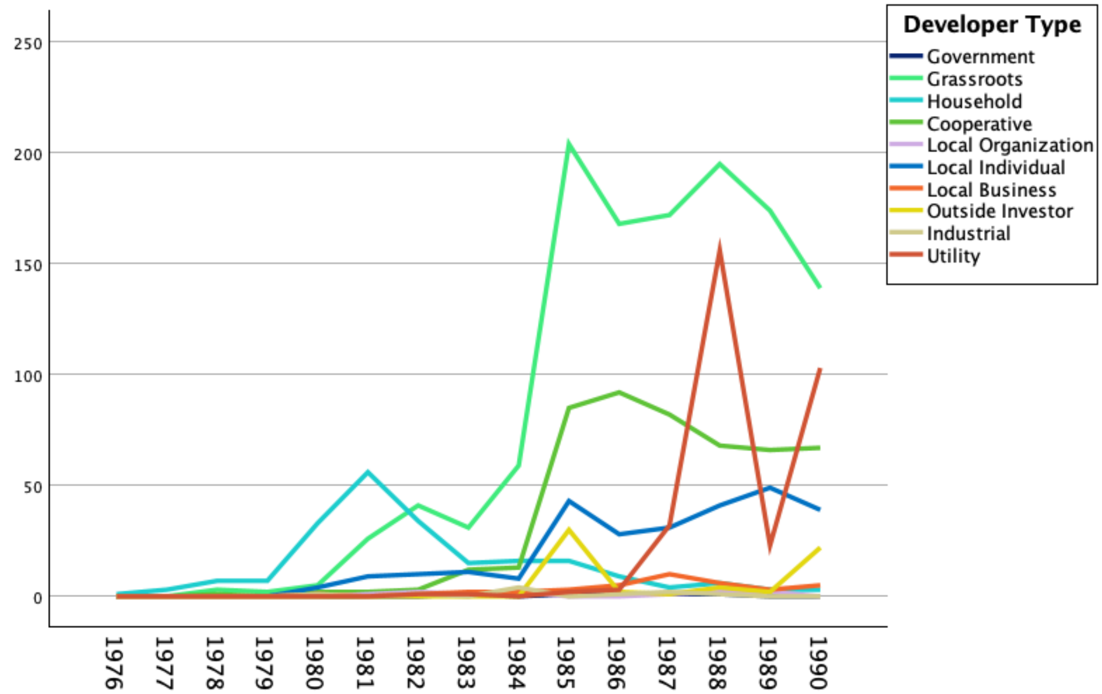

Figure 4.2. The growth of the Danish wind network from 1980-1990, categorized by type of project developer. For a full explanation of the developer typology, see Appendix A. Local, grassroots developers dominated the domestic wind scene for most of the decade, but note the brief bubbling up of outside investment when residency requirements were relaxed in 1985, and the large spikes in utility installations at the end of the decade, aimed at fulfilling a pledge to build 100 MW of capacity.

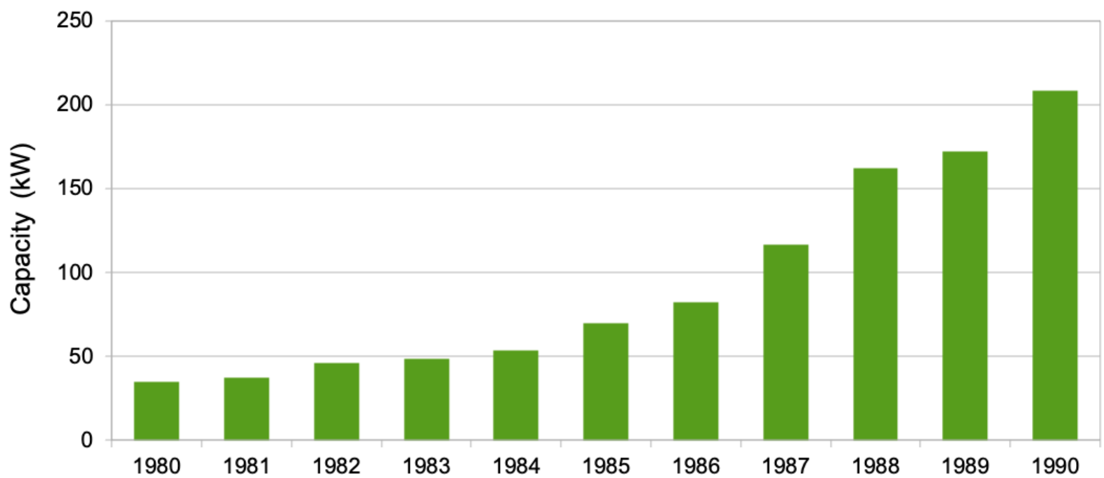

Figure 4.3. The average turbine capacity of new installations, 1980-1990.

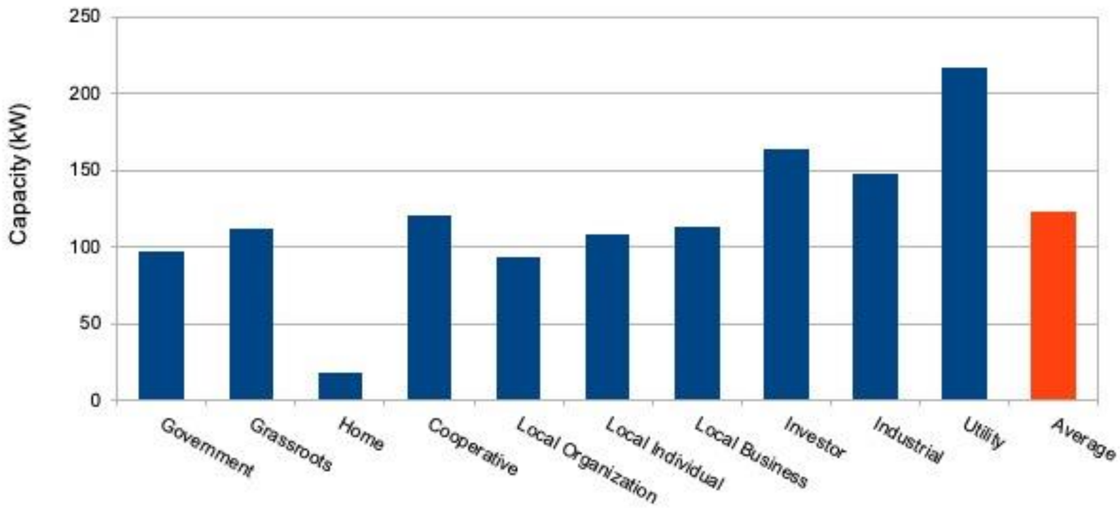

Figure 4.4. The average turbine capacity by developer type in the 1980s. Note that the more business-oriented development styles toward the right side of the chart favored larger turbines, a trend that continued in later decades. In this chart, the relatively large average size of utility installations is somewhat skewed by the fact that the utilities only entered the wind sector at the end of the decade, when the capacity of turbines available on the market had increased.

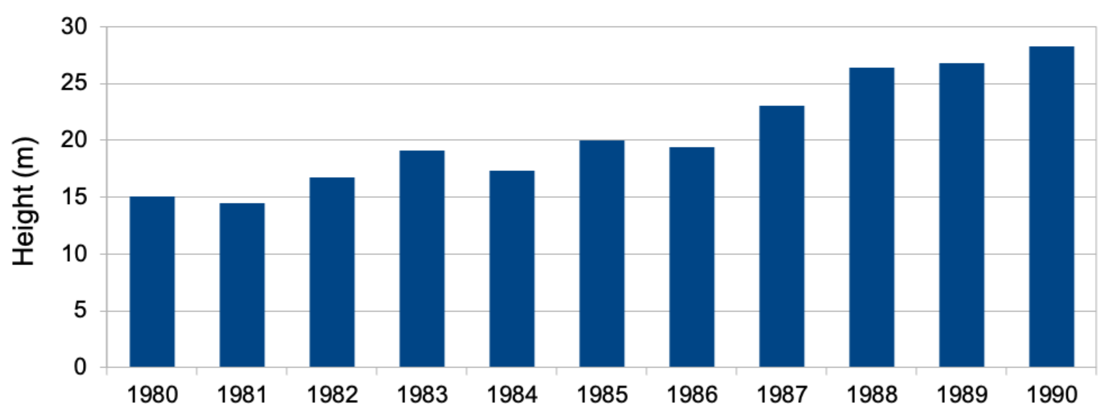

Figure 4.5. Average hub height of new turbine installations in the 1980s.

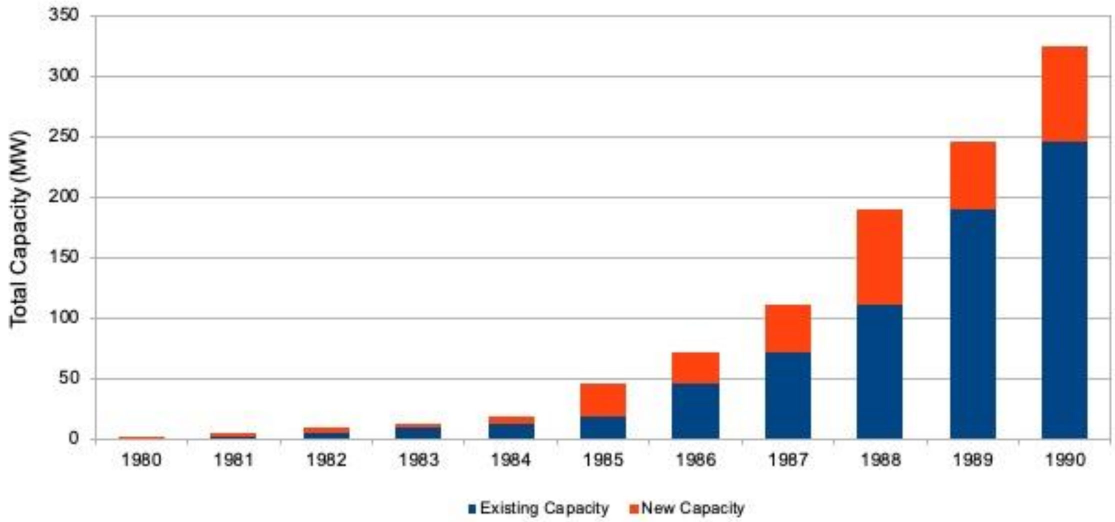

Figure 4.6. Total new and existing wind capacity installed in Denmark in the 1980s.

Notes

1. From personal communication with Henrik Stiesdal, Odense, Denmark, May and June 2015.

2. ibid.

3. ibid.

4. ibid.

5. ibid.

6. ibid.

7. ibid.

8. ibid.

9. ibid.

10. ibid.

11. ibid.

12. More information on the Great Belt power cable is available at energinet.dk, http://energinet.dk/EN/ANLAEG-OG-PROJEKTER/Generelt-om-elanlaeg/Sider/DenelektriskeStorebaeltsforbindelse.aspx

13. From personal communication with Christina Aabo, DONG Energy headquarters, Fredericia, Denmark, May 2015.

14. It is telling that when utilities began to seriously invest in wind around the year 2000, they often had to clean house in their engineering departments, phasing out their older coal power plant engineers for a new generation. This transition is discussed in more detail in Chapter 6.

15. For example, the regional transmission system operator in the Northeast, ISO-New England, has estimated that an additional $20-$25 billion would need to be invested in the grid to support wind turbines generating 30% of the region's electricity. (ISO New England 2010, 21) It is unknown at present where the money for such costly upgrades would come from, or when the improvements might be made. It is a credit to the foresight of the Danish grid operators that comparable investments have already been made over decades, producing one of the world's most modern and robust grid systems.

16. Statistics from Danish Energy Agency 2016. From 1990 to 2015, electricity consumption actually increased 13% at the same time overall energy consumption declined. These divergent trends can be explained by Danes' increasingly switching from oil to electric heat pumps, boilers, and vehicles. (Energinet.dk 2016) Since electric heating and transportation can be fueled by renewable sources, the growing percentage of Denmark's energy needs served by the grid indicates progress in transitioning away from reliance on fossil-fueled technologies.

17. Henrik Stiesdal explicitly credits the owner's association, DVF, with championing the early state subsidy programs. (Stiesdal 2013, 273) But DVF pushed for policy support for wind development in association with another of other interest groups, notably turbine manufacturers and environmental activists. According to social scientists Peter Karnøe and Ulrik Jørgensen, “the alliance between the energy idealists, especially OVE, and the group of wind-turbine owners created a political pressure group with strong and direct connections to political parties in parliament.” (Jørgensen and Karnøe 1995, 75) Kristian Hivdtfelt Nielsen has detailed an example of this collaborative rule-making process in the creation of the Risø Test Station's system approval scheme in 1981. After a protracted debate involving editorials, letters, and face-to-face meetings that dragged into the winter of 1982, representatives of the manufacturers' association, the owners' association, OVE, the Test Station and the Danish Energy Agency hammered out a compromise agreement. (Nielsen 2001, 221-237) This sort of collaborative governance was typical of Danish renewable energy policy throughout the 19880s.

18. From personal communication with Preben Maegaard and Jane Kruse, Hurup, Denmark, August 2015.

19. ibid.

20. From personal communication with Anne Højer Simonsen, Copenhagen, Denmark, May 2022.

21. Descriptions of Møller's property compiled from articles in Windpower Monthly, interviews with close associates of Møller, and the author's visit to Mols national park.

22. The size of the first turbine is variously reported as 7-17 kW. Likely the differing sources are referring to several stages of prototypes Riisager constructed. Jensen 2014 records the size of the final prototype as 15kW.

23. In characterizing the qualities that made Møller's ventures successful, longtime friend and collaborator Lynn Harrison called him tirelessly optimistic and a skilled communicator, as well as clever and resourceful. Of Møller's political leanings, said he “was too much of a businessman, too sharp, to be a hippie, but he had tendencies in that direction.” From personal communication with the author, Aarhus, Denmark, July 2015.

24. Møller, Torgny. 1978. *Vinden vender : en historie om et år med vindkraft, forskere, politikere, storindustri og gullaschbaroner*. Knebel, Denmark: Vistoft.

25. From personal communication with Lynn Harrison, Aarhus, Denmark, July 2015.

26. ibid.

27. From personal communication with Preben Maegaard and Jane Kruse, Hurup, Denmark, August 2015.

28. ibid.

29. This observation comes from several conversations the author had in 2015 with industry and Folkecenter representatives, during which several specific accusations were mentioned.

30. The Hvide Sande cooperative is discussed further in Chapter 6.

31. Initially, the number of tax-exempt shares was limited to the equivalent of 135% of household consumption, though that limit was relaxed to 150% in the 1990s. (Nielsen 1999)

32. Wind expert Paul Gipe estimated the number at 2,100 in 1996. (Gipe 1995) My own analysis of the Danish Turbine Registry has identified more than 1,280 cooperatives, which likely underestimates the actual total, as numerous older windmills have been sold to private investors, making it difficult to identify their original owners—many of which can be safely assumed to have been cooperatives.

33. The description of the Hornstrup Mark cooperative in this section is recounted from personal communication with Jane Kruse at the Nordic Folkecenter for Renewable Energy, Thisted Kommune, Denmark, July 2015, and cooperative records supplied by Kruse.

34. For case studies of the United States, Germany and China, as well as Canada and Japan, see Valentine 2014.

35. The hub height, a standard measurement of the size of turbines, is roughly equivalent to the height of the tower. It measures the distance from the ground to the nacelle, which houses the major subcomponents, such as the drive shaft and generator, and on which the rotor is mounted. Sometimes the height of a turbine is measured to the blade tip, which is the hub height plus the radius of the rotor (the length of a single blade).

36. From the author's analysis of the Master Data Register of Wind Turbines published by the Danish Energy Agency. See methodological appendix for more information.

37. From personal communication with Jakob Ferløv Greth, Aalborg, Denmark, June 2016.

CHAPTER 5

SETTLEMENTS: DENMARK'S ENERGY TRANSITION LOCKS IN

5.1 Introduction

Nearly two decades in, Denmark's renewable energy transition was still in its infancy, but the transformations underway were becoming more noticeable, and the stage was set for an explosion of growth. Throughout the 1980s, thousands of quaint little turbines had sprung up across the countryside, acclimating most Danes to the idea of generating power from the wind, allowing a domestic industry to germinate and mature, threatening the dominance of the utility monopolies and reducing the country's reliance on fossil fuel imports, among numerous other developments. Yet wind energy remained a minor contributor to the overall energy mix, with a total of 326 MW of wind capacity installed by 1990, generating only 1.9% of the electricity supply. A decade later, the share of wind on the grid had increased more than sixfold, to 2340 MW supplying more than 12% of the nation's electricity. (DEA 2022, 9-12)

The yarns I have spun in preceding chapters about scrappy enthusiasts and pioneering innovators are inspiring, perhaps to a degree mythologizing, and offer practical guidance for how to incubate ahead-of-the-curve technological experiments. But the serious people who wear suits to work care about scale. They think in tons of CO2 emitted, and not kilowatts, but gigawatts generated. While the macro-scale perspective on energy and climate favored by businesspeople and bureaucrats has its own limitations—as I argue throughout this dissertation, it can obscure important micro-scale processes and distinctions, critical in understanding how to successfully execute an energy transition—it also captures some unavoidable truths about the nature of the problems the energy sector is grappling with today. The climate crisis cannot be solved by erecting a few windmills in far-flung locales in a tiny country. Achieving five or ten or even 20 percent grid penetration for renewables will not be enough. As increasingly-alarmed climate scientists have repeatedly warned, in order to have any hope of avoiding catastrophic environmental changes with cascading social consequences, industrial societies must rapidly get closer to 100% renewable energy. In other words, what is needed is systemic change.

Many countries have now, belatedly, made marginal investments in promoting the growth of renewables. No wealthy nation has been more committed to or made more progress in transforming its energy system than Denmark, making it a case of singular analytic value. To some extent, the Danes have already walked the path other countries must follow, and many lessons can be gleaned from their experiences. While decades of work remain ahead, the historical evidence suggests that Danish society reached a tipping point in its energy transition sometime around the turn of the new millennium. In the 1990s, successive governments singled out wind as the present and future in their energy planning. The full embrace of renewables by the corporate sector would have to wait until after 2000, as I detail in the next chapter, but already by 1990 investing in the wind had become an attractive business proposition, and not merely a political statement or a matter of home economics. The renewable energy sector evolved from an insurgent challenger to the status quo, the new normal in Denmark. (Aklin and Urpelainen 2018, 183) How did the Danes do it?

Scholars of energy policy have in recent years put forth numerous theories of how energy transitions are stimulated and sustained. In the following section, I will survey some of the more prominent recent contributions to this literature. In the 1990s, the Danish wind energy network achieved what scholars of business, technology, and public policy have all referred to as "lock-in." I already discussed in Chapter 2 how organizational and political ecologists also frequently employ this terminology. Historian of technology Thomas Hughes developed the analogous concept of "technological momentum" to describe the stage of development during which technological systems mature and acquire inertia.

While much of the recent scholarship on renewable energy policy frames its analysis as expressly political economic, none makes the leap to political ecology. It is worth noticing that all the schools of thought on "lock-in" are conceptualizing technological and social developmental processes in basically evolutionary terms. I detect a lurking affinity for ecological ideas in their models that is never explicitly articulated; the stages they describe of technological and policy evolution call to mind theories of ecological succession. If I am right in making that link, it puts these theoretical models on somewhat dated ground as political ecology. Antiquated models of ecological succession are probably one of the most challenged well-known theories of ecological science. Stability is a relative and effervescent quality in natural systems. I suspect part of what biases ecologists toward this more skeptical take on concepts like the "climax stage" is their preference for the close, grounded study of local ecosystems, where all they see is constant flux at the micro-levels. (Drury 1998) Though early-twentieth century succession theory should not be taken too literally, as some kind of structural destiny, my estimation is that it retains some analytic utility as a rough approximation of widely-observed processes common at the ecosystem level, such as the usual succession of tree species in maturing forests. Many biologists would endorse the proposition that a defining feature of biological systems—from organisms to ecosystems—is that they are largely self-regulating. (Carroll 2016) The degree to which the homeostatic properties observed in organisms can also be applied to ecosystems is a matter of controversy. At one end of the spectrum is Gaia theory, whose basic proposition is that the Earth's intersecting systems do self-regulate, functioning in a way that resembles a superorganism. (Lovelock 1975) However far one is willing to travel with the superorganism hypothesis—Gaia theory founder Lynn Margulis didn't even accept the comparison—it is evident that on a day-to-day basis, high levels of regulation are visible in nature, at all levels of earth systems, indeed, all life depends on the stability of these systems. But observing all this high-functioning stability does not mean it is guaranteed, or should be taken for granted. Biological systems fall out of homeostasis all the time, which keeps doctors and undertakers employed. Systems can decline slowly or collapse suddenly. Technological systems share this propensity to lose equilibrium, and to the extent they do achieve the inertia and permanence of "lock-in," it is only relatively so, as multiple periods in the Denmark's history with wind power attest. For proponents of renewable energy development, it is critical to understand the forces that can destabilize an energy transition already underway, and how to get the process back on track.

The main conclusion of recent public policy research on energy transitions is that they require stable government policy support, and whether or not such policies can be passed and implemented depends on the outcomes of pitched battles between opposing interest groups. My analysis of the Danish case generally supports the first proposition—the policy environment is clearly a critical layer of any technological ecosystem. The

Danish case offers dramatic evidence of how policy decisions can either stimulate or suppress the adoption of renewable energy. As industries mature and achieve lock-in—as has occurred in the wind business, where production costs have dropped precipitously—less and less direct financial support may be needed over time, though price sweeteners and tax breaks for wind producers are not the only forms of government policy that sustain wind energy systems, an often-overlooked fact in analyses that focus on subsidy schemes. Supportive policies and administration are needed at all levels of government, and at various levels of the value chain and system function, maintenance of the grid being one of the most significant areas where infrastructure policy provides essential support to wind businesses.

Most of the current literature on renewable energy policy frames Denmark as a case of a "successful" transition, thanks to an unusually stable policy regime made possible by the triumph of a coalition of clean-energy interests over comparatively weak opposing groups. My case history does find some evidence of the interest group dynamics described in these theories present in the Danish case. But explanations that focus on the stratagems of institutional actors within the formal policy arena grossly oversimplify the forces that set Denmark on its current renewable energy trajectory. A closer look at the history examined in this dissertation reveals a far more complicated picture. Despite starting earlier than other industrial nations, and on the balance ramping up government support for renewable development over time, policy schemes have not been stable or smooth, but iterative and stochastic. The most distinctive feature of Danish energy planning over the past four decades has been consistent and constant activity. Danes revise policies on an almost annual basis. Some of those revisions have been relatively minor tweaks, and gradually expanded support for wind energy, others have been dramatic shocks to the system, interruptions, and setbacks. But every step in the evolution of the country's energy policies has had significant consequences for the character of wind development. Interest groups coalitions have been shuffled over time, new interests have emerged, new players have become dominant. The reduction of the relevant parties to pro- and anti-wind groups in the public policy literature on energy transitions obscures this variation, and its significant political effects. When these internal dynamics are taken into account, the success of Danish energy policy looks far more contested, and far more uncertain. It is too early for Danes to take a victory lap, an unsettling reality of which only the closest observers of their energy transition seem to be aware.

The interest group model has two major shortcomings as an explanatory theory. Certainly, lobbying groups have substantial influence in the formal policymaking process, including in Copenhagen. But recent studies of renewable energy policy have tended to take the composition of interest coalitions and their policy preferences for granted. They reveal little about how interest groups emerge, how they gain power, or how their preferences shift over time. The ecological perspective I apply to the analysis of the Danish case generates more robust data for answering all of those questions.

Secondly, wind power has achieved "lock-in" in Denmark to that extent that, in all likelihood, there will be a significant number of wind turbines connected to the electric grid for the foreseeable future. That does not mean that the wind network can coast on its momentum, or that it will continue to grow in the next three decades at anything like the pace it grew during (most of) the last three decades. The challenge of getting to 100% renewable energy will likely present a very different set of obstacles than getting to 50% did. One of the major contributions of this dissertation to theories of technological innovation is its novel attention to the late-stage dynamics of mature energy systems. Technological systems do not settle into some sort of stable equilibrium once they reach maturity; they continuously evolve. Failure to consider these ongoing fluctuations within interest coalitions, policy regimes, and technological networks leads public policy scholars into some wayward recommendations for how governments can encourage energy transitions.

At the same time it was breaking through into the mainstream, the Danish wind business in the 1990s was undergoing some dramatic shifts. A new development model was emerging, and beginning to displace the first-generation wind network composed primarily of farmers and local cooperatives. A combination of policies, technical developments, and sociocultural factors fed back on one another to drive this reconfiguration of the wind system. The profile of the newest entrants often looked like Peter Møller—they were typically proprietors of small and medium-sized, often family run, development firms, who got into the wind business primarily to turn a profit, and usually without any larger political motive. The next section takes a closer look at this development model, and the factors that facilitated its growth. The following sections identify several weaknesses of recent scholarship on the policy dimensions of renewable energy transitions, then draw on that analysis to explain how Danish policymakers set the country on a path to carbon neutrality beginning in the 1990s. The chapter closes by presenting several case studies of the varying experiences of municipalities around Denmark with wind power, in an effort to show how the interaction of local and national politics impacts the course of energy development, a complicating factor that is often missed in studies that focus only on local cases, or only on national institutions and policies.

The major contribution of the present study to this policy literature is its sustained attention to tracing the history of the world's most advanced energy transition, at multiple levels, across multiple technical, social, environmental and political dimensions. This nuanced portrait reveals the internal system dynamics that reshaped the wind coalition and set the energy system on its current trajectory. Identifying a range of distinctive developer types—from home turbines and cooperatives to for-profit firms and utilities—allows me to introduce within-case variation that makes possible a far more thorough process tracing than previous research on the Danish case has attempted, showing how competing development models interacted, influenced policy, and fared through the decades. Previous chapters detailed how the utility sector underestimated wind power in the 1970s and 1980s, and they remained mostly begrudging participants in Denmark's energy transition through the 1990s. The influence of farmers and cooperative developments that had pushed against the utility consensus had peaked, and began to wane as they were increasingly muscled out by more professional firms. It is to this professionalization of the wind sector that the discussion turns now.

5.2 Profiting off the wind

Wind entrepreneurs like Peter Møller quite literally watched the wind industry grow up. During his lifetime, he built turbines ranging in size from 50 kW to 3.6 MW. A key factor that precipitated the professionalization of the wind business in the 1990s was the rapid advances in turbine engineering. Danish manufacturers were putting ever-larger models into production, thanks largely to the accumulation of experience in both California and on the home market, to feverish domestic competition, and to the incrementalist design philosophy that initially overbuilt turbines for reliability, allowing Danish firms to quickly scale up their initial successes, while wind programs in other countries flamed out and had to go back to square one. In 1981 and 1983, Danish academics had produced alternatives to the government's official nuclear-powered energy plans detailing pathways toward an "alternative" future, in which up to 10% of the country's energy needs could be supplied by tens of thousands of small turbines. (Nielson 2001, 137-139) Only a decade later, those projections already looked wildly unambitious, mostly because the latest turbines were capable of producing far more power than those models had assumed. Vestas' first turbines were rated at only 22 kW, enough to power a small family farm. But the company almost immediately increased that output tenfold with their second-generation, 225 kw machines. By the 1990s, the rated capacity of commercial turbines grew another order of magnitude, reaching 1-2 MW, giving wind farms enough juice to power hundreds or even thousands of homes.

The hundred-fold improvement in turbine capacity over the course of a decade had a range of consequences for the wind network, including financial implications that worked to the benefit of private investment firms. The kilowatt-scale turbines of the 1980s had been within reach of homeowners, neighbor cooperatives, and family farm businesses. Energy planners estimated that 55 kW turbines cost on the order of 450,000 DKK (around $65,000 USD), feasible to finance by pooling savings among shareholders or taking out a bank loan with a home or farm mortgage as collateral. Rural community banks specialized in financing projects on this scale. But the larger the development projects grew, the more investment capital they required, necessitating more complex financing mechanisms and more professional management. Peter Møller's son, Jakob Ferløv Greth, told me that the increasingly technical nature of planning a wind project was one of the major factors that had marginalized the community development model. Greth estimated that 95% of new wind projects today were being built by for-profit interests. "It's getting too difficult for private people," he said. "For me, it's a full-time job." (1)

The growing scale of wind projects also made them an increasingly attractive investment opportunity for private capital. Installing a wind turbine was no longer just a means of subsidizing winter heating costs, or funding Christmas celebrations. As megawatt-scale turbines hit the market, it became clear to those watching the industry that there was serious money to be made. Speculation on wind farms by wealthy individuals had been disastrous in the United States, and briefly in Denmark, in the 1980s. Since those investments were made primarily as tax writeoffs, the investors had little incentive to ensure the quality of the projects they built as they rushed to snap up generous government subsidies, or the longevity of those projects once the subsidies disappeared. The Danes partly addressed this perverse investment incentive by switching from investment tax credits to a production-based subsidy scheme in the 1980s. The Danish government also imposed strict residency requirements on who could own a wind turbine, essentially limiting development to individuals putting up turbines in their own backyards, and keeping land speculators at bay, until those restrictions were loosened later in the decade, and eliminated entirely in the 1990s.

As the market opened up to more outside capital, raising a windmill in Denmark looked like an appealingly low-risk investment due to the alignment of several factors in the domestic policy and institutional environment. The government had funded extensive mapping of the nation's wind resources, and also sponsored the collection and publication of turbine production data, making it relatively easy to accurately forecast expected production with given equipment at a given site. The Danish feed-in tariff furthermore stipulated a guaranteed price turbine owners could expect to get for each watt of electricity they produced. Under these conditions, investors calculated wind developments could typically be paid off in 4-5 years. As long as the turbines didn't experience major mechanical failures before then, the investment would turn a profit. The strong business case gave Danish banks confidence to make loans to all types of investors. "Seen from the bank's perspective, it is a very safe loan," Greth said. (2)

Greth made his first investment in a wind project in 1997, at the invitation of his father, while still a university student studying civil engineering and acoustics. He recalled worrying, at the time, how he would pay back the bank loan if the project failed. "It felt like a risk, but not a big risk," he said. The reason he felt comfortable taking the risk was primarily his father's past experience with wind projects, which had always generated a good financial return. This project proved to be no exception, and Greth still owned the 600 kW Micon turbine, which was still generating annual returns some 20 years later. (3)

Peter Møller had built his expertise in the wind sector on the old development model—beginning in the mid-1980s by organizing a small cooperative with his neighbors to purchase a 55kW Vestas turbine, as described at the end of Chapter 4, and later working directly for turbine manufacturers Danish Wind Power and Nordtank (which through a series of mergers was absorbed by Micon, and then Vestas), supplying equipment and technical know-how to other community wind developments. Greth estimated that his father had participated in somewhere between 150-200 wind projects around the country, many of them cooperatives. (4) Møller leveraged this experience in Jutland's hotbed of wind innovation to go out on his own in the 1990s. Although he had grown from roots in local farming communities, he was helping pioneer a very different approach to energy development. One significant way in which the emerging model of investor-owned wind farms differed from the community development model was in how these projects were registered for tax purposes. All Danish wind turbines—even anarcho-communist projects like Tvindkraft—are technically for-profit enterprises by virtue of being connected to the grid and receiving payments from the utility companies for the electricity they generate. However, most of the early turbines raised by farmers and hobbyists were registered as sole proprietorships, *enkelmandsvirksomhed*, for which the owner is personally liable. Local cooperatives were usually established as partnerships, I/S or *interessentskab*, in which members share liability for debts. The new investment firms, by contrast, were usually registered as A/S or ApS, *anpartsselskab*, the Danish equivalent of a limited liability corporation. One Copenhagener who owns shares in a cooperative wind farm explained to me that the organization of the project as an I/S made him hesitant to pass on his shares to his children, since he worried about the joint liability for repairs as the turbines aged. The potentially large risk, he deemed, was not worth the paltry rewards. (5) Such fears are probably unlikely to be realized—well-managed cooperatives budget for expenses like repairs and decommissioning—however, the risks to amateur investors have become more serious as projects have grown in scale. The financial risks associated with raising a small turbine worth $100,000 USD on a neighboring farm are orders of magnitude smaller than the risks associated with building and maintaining multimillion dollar offshore arrays. The shift in how wind projects are funded that began in earnest in the 1990s is just one example of how the tax and lending structures in Denmark that had facilitated citizen participation in the wind network in the 1980s are today disincentivizing community development. Professional firms employ the whole gamut of modern financial tools to minimize their investment risks, often obscuring the true ownership of a project behind a web of shell companies. In these respects, Peter Møller's operation is a relative minnow, a small family business operating a total of 15 turbines in Denmark and the United Kingdom under three corporate entities: Peter Møller Vindmøllerådgivning ApS, PMN Holding ApS, and JP Wind Ltd. After Møller's death, his son Jakob took over the family business, which he personally runs from his apartment in central Aalborg.

Just 50 kilometers south of Greth's apartment, perched along the inner edge of the Mariagerfjord that cuts through northeast Jutland, Jens Rasmussen is running another wind company with a similar history, but one that has scaled up more aggressively. Like Greth, Jens and his brother Søren learned the wind business from their father, Ove, who, like so many Danish wind pioneers, had close personal ties to the early innovators described in chapters 2-4. Ove Rasmussen, an electrician from Hobro, had visited Torgny Møller in nearby Vrinners in 1977. "At that time, many people encouraged the public to utilize renewable energy, but not many people took action. And nothing will happen if we just continue to talk about it," Ove once said. Seeing that Møller was getting good production from his Riisager windmill, Rasmussen decided to purchase and install one of his own at the family farm in Hobro. (Eurowind) Today, the rotor of that Riisager turbine is handsomely mounted inside the two-story atrium of the company's sleek modern office building. When I visited, the brothers' twin Tesla sedans were parked side-by-side near the front door.

Their father Ove went on to help Torgny Møller found the wind turbine owner's association in 1979; the organization's central role in promoting the first generation of wind development was described in Chapter 3, and Danish policymakers regularly cite the group as one of the most influential lobbies in national energy policy debates. During the 1990s, Ove invested with his sons in a dozen turbines in Denmark, though the business remained a sideline to their day jobs. Søren had become a pig farmer, and Jens had trained as an electrician, which gave him some hands-on experience in windmill construction, when he built a transformer for a 750 kW NEG Micon turbine. He then started an energy consulting firm in the UK, working on the commissioning of coal-fired power plants. Jens recalled feeling trepidation similar to Jakob Greth's when he bought into a wind development for the first time, purchasing half a turbine near the resort town of Skagen, at the far northern tip of Jutland, 1999. Like Greth, Jens Rasmussen still owns that initial investment. Jens made clear that his motives for investing were largely financial, though he did say that growing up around wind turbines was one "soft" factor that made the industry more appealing to him. (6)

In the 1990s, gearbox failures were distressingly common in the first generation of large turbines, and though Rasmussen calculated his investment would break even after five years, he worried about how he would repay the loan if the turbine only lasted three years. But the risk-return ratio made sense. Over the last two decades, those mechanical risks have decreased significantly. “Today we are more confident,” he said, “simply because we have more experience.” Contemporary onshore turbines are a mature technology, field tested and highly reliable. (7)

Jens and Søren founded Eurowind Energy in 2006, initially to invest in German wind turbines. The company only began developing wind projects in the Danish market after 2009, and has since grown rapidly, to more than 100 employees today. Business records indicate more than a half dozen interlinked corporate entities registered at the address of the company’s Hobro headquarters. Jens told me that the company owned about 120 MW of wind projects, though only 12 MW were in Denmark at the time. The company managed a total of 50 MW of wind in Denmark. (8) Since we spoke, Eurowind in 2019 purchased the portfolio of another medium-sized investment firm, SE Blue Renewables, adding another 184 MW of wind power to their books. (Eurowind)

Eurowind Energy is a full-service project management firm, involved in the full life cycle of a wind development, from the initial planning and design phases, to construction, operation, and decommissioning. The firm does subcontract a number of aspects of the projects it manages, including engineering design and the servicing of operational turbines. While the company now has stakes in wind projects across Europe, most of their Danish projects remain close to their headquarters in Jutland. “Our success rate is highest closest to home, It’s always like that,” CEO Jens Rasmussen explained. “If you can feel politicians are not eager to do projects in certain areas, you can get an easier feeling that it’s going to be difficult when you are close to home. When you are 200km from home and you don’t know anyone in the administration you don’t get that feeling.”

(9) Eurowind's website further details how Søren's agricultural network has been crucial in building relationships with the farmers who typically lease their land for wind developments, and the company has even hired former farmers to staff their domestic division. (Eurowind) This sales strategy echoes how Vestas built its turbine business in the 1980s by leveraging its network in the farming community.

Just as it has been a hindrance to forming new wind cooperatives, getting access to land on which to build a wind park is one of the major hurdles for private development projects today, for a combination of geographic, technical, policy, and political reasons. For starters, Denmark is land poor, and with more than 5,000 turbines already erected, most sources agree that the domestic market for onshore wind is thoroughly saturated. But it has gotten even more difficult to identify a site where it is possible to build as the turbines themselves have grown larger. Due to a growing phenomenon of local opposition to nearby wind development, Danish law was amended to require that the distance from a turbine installation to the nearest home be at minimum four times the height of the machine to the rotor tip. As those heights top 150 meters on contemporary models, it is getting harder and harder to find large enough tracts of unpopulated land to erect an array of more than a few turbines. In recent years, developers have resorted to buying up nearby homes and demolishing them. Local governments have also gotten more involved in the planning process for new wind parks, restricting development in highly-populated and natural areas, and setting aside only a handful of designated "wind energy areas" where new construction is allowed.

Under these conditions, securing a lease agreement with a local landowner and approval from the municipal government is pretty much the entire game. Jens Rasmussen estimated 95% of the value creation occurs in these initial stages of project development, and said success requires a "gut feeling" to pursue the right projects in the right areas. (10) It all comes down to correctly assessing and managing the local political climate. Rasmussen cited public opposition as the "biggest hurdle" to wind development today, though he added he did not believe local protests were as serious a threat as media coverage often made them appear. "We are building still a lot in Denmark," he said. "It's a risk for us as individual firms, but not necessarily for the country as a whole." Rasmussen suggested that local opponents had always existed, and he wasn't sure it was any greater proportion of the population today. Instead, those protests are usually led by a small but vocal minority. But in the Danish system, a handful of opponents can grind the local approval process to a halt, something Rasmussen said was not a problem in their German developments, where local lawmakers have less discretion over project approval. Rasmussen speculated that opposition movements were being fed by misinformation about the (imagined) health impacts of living near a wind turbine, which spreads like wildfire on social media, and by homeowners' more justified fears about potential impacts on their real estate values. He also granted that as turbines have grown larger, their viewshed impacts have increased substantially, expanding the radius of locals affected by new developments, and making those impacts more acute for the nearest neighbors. Rasmussen described one project the company decided to abandon in their own hometown after 150 people showed up to oppose the project at the first public hearing. In that case, the chief concern was the proposed project's close proximity to the city limits. Afterward, Rasmussen said the municipality did "what is right," and prohibited wind developments within 2.5 km of the four largest settlements inside their administrative borders. Rasmussen said developers were grateful for the transparency of such guidelines, though he worried that as more and more zones were restricted, there would be nowhere left to build. (11) Developers are particularly fearful of how local protests can politicize a project, especially at later stages in the approval process. A developer may secure technical and environmental approvals from the municipal planning department, but still have the project derailed when it is put to a vote before the full city council. That gumming up of the works has been evident in Aarhus Kommune, which despite being a center of the wind industry, has seen very little wind development in recent decades, in part due to paralysis on the city council.

Because of the difficulties associated with greenfield projects today, wind developers have increasingly turned their attention to repowering existing farms, replacing older and smaller turbines with larger and more efficient models. This strategy is driven, in part, by a change in national energy planning in the 1990s—adopted in response to concerns about the proliferation of windmills around the countryside—which required new installations to first take down an equivalent amount of existing wind capacity. That policy led to a rush of wind developers snapping up cooperative windmills, like the one Jane Kruse managed (see Chapter 4), for the sole purpose of demolishing them in order to build another, larger turbine elsewhere. Repowering projects tend to have the attendant benefit of limiting public opposition. Residents who are accustomed to living amongst wind turbines are generally more understanding and accepting of the impacts, and Rasmussen characterized “fear of the unknown” as the overwhelming source of public opposition. He said his company receives very few complaints from neighbors after their wind farms begin operation. (12)

So-called “NIMBY” opposition has been a common obstacle to wind development around the world, and for decades Denmark was exceptional in its relative avoidance of such public fights. Since the 1990s, public controversy over wind development in Denmark has regressed to the international mean. The causes of this uptick in public protests against wind projects, and political responses to it, will be further explored in Chapter 6. The social science literature recommends that early and transparent communication between developers, local government, and the public is key to building trust. Rasmussen implied that his company tries to get a good read on a project’s likelihood of being approved before they accumulate too many sunk costs. Researchers also find that locals are more likely to support projects they believe provide direct benefits to the community, though it’s clear developers are leery of such financial concessions. By law, they are required to offer 20% of the shares in any project to nearby residents. Municipalities are also increasingly asking developers to create some sort of public benefits fund—say, to purchase iPads for the local elementary school, or to support the local football club. While such arrangements cannot be required, as they would constitute bribes, the developers I spoke to suggested they are strongly encouraged by local officials. Jakob Greth made his distaste for these payoffs explicit, comparing them to the governing body of FIFA taking bribes to award hosting rights for the World Cup. “I think it can backfire, it seems a little corrupt,” he said. “It's buying people's opinion.” (13)

The shrinking domestic market for new onshore wind installations has led developers like Eurowind Energy to expand abroad. In addition to their early investments in Germany, Eurowind is now operating in Poland, Romania, Portugal, Italy, Spain, Sweden, France and Bulgaria. (Eurowind) Both Rasmussen and Greth pointed to a supportive “political climate” as one of the main things that made investment in Denmark attractive, by which they were referring not to local politics, but to the generous subsidy scheme. However, both were worried those policies were in danger after the election of a center-right government in 2015 led by Prime Minister Lars Løkke Rasmussen. Still, both said their businesses were 100% committed to onshore wind. Greth said his company had once attempted to get involved with an offshore project, but it proved “way more complicated and way more expensive.” The high costs of doing repairs offshore, in particular, made the investment too risky. (14) Rasmussen said the reason his company worked exclusively on onshore projects was because they offered “the lowest capitalized cost of energy,” and in any location that had decent wind resources, “you can’t compete with it.” (15) Like many in the Danish wind sector, Greth and Rasmussen are placing a bet on whether the future of wind energy will be onshore or offshore, a subject that remains hotly debated. The clash of these two competing development models, and the consequences for the character of the Danish wind network, will be explored in the next chapter.

5.3 Theories of Renewable Energy Policy Lock-In

The 1990s were an important turning point in the history of Denmark’s energy transition, as an infusion of private capital helped boost the wind network from a niche curiosity to a major player in the electric power sector, spurred in large part by government subsidies that created an attractive business case for investors. Scholars and industry experts pretty universally agree that government policies offering price supports to renewable technologies have been necessary to sustain the growth of the sector, at least in early generations of development. My own analysis provides confirming evidence for that conclusion, though I argue that policy support, while necessary, is not sufficient on its own to create a self-sustaining renewable energy system. Those who want to encourage renewable energy transitions should be more concerned with how to sustain the political support for the next round of policymaking.

The question of how policies encouraging the growth of renewable energy can be enacted and implemented has made the Danish case of particular interest to scholars of public policy, who typically view Denmark as an unparalleled success story in this respect. The most noted aspect of the Danish policy environment across the literature is its stable support for wind power for decades. The policy history I detail in the following section suggests the truth is more complicated. When that history is examined in detail, it is obvious that Danish policies toward wind power have changed frequently, varied dramatically in their level of support from year to year, and more recently have favored very different mechanisms and objectives than earlier policy regimes, leading to substantial alterations in what got built over time. If one squints and focuses only on the broad outlines, it is accurate to say that Danish governments have been more supportive of renewable energy than most other countries. In most years, the wind sector received at least some subsidies from the national government, and the stop-and-start nature of Danish wind development as subsidies expired or were adjusted reaffirms the importance of consistent policy support. The key puzzle for public policy analysts is explaining how supporters of Danish wind power have managed to secure so many policy wins, while similar efforts in other countries faced stiffer resistance.

In just the last few years, a critical mass of policy research has emerged asking just this question, and sharing with this dissertation the approach of examining empirical cases of renewable energy transitions in progress, in the hopes of understanding how governments can craft policies to stimulate a more rapid shift to carbon neutral systems. A consensus appears to have emerged in this literature that policy debates over renewable energy should be understood as distributional conflicts over who will reap the financial benefits and who will bear the costs of policy change, with organized interest groups as the most influential actors. The author of one of those studies, Matto Mildenberger, summarized the challenge of implementing climate reforms this way: "Policy opponents face concentrated losses while policy benefits are diffusely distributed … In these accounts, climate policy action is frustrated by entrenched policy opponents, not by free-riding concerns." (Mildenberger 2020, 16)

To these authors' credit, their theories have found receptive audiences beyond the academy, garnering favorable coverage in elite media outlets in the United States, and even reflected in the Biden administration's approach to climate policymaking. A recently editorial by *The Atlantic*'s Robinson Meyer argued "the challenge of global climate action isn't that other people will benefit from your emissions cuts; it's that many interests actively *oppose* decarbonization. The key to passing climate policy is stitching together a coalition that will support and sustain decarbonization." (Meyer 2021)

The resurgence in scholarly interest in renewable energy policy over the last few decades is a welcome development. After some early interest in the subject from policy analysts like Amory Lovins (discussed in Chapter 2) during the heady days of the 1960s and 1970s, the issue largely dropped off the radar of social scientists until the public salience of climate change began ticking upward toward the end of the century. In the 2000s, many studies focused on evaluating the efficacy of the policy mechanisms adopted to support renewable energy in early mover countries like Denmark and Germany.

Joseph Szarka (2007) argued that Denmark's feed-in tariff compared favorably to the quota schemes deployed in neighboring countries like the UK. Feed-in tariffs, he found, have been more successful in encouraging distributed ownership and generation of wind power, encouraging smaller investors to enter the market by minimizing long term risks. These investors are typically satisfied with lower rates of return, which allows the tariff prices themselves to be set lower, "provided they are guaranteed." (Szarka 2007, 92) Feed-in tariffs don't have big impacts on public budgets, since the costs are borne largely by electricity consumers, and most electric bills see only marginal increases. Many own analysis lends some support for these assertions. Denmark's feed-in tariffs certainly succeeded at generating public interest in purchasing a wind turbine, as the response to the first investment subsidy program in 1979, discussed in Chapter 4, demonstrated. The guaranteed prices for wind power fed into the grid were a key factor in giving banks the confidence to make loans to wind turbine buyers of all types, and that prospect of guaranteed income was especially important in encouraging private development firms to make investments in wind power in the 1990s, as discussed in the preceding section.

However, some former government officials have criticized the costs Denmark bore as a first mover, and suggested other countries could achieve similar results at less expense today. (16) That view hints at what it must feel like on the receiving end of the so-called "free rider" problem that frustrates environmental policy enactment from the traditional collective action framework, a theoretical perspective recent scholarship is working to undercut. It's debatable whether policies that encourage broad-based participation in energy transitions are efficient (I take up that debate, on political grounds, throughout this dissertation). Utilities would argue that the economies of scale they can realize offshore deliver the lowest prices per kilowatt hour. Interestingly, those who raise concerns about the market competitiveness of wind energy usually cite as examples the earliest utility-led offshore farms, which were punishingly expensive (and were paid for with government tenders, not feed-in tariffs). Bids for subsequent offshore projects in Denmark have declined precipitously, to the point where utility companies have recently placed bids that could pay the state for the pleasure of operating an offshore wind farm. This trajectory is a hopeful one for countries like the United States, which are just building their first offshore wind parks today, at prices significantly above market rates. But as noted in the preceding section, whether onshore or offshore development is ultimately more cost-effective remains a live question, on which company managers are placing significant bets in opposing directions.

What gets missed in debates over the cost of wind developments, as the policy literature correctly observes, is that numerous other variables must be considered when evaluating the efficiency of any government program. Energy production is such a multidimensional and complicated process that it is hard enough to estimate the levelized cost of energy for competing fuel systems, but those calculations look manageably technical compared to the complexity of the larger political equation.

Utility companies have historically opposed feed-in tariffs, for reasons of self-interest rather than economic efficiency. Utilities are generally unenthused about buying power from independent generators; they would much rather be sellers of power they produce themselves. “Obviously, power utilities prefer [the quota] system,” Sergio Oceransky writes, “since they have almost complete control and make large profits from the few renewable energy projects that come into being, while in a feed-in system they simply pass on the cost to the consumers but do not (or should not) make a profit.” While feed-in tariffs are a threatening disruption to utility business models, Oceransky argues that from a broader social point of view, they have the advantage of increasing public support for renewables. (Oceransky 2010) The International Renewable Energy Agency assessed Denmark’s subsidy scheme in similar terms: “The involvement of a large number of small investors has contributed to broad public sector support for wind energy projects, and has significantly reduced the 'not in my backyard' problem that has been encountered in other large markets.” (IRENA 2012) On a political level, public support and the absence of controversy are their own kinds of efficiencies, improving the likelihood of successful policy implementation and the stability of the policy regime over the long term.

Many other policy analyses have reached similar conclusions about the most effective subsidy schemes to promote the growth of renewables. Roger Karapin (2014) praised the success of Germany’s 1990 Feed-In Law in stimulating the renewable energy transition in that country. Janet Sawin (2001) compared the U.S., Danish, and German cases to advocate the superiority of “demand-pull” as opposed to “supply-push” approaches for achieving lock-in of new technologies. The rate and diffusion of renewable energy, she argues, are matters of policy choice. “Simply throwing money at technologies—for research and development, for example—is not the answer,” she concludes. “To be effective, policies must focus on creating demand rather than creating supply. Create a market, establish guidelines … encourage broad participation, and all else will follow. (Sawin 2001, 435)

These sources are surely correct that some kind of policy support is a major causal driver of renewable energy transitions, and at an administrative level getting the policy mechanisms right is no doubt important. But to spur systemic change, it might be necessary to think a little bigger about the nature of the problem. Designing optimal policy instruments might not be enough. The more pressing question is how to put those policy ideas into practice. Recent public policy research has raised just this concern about that first-generation approach to analysis. Matto Mildenberger has cautioned against a focus on policy design, in part because comparable quantitative data with which to make reliable cross-country comparisons can be hard to come by, and because “carbon pollution levels are so overdetermined by diverse economic and social forces that retrospective causal identification of policy impacts remains difficult.” (Mildenberger 2020, 12, 26)

Mildenberger is author of one of a recent trio of books—alongside his regular collaborators Leah Stokes, Michael Aklin and Johannes Upelainen—that have applied the broader “energy transitions” perspective to studying renewable energy policies. All three authors point to the shortcomings of techniques like statistical analysis for studying energy transitions, and opt instead to conduct in-depth, longitudinal, qualitative case studies, which they refer to as “process tracing” in the historical institutionalist tradition.

This methodological strategy—common to the new institutionalist policy literature most closely associated with the likes of Kathleen Thelen, Paul Pierson, Jacob Hacker and Suzanne Mettler—has close affinities with what this dissertation calls an "ecological" approach to explaining systemic change. Both are attuned to context, interaction effects, and charting changes over time. Kathleen Thelen and James Mahoney have described the method of comparative-historical analysis as a "combinatorial approach" that examines how variables work together in causal packages. "There is no alternative to analyzing the effects of causes in light of the context in which they occur," they write. (Thelen and Mahoney 2015, 7-8) I have proposed that such an explanatory strategy is particularly well-suited to capturing the complex dynamics of large-scale and long-term technological transitions (see Chapter 2).

One of the major strengths of this sort of longitudinal analysis is its emphasis on identifying mechanisms and relations of power that may not manifest in discrete episodes of open conflict. Drawing heavily on John Gaventa's analysis of three-dimensional power (discussed in Chapter 2), Paul Pierson argues that many important political processes operate at a "subterranean" level. "Power is like an iceberg; at any moment in time most of it lies below the waterline, built into core institutional and organizational structures of societies." (Pierson 2015, 124)

The present study shares this interest in using techniques of historical analysis to reveal underlying, often hidden structures of power at work in political processes, and hopes to build on this research tradition in four main ways. The basic weakness of much of the scholarship in this vein—at least for the studying energy transitions—is that it does not conceive of the relevant political processes and communities broadly enough.

Historical institutionalists are absolutely correct that “policies enter dense social environments that pervasively condition their effects, sometimes in unexpected ways.” (Hacker et al. 2015) As the world changes around policy institutions, “their survival often requires ongoing active adaptation to their political and economic environment.” (Hacker et al. 2015, 193, 204) Yet for all of this talk about the adaptation of policy regimes to their environments, that broader context often gets relegated to the background in these accounts, which tend to focus primarily on events and actors within the formal policy community.

This relative lack of attention to extra-institutional factors makes it harder to see how those external forces shape the dynamics observed within institutional settings. Often, these studies take the arrangements and preferences of organized interests for granted, and provide little or no account of how interest group coalitions are built and maintained. Unlike this dissertation, they rarely emphasize technological development as a mechanism of interest formation and realignment. While historical institutionalists are well aware that technological innovation is a significant driver of policy change, technological development is rarely treated as a political process worthy of attention in its own right. Instead, this literature usually discusses technology only to the extent it has ripple effects in policy community and debates. Finally, theories of path dependence, particularly those that draw from Pierson’s work, tend to exaggerate the stability of systems that achieve “lock-in,” and have undertheorized the later-stage dynamics of policy evolution, a gap this dissertation works to address. All three of the recent analyses of energy transitions in the historical institutionalist tradition exhibit these limitations.

The application of these techniques to a series of cases around Europe and the United States leads the authors to a surprising convergence of results. All three books make clear their disinterest in optimizing renewable energy policies, and the authors are particularly skeptical of the carbon pricing mechanisms favored by economists and policymakers. “Renewables would be much more competitive if fossil fuels came with a tax based on the damage caused by carbon dioxide emissions,” Aklin and Urpelainen admit, but the abstract rationality of that strategy may not prove to be the most effective means of making renewables competitive in practice. “The argument for such instruments is weaker in a political setting,” they conclude. (Aklin and Urpelainen 2018, 10, 227) Mildenberger and Stokes similarly worry that because carbon taxes impose direct costs on polluters, affected parties are more likely to mobilize opposition to such policies, threatening progress in fighting climate change. Rather than designing policies in a vacuum, “substantially more attention must be paid to the political economy of climate reforms,” proposes Mildenberger. (2020, 24) By “political economy,” he seems to mean how policy regimes distribute economic winners and losers. Aklin and Urpelainen similarly see the politics of energy transition as a contest of interest groups over the distribution of resources. “The balance of power between the advocates and opponents of renewable energy determines the outcome of the political struggle,” they conclude. (Aklin and Urpelainen 2018, 47)

These studies are part of a broader resurgence of interest in the influence of lobbying on policymakers (see, for example, Baumgartner et al. 2009, Kalla and Broockman 2016), but they center organized interest group competition at the expense of other relevant causal variables and processes. This framing of recent energy transition research is partly an effect of the influence of Pierson, who frequently describes policy debates as “pitched battles” and “organized combat” and praises studies that stress “the (often brutal) political contests between competing forces, in which one side wins and the other loses.” (Pierson 2015, 136)

My own case history casts doubt on whether interest group competition is nearly as pervasive a feature of the Danish policy process, in which institutional actors have demonstrated a remarkable commitment to coalitional and consensus-based decision making since the 1950s. I do not mean to suggest that interest groups are nonexistent or unimportant in Danish politics—on the contrary, this dissertation paints a portrait of a culture rife with enough associational activity, at all levels of society and government, to make Alexis de Tocqueville blush. Surely, competitive relationships do exist between various policy actors, and surely there are policy winners and losers, but it does not follow that those fights and their outcomes are necessarily the motors of policy change. The ecological perspective I adopt places greater emphasis on how underlying processes—be they structural, functional, cultural, ideological, technological, environmental, etc.—combine to sharpen the contours of conflict in formal policy arenas, or to dull them.

While the adaptability of policy coalitions is a core proposition of historical institutionalism, research in that tradition often gives short shrift to the forces shaping identities, values, preferences and coalitions *outside* of formal policy domains. “Institutions do more than channel policy and structure political conflict; rather, the definition of interests and objectives is created in institutional contexts and is not separable from them,” Kathleen Thelen writes. “Institutional arrangements affect the capabilities of various groups to achieve self-consciousness, organize, and make alliances." She cites as an example Theda Skocpol's *Protecting Soldiers and Mothers*, which shows how "the fragmentation of the state, as well as the organization of party competition along patronage lines, actively mediated against the development of a unified working class that could then spearhead the movement for comprehensive social policies in the United States." (Thelen 1999, 394) What sorts of extra-institutional factors might also mediate against coalition formation, or work to promote it, goes largely unaddressed.

It is interesting that none of the recent books on climate policy makes any mention of Elinor Ostrom's socio-ecological systems framework. I can only speculate that these sources would consider Ostrom's framework excessively structural and inert, and thus not an ideal match for modelling the dynamics of policy change. It is also the case that Ostrom's CPR and later SES frameworks have been applied mostly to examining resource management strategies, mostly in the developing world. They lack the desired resolution for a narrower focus on formal policymaking processes in advanced democracies. While Ostrom's SES framework does include the policy environment as one of numerous system components, it lacks any detailed account of the institutional processes that produce policy regimes. On the flip side, Ostrom's systemic approach does do a better job accounting for extra-institutional variables likely to influence system change than the institutionalist frameworks discussed in this section.

The recent works on renewable energy transitions also provide few insights into the processes of interest group formation and realignment. The authors lament that environmental advocacy groups are often splintered and at each other's throats, but they tend to present fossil fuel interests as an organized monolith, with elites like the Koch brothers pulling the strings behind the scenes. My own analysis of the Danish case suggests that policy actors are deeply entangled with one another, with alliances continuously being reshuffled, making it difficult to cleanly separate them into opposing camps.

"Defeating climate change is, at its core, a political battle over policy," Stokes writes, "We must be ready to fight." (Stokes 2020, 227-228) Her goal is to grow and strengthen the pro-renewables coalition, but she doesn't have a strategy for how to do that coalition-building work, beyond imploring lawmakers to pass a Green New Deal. In reaching these conclusions, she has primarily talked to government officials and professional advocacy organizations. She does not explain how these groups formed, how they gained political influence, or even say much about how they wield that influence in the lawmaking process. Stokes limits her focus to the roles interest groups play in electoral primaries, advocacy campaigns, and court challenges. "Of course, these three indirect pathways to political influence and policy change do not capture all the critical actors, institutions, or interest group strategies in American politics," she grants. The media is another example of a significant site where political battles are waged, but Stokes says she will have to leave the media analysis to other scholars. (Stokes 2020, 233) The minimum justification I need for my own focus on technology development is that it represents another of these "indirect pathways to political influence."

"Policy networks" play a central role in Stokes' account of the political coalitions frustrating climate action, but she does not have in mind ecological networks, or sociotechnical networks, or even the more familiar concept of social networks. Instead, the networks she refers to are national lobbying groups that that work to facilitate advocacy campaigns and legislative pushes in state houses around the U.S., like the American Legislative Exchange Council and the Koch family-led donor network, Americans for Prosperity. Stokes argues that conservative groups have generally done a better job than progressives of organizing these interstate lobbying efforts.

For his part, Mildenberger suggests coalition-building is a task for social movements. He cites the advocacy of Greta Thunberg, the Extinction Rebellion (a real thorn in the side of Danish policymakers today), and the Sunrise Movement is examples of grassroots movements doing effective mobilization work. “Recognizing their strategic missteps, climate advocates have begun to invest in climate movement-building,” he writes. “The study of these movements must be a central part of political science scholarship going forward.” (Mildenberger 2020, 246) But this is not the kind of political science research Mildenberger and his compatriots conduct. He has not written a social movement analysis, or even an interest group analysis in the style of Fred Baumgartner. Instead, he has mainly produced a traditional institutional analysis, showing how variations in the structures of liberal democratic government procedures lead to contrasting policy pathways.

Aklin and Urpelainen point out that the “set of potential allies for renewable energy is diverse.” In the Danish case, they point to manufacturers, their workers, the engineering community, farmers, environmentalists, and municipalities as core constituencies. They argue that “fast and steady growth of renewable energy depends on the continued growth of its advocacy coalition.” (Aklin and Urpelainen 2018, 226, 228) But they make no attempt to follow these constituencies throughout the process of Denmark’s transition, an oversight I aim to remedy in this dissertation. It is for this reason that I went out of my way to interview not only lobbyists and politicians and civil servants, but also industry managers and employees, wind engineering experts, farmers, environmental activists, and municipal officials, among other stakeholders. One interesting outcome of this broad-based conception of the relevant interest groups is that my case history shows how the evolution of Denmark's government policies may be hollowing out the pro-wind coalition, a trend I detail later in this chapter and the next.

The recent public policy literature on energy transitions does not exhibit a particularly three-dimensional understanding of where power resides, or how it is reproduced. These studies only really pay attention to institutional power, and processes that play out within government. But the institutional muscle that fossil fuel interests flex through their lobbying arms is not the only source or the primary mechanism by which these polluters accumulate power; instead, that policy influence is largely an effect of power they have accumulated in other arenas, by other means—for example, ideological and cultural and discursive power, media power, economic power, technical expertise and control of infrastructure. All of these critical means by which political coalitions are formed get shunted to the side in the recent wave of policy studies. Once the formal policymaking process commences, the coalitions participating in those debates have already largely settled, and the universe of possible policy actions has been whittled down just a handful of "realistic" alternatives. In the language of multiple streams theory, these studies focus too much attention on the policy stream, and not enough on activity in the problem and politics streams that precedes and supports issues rising up the policy agenda. From a sociotechnical systems perspective, I would say that these studies give insufficient attention to how institutional processes interact with interconnected social systems.

Looking at the history of interest group influence on Danish energy policy, Aklin and Urpelainen single out the 150,000 Danish households owned shares in turbines by 2001, about 6% of all households, as particularly important. They also note that wind turbines accounted for about 5% of all Danish exports, and there were about 30,000 full-time employees in the industry in 2015. (Aklin and Urpelainen 2018, 164) While the analysis presented in this dissertation supports the assertion that both of these constituencies have played critical roles in Denmark's energy transition, neither of these data points is an example primarily of an organized lobbying group. Members of both groups did create formal associations and increasingly lobbied lawmakers directly in Copenhagen over time, but this was only a secondary development and purpose to their direct role in building renewable energy technology—the first group as developers of wind projects and electricity producers, and the second as designers and manufacturers of the electrical machinery. In was out of those capacities that their interest in participating in the policy process grew, a subject that gets little attention in the policy literature.

This inability to see renewable energy producers as political actors in their roles as technological innovators and system managers is a common shortcoming of the historical institutionalist literature, which is well aware of the importance of technological change for policy evolution. "Rapid technological change introduces new possibilities for social organization or interaction that can radically alter the function of existing policies," write Jacob Hacker, Paul Pierson and Kathleen Thelen. Yet they tend to treat technological developments as exogenous pressures that impinge on institutional imperatives, preferences and debates, rather than as integral components of political networks.

Leah Stokes argues that “battles over climate policy are fundamentally material,” but the materiality she has in mind amounts only to “who will get to own the assets of the energy system and the resulting profits.” (Stokes 2020, 4) I share these scholars’ interest in bringing more attention to the material underpinnings of policy change, but their conception of the materiality of politics differs sharply from that of political ecologists and sociotechnical systems theorists. In this respect, the new institutionalist accounts are notably weaker than classic approaches to energy geopolitics, such as the oil curse literature out of which Timothy Mitchell’s research grows, which at least did a good job of emphasizing the distribution of natural resources and industrial capacities.

Among those “subterranean” variables that shape energy policies, some share must be technological. Stokes would agree with that assertion, even if she has little to add on the subject. She hypothesizes that the course of policy enactment grows more to predict in four specific circumstances: “policies that have not been implemented widely elsewhere, major reforms that involve complex rules, technical policy domains, and policy areas that have overlapping jurisdictions.” (Stokes 2020, 47) All four of those conditions apply when making national renewable energy policies.

Stokes says little about how technology and policy development interact, beyond claiming that highly technical policies increase what she calls the “fog” of enactment “because technology changes quickly, making it difficult for politicians or interest groups to forecast.” (Stokes 2020, 53) The implication seems to be that technical matters like running a grid are far too complicated for unexpert government officials to get their heads around when drafting laws, and the energy sector will react to policy changes in unintended ways, so the impacts of specific mechanisms can really only be ascertained after they have taken effect, making policy design in this area always a bit of a trial-and-error process. That's probably a truism about the policy process, in general, but it does track Denmark's experience with efforts to support wind energy. One former Danish official I interviewed characterized the country's renewable energy policies over the past few decades as a series of attempts to fix the mistakes they had made previously, first overcorrecting in one direction, and then in the next round pulling back in the opposite direction. (17)

Stokes misses an opportunity to draw a more complex portrait of the policy community from the energy transition literature that also informs her study. In a chapter she dedicates to explaining the more technical aspects of the electricity system's evolution in the United States, she leans heavily on the work of historians of technology Thomas Hughes and Richard Hirsh, whom she cites as her sources on the following claims about electricity policy:

> All political institutions are resistant to change. But the regulations governing electricity are particularly sticky. In part, this is because of the nature of the technology. Unlike other goods, electricity supply and demand much match in real time, moment by moment—otherwise, the grid will grind to a halt. But technology is not the whole story. Politics have also made electricity institutions stable. As this chapter will argue, electric utilities have ossified institutions, shaping the regulatory structure to their benefit … Once monopoly rights were granted, innovation in electricity technologies slowed. Instead, utilities focused on increasing profits rather than adopting new technologies
> (Stokes 2020, 68-70)

The implications of grid balancing concerns for renewable energy development are not explored further, nor is the relationship between monopoly power and technological innovation. Whereas Hughes and Hirsh would see expertise, innovation, infrastructure, policy and politics all interlinked in energy systems, Stokes tells a much simpler story about regulatory capture by powerful vested interests. Her recommendations for changing this dynamic largely amount to reforming public utility commissions to give environmental advocacy groups a seat at the table, as a counterweight to the influence of utility companies. Denmark, too, once had an ossified electricity system, dominated by utility companies resistant to new technologies. Chapters 3-4 detailed how that utility consensus was disrupted in the 1970s and 1980s by grassroots renewable energy enthusiasts. The most important step Danes took to challenge utility dominance was to start building wind turbines, and at least in the beginning, without any regulatory mandate to do so.

Stokes seems to be forgetting this lesson of the Danish case when she argues that clean energy advocates should "focus less on ownership." This advice runs counter to virtually every study I have read of Denmark's energy transition, whose authors almost universally highlight the widespread public ownership of turbines as a key factor in creating a powerful constituency in favor of wind energy. Michael Aklin and Johannes Urpelainen, for example, share with Stokes an emphasis on interest group conflict, but conclude that "a particularly important prorenewables group is small producers." (Aklin and Urpelainen 2018, 71)

Stokes is also worried that since distributed generation poses a direct threat to the utility business model, it is a fight that advocates may have difficulty winning. "Advocates can choose to focus attention on improving the existing regulatory structure and on passing clean energy laws. Or they can fight life-or-death battles with private utilities," she writes. "With the hour running short and with limited resources, my own view is that advocates should focus more on reforming existing institutions." (Stokes 2020, 248) She pitches that retreat as a strategic choice, but it's a perplexing strategy, given the book's take-home message is that environmentalists must take the fight to fossil fuel interests.

She also seems to accept the utility logic that centralization is conducive to scaling up, arguing "the clean energy transition will require an enormous amount of investment in big projects … Breaking the electricity system up into smaller and smaller utilities will likely make these projects harder to build, not easier." (Stokes 2020, 246-248) Certainly, achieving scale is an end goal of an energy transition, in the aggregate sense of replacing sufficient amounts dirty generation with clean alternatives. Whether achieving the desired emissions reductions requires giant offshore wind farms funded by deep-pocketed corporations is a question this dissertation treats as an open one, rather than a foregone conclusion. Thankfully, Denmark has decades of experience with both decentralized and centralized renewable power generation at significant scale, making it possible to assess empirically the potential of each.

Those decades of experience make possible a more thorough tracing of the evolution of a renewable transition than any of the studies discussed above attempts, shedding light on the variety of pathways an energy transition can take, and their divergent political characteristics. Another benefit of closely examining an advanced energy transition is the ability to observe the late-stage dynamics of mature systems, a subject that remains underdeveloped in both the technological innovation and policy literatures. Existing theories of "lock-in" have tended to assume that as regimes develop, they grow more stable and resistant to change. "A core claim that runs through virtually all of this work is the idea that early events in a path-dependent sequence exert a stronger causal impact on outcomes than later ones do." (Thelen and Mahoney 2015, 20) Paul Pierson describes lock-in as a process of "increasing returns" and argues that this effect is "particularly intense" in political systems, given "the absence or weakness of efficiency-enhancing mechanisms of competition and learning; the shorter time horizons of political actors; and the strong status quo bias generally built into political institutions. (Pierson 2000, 257) Additionally, once policy institutions are enacted, "actors adapt their strategies in ways that reflect but also reinforce the logic of the system." (Thelen 1999, 392) The result of all these mechanism of reinforcement is inertia. "Once an increasing returns process is established, positive feedback may lead to a single equilibrium," Pierson writes. "This equilibrium will in turn be resistant to change. (Pierson 2000, 263)

Kathleen Thelen has critiqued such theories of path dependence as "overly deterministic." A focus on the mechanisms that reproduce the status quo "frequently obscures the fact that, because institutions are embedded in a context that is constantly changing, stability, far from being automatic, may have to be sustained politically … Institutions rest on a set of ideational and material foundations that, if shaken, open possibilities for change. (Thelen 1999, 396-397)

One of the major contributions of Stokes' book is her consideration of how mechanisms of policy feedback during the implementation phase can work not only to reinforce policy gains, but also to reverse them. Her empirical analysis focuses on four cases of U.S. states where early momentum on climate policy has been arrested or turned back. While most policy research focuses on the factors leading up to policy enactment, Stokes rightly draws attention to the dynamics of policy evolution post-adoption, during enactment and successive rounds of policy debate. “Ambiguity plays a central role in policy change,” she argues, a condition she dubs the “fog of enactment” and defines as “the gap between actors’ expectations and the policy’s actual outcome.” That initial uncertainty about the effects of any new policy, however, “shrinks after implementation. As actors learn, they update their beliefs and come to attack policies they previously ignored or underestimated.” (Stokes 2020, 4) In the public policy literature, “policy learning” usually refers to the ability of government officials to refine policies over time and improve their effectiveness. Stokes argues that “political learning” happens as well, as interest groups adjust their strategies the more they learn about a given policy regime. (Stokes 2020, 58) Because of this persistent influence of organized interests at all stages of the policy process, “battles continue through later rounds of policy enactment and implementation. Hence, there is an iterative relationship between policy and politics.” (Stokes 2020, 5) Interest groups are particularly adept at playing the long game.

With energy policy especially, because it touches so many different interests and involves so much fundamental social infrastructure, it pays to be patient. Evidence from past energy transitions, as well as from the renewable transition currently underway in Denmark, suggests that these processes typically play out over periods of 50-100 years. In the next section, I will describe the political negotiations that led to landmark commitments to carbon neutrality in the 2010s. But the policy processes that made it possible to achieve those agreements began as far back as the 1970s, and the impacts of those agreements won’t be fully known for another decade or more. No single policy achievement set Denmark on its current path, rather, the country’s current trajectory is the cumulative effect of numerous policy adjustments over decades.

Theories of path dependence figure most prominently in the analysis of Aklin and Urpelainen, who, unlike Stokes and Mildenberger, consider the Danish case directly, though they appear to rely entirely on accounts from secondary sources. This sustained empirical attention to what has worked to grow renewables in Europe does seem to help Aklin and Urpelainen develop a more complex causal model of energy transition pathways, though they still see policy change broadly as a problem of distributional conflict among interest groups. The authors begin from the problem of carbon lock-in, which they see as a combination of technological forces—fossil fuel energy technologies are mature and cheap, and the status quo—environmental forces—fossil fuel systems benefit from their (at least in the past) largely invisible environmental externalities—and political forces— "traditional energy industries have accumulated a lot of political capital over time." (Aklin and Urpelainen 2018, 10)

The influence of sociotechnical systems theories is more visible in Aklin and Urpelainen's model, which conceives of energy transitions as multidimensional, systemic changes. "Such a transition requires the technical, economic, infrastructural, and institutional development of a social system for renewable energy," they write. The need to solve for multiple variables simultaneously is especially challenging when reconfiguring complex electricity networks, where maintaining consistent system function is imperative, making it necessary for system managers to understand how changes in one subsystem will interact with other system components—it's not nearly as simple as disconnecting a nuclear power plant from the grid and plugging in an array of solar panels to replace it. "The stability of the system depends on how well different actors coordinate their operations in both the short and long run. The need for coordination strengthens the carbon lock-in because a single agent cannot change the status quo." (Aklin and Urpelainen 2018, 44)

The inertia of status quo is so significant in energy systems that Aklin and Urpelainen hypothesize a significant external shock is necessary to disrupt carbon lock-in and open a window of opportunity for alternatives. In Denmark, several factors combined to make the nation's leaders uniquely open to reconsidering business as usual. The first is that carbon lock-in was comparatively weak in Denmark, at least compared to industrial giants like Germany and the United States, since the Nordic country was a relatively late modernizer, hosted relatively little heavy manufacturing, and had no domestic oil production in the 1970s. That changed with the discovery of North Sea oil, and Denmark became a net exporter of oil and gas in the 1990s, led by shipping giant Maersk, one of the country's most powerful companies. I have seen evidence that the influence of the domestic oil sector in policy debates, but the authors are correct that in the early decades of Denmark's transition the economy "did not rely on heavy industrial sectors that would have lobbied aggressively for low electricity prices." (Aklin and Urpelainen 2018, 165)

Aklin and Urpelainen theorize that a state's willingness to promote renewable energy depends on the severity of the shock, moderated by the country's energy security and elite ideology. (Aklin and Urpelainen 2018, 59) There is no disputing that the shocks of the twin oil crises in the 1970s kickstarted interest in renewable energy in Denmark, and those shocks explain the timing of the first national policies to support renewables, which were clearly passed as a direct response to those events. But Denmark was far from the only country severely impacted by the oil crises, and energy security became a highly salient policy concern for many Western states during the 1970s. I would argue that Aklin and Urpelainen overestimate the importance of external shocks in explaining Denmark's leadership on renewable energy. They place a lot of weight on painting Denmark as uniquely vulnerable to the energy crises, arguing that few other countries were as dependent on imported oil.

Despite the emphasis Aklin and Urpelainen put on external shocks as catalysts of policy change, one of the book's contributions to the public policy literature is to challenge the models of "revolutionary upheaval" predicted by punctuated equilibrium theory. "We do not argue for a rapid transformation of the energy sector as a result of the critical juncture created by the shock," they write. "Instead, we expect renewable energy to make modest progress while remaining dependent on the support of the state for growth and expansion." (Aklin and Urpelainen 2018, 57, 65)

While Denmark's path to renewable lock-in could accurately be described as gradual, Aklin and Urpelainen may be a little overconfident about the country's ability to coast on its momentum. Throughout the book, lock-in is associated with system stabilization, and the transition to a new energy system is presumed to become more stable as it proceeds. This new equilibrium is primarily a result of two forces—improved technical and economic performance, and increased social acceptance. (Aklin and Urpelainen 2018, 77) Their theory assumes that once lock-in is achieved, energy systems maintain "a stable equilibrium that can only be broken after a long and intense political struggle." (Aklin and Urpelainen 2018, 12) This idea that mature systems reach a settled stage during which innovation and competition subside is common in evolutionary models of technological change, as well.

In reality, stability is a relative phenomenon; evolution is continuous and unpredictable even in mature systems. Thus, Aklin and Urpelainin may not be justified in their expectation “that frontrunners—mostly Denmark and Germany—continue to experience sustained growth. In these countries, renewables have survived the pushback from the politicization phase.” (Aklin and Urpelainen 2018, 178) Wind power in Denmark may not be in any immediate danger of disappearing, but that does not mean it has achieved a consistent configuration that will be maintained over the long term. In each of the five decades my history covers, Denmark’s domestic wind energy network evolved in significant ways, and the pace of those disruptions has not really slowed. The ecological framework I advocate in this dissertation would predict that ten years from now, wind energy in Denmark will look noticeably different than it does today. The same could be said of Denmark’s policies to support renewable energy, which are dramatically different today than they were in the 1970s.

When not just the wind energy network, but the broader energy transition, is considered, even more systemic shakeups are inevitable. Wind turbines have achieved lock-in on the Danish grid and national energy policy. But electricity only accounts for about one-third of the entire energy system, with transportation and heating accounting for the other-two thirds. The Danes have mostly made progress in greening their grid, and they know larger challenges await in those other two sectors of the energy system, challenges the steady growth of wind power may prove unable to solve. Denmark may arguably already be too dependent on wind turbines, as their existing capacity generates more electricity than the country consumes on windy days. Policymakers may seek to diversify the energy mix in the future, especially as technologies like solar become more popular. New carbon-neutral technologies may emerge that challenge the current dominance of wind and solar.

It would be a mistake to assume that once lock-in is reached, the battle to green the energy system is won, which is exactly what Aklin and Urpelainen's theory seems to predict. "As the cost of renewable energy decreases over time and it becomes an attractive solution to different societal problems, political controversies surrounding it also diminish," they write. (Aklin and Urpelainin 2018, 81) In fact, precisely the opposite has occurred in Denmark. As the price of wind power has gone down, political controversies surrounding turbine development have increased, for reasons I explain in the remainder of this chapter and the next.

Aklin and Urpelainen admit that the "rosy picture" usually painted of Denmark's embrace of wind power is "somewhat misleading." They note that the renewable energy coalition had to "parry and thwart several attacks," and what is remarkable about the Danish case is not the absence of political contestation, but how decisively clean energy advocates have won those battles. (Aklin and Urpelainen 2018, 158) "Denmark's wind energy boom has continued unabated since the threat posed by the right-wing Rasmussen government subsided by the year 2009," they write. Since their book was published in 2018, the authors did not have the luxury of observing how a different right-leaning government put wind on shaky ground again after 2015, followed by the disruption of a global pandemic, and, most recently, the discovery of major mechanical flaws in offshore wind turbines and growing concerns about the costs of offshore development.

The history I present here reveals a much choppier track record of policy support in Denmark. The progressive normalization of support for wind turbine installations in

Danish energy policy has never been a particularly smooth or stable process. Scott Valentine characterized the ever-changing Danish support schemes as “eclectic,” and government policy as a facilitator rather than a catalyzer of wind development. (Valentine 2015, 111-113) Multiple sources have described the country’s subsidies for wind power as following a “stop-and-go” pattern. As each round of government funding approached its expiration, new turbine installations would reliably briefly explode up until the deadline to qualify for subsidies, and then fall off a cliff until a new support scheme was approved. These jagged spikes and dips in development are clearly visible in my quantitative data (see Figure 1.1), and provide powerful evidence of how significant a causal driver government policy is in stimulating renewable energy investment. It also shows that the rug can be pulled out from under the wind sector with little warning, and the industry has trouble adjusting to these disruptions. Any prolonged period of delay, gridlock or government opposition to renewable energy policy can mean bankruptcy for individual firms or across entire business sectors, eventually entire development models can wither away.

Very little of these dynamics are visible in Aklin and Urpelainen’s account of how European nations achieved lock-in. They construct a generally linear, progressive model of energy transitions in which both policy and technology go through successive stages of development, culminating in lock-in. If systemic processes are at work in Denmark’s energy transition, their model has difficulty detecting them. “Denmark has managed to grow renewable electricity generation without major systemic changes,” they conclude. (Aklin and Urpelainen 2018, 235) It’s true that the rise of wind power has not inspired a political revolution in the usual political science senses of that term—the wildest dreams of idealistic leftists have not been realized—but that does not mean more subtle political transformations have not occurred, or are not possible. As I argue in later sections of this chapter and in more detail in the next, systemic changes absolutely have occurred during Denmark's energy transition, in a variety of subsystems. The wind energy network has been through several phases of evolution, as has the policy regime. The broader national culture has undergone a huge shift in embracing the renewable transition that shows up in public opinion polls. The transformation of the energy system has probably had a range of other political effects in society at large that are harder to identify in quantitative data, but that I attempt to tease out through my qualitative case study.

Numerous other policy studies have specifically examined the Danish case, but that pre-existing literature—from which Stokes, Mildenberger, and Aklin and Urpelainen draw heavily—has its own limitations. Most of this research is now pretty outdated, focusing on the first generation of wind development in Denmark, and tends to sound two major themes: the uniquely small-scale, community-led, "bottom-up" development of turbine technology in Denmark, and the importance of grassroots social organizations like the anti-nuclear movement in building political support for renewable energy subsidies (see, for example, Vasi 2011, Sovacool and Sawin 2010, Toke 2011b, Meyer 2007). These authors all seem to have read and internalized Andrew Jamison's (lovely) contemporaneous dispatches on the Tvindmill construction, which I referenced myself in Chapter 2, and Matthias Heymann's comparative analysis of early wind turbine R&D efforts in Denmark, Germany and the United States. I do not think these authors are wrong to heap praise on the grassroots social movements that were the first believers in wind energy, and the distinctive development model they pioneered to make that dream a reality. But, of course, there is much more to be said about the course of Denmark's energy transition, particularly about what happened next. Few of these studies have much insight into the reconfiguration of the wind sector that was already beginning in the 1990s, and accelerated in new directions after 2000. Simply by virtue of being late to the party, I am able to update this historical record to include the latest twists and turns in both policy support and wind power deployment, which have significant implications for both the future of Denmark's energy transition, and how scholars understand transition pathways more generally.

Many studies of Denmark's energy transition have adopted a sociotechnical systems perspective, and focus on explaining the maturation of wind technology, rather than taking policy change as their dependent variable. This scholarship is far less prescriptive about policy mechanisms; as Scott Valentine argues in *Wind Power Politics and Policy* (2015, 308), the significance of local dynamics make it hard to recommend universal best practices. There are simply too many variables interacting in complex ways to single out any one causal driver as the most important, in isolation from the others. (Valentine 2015, 342-343) Mildenberger similarly recommends that "rather than pushing similar reforms across every country, climate advocates will need to tailor their domestic demands to align with each country's political context;" (Mildenberger 2020, 246) Aklin and Urpelainen encourage governments to select policies that are a "good fit" for domestic conditions. (Aklin and Urpelainen 2018, 221, 38)

One of the most detailed empirical studies of the evolution of Denmark's wind energy policies is Rinie van Est's *Winds of Change* (1999), and I draw on some of his findings to reconstruct that policy history in the next section. Van Est frames his research question in terms similar to my own: "How can policy makers guide techno-economic innovation into a democratically legitimate direction?" (Van Est 1999, 15) He concludes (much as I did in Chapter 2) that "the democratic fight is not solely a battle of words and arguments, it is strongly related to technological and industrial practices." The implication for policymakers is that they cannot afford to neglect any dimension of the innovation process, and "by exposing the fuIl complexity of innovation, the network approach strongly widens the scope of innovation policies, placing greater demands on policy makers and the content of innovation policies." (Van Est 1999, 282, 286) Van Est sums up Denmark's policy evolution in this way:

> The meaning of wind energy innovation in Denmark changed gradually, as a result of a steady and cooperative policy-oriented learning process between two different but cooperative coalitions. Techno-economic innovation advanced a policy learning process that led to a novel political understanding of wind energy innovation, which in its turned maintained political support that fostered wind energy innovation. The wind energy innovation process in Denmark again demonstrates the interpretive flexibility of techno-economic innovation … in the Danish case flexibility refers to a truly creative political process, in which, through a continuous, open and constructive debate, new political meaning was given to wind energy innovation. (Van Est 1999, 281)

The emphasis here on "continuous, open and constructive debate" is noteworthy, given that so many other scholars who have examined renewable energy policymaking characterize those debates as a zero-sum conflict. Even more remarkably, van Est observes a "creative political process" out of which emerge new "political meaning" associated with wind energy. The Danes brought together a diverse coalition of people from all corners of society, and those interactions produced a creative fusion, generating new ways of thinking and doing that far outpaced anything larger, better-resourced, more technically expert governments could come up with. This is the essence of innovation—

finding ways, through persistence and trial-and-error, and often by unexpected avenues, to make what previously seemed impossible possible.

The chief defect of van Est's book is that it is more than twenty years old, and was written at a time when Denmark's transition was still at a relatively early stage. My own study can account for several additional phases of development that have occurred in the wind system since then, and with these additional insights into the later-stage dynamics of energy transitions, my hope is that I can say with some more specificity precisely which kinds of technological, industrial and political processes have nudged Denmark's transition in more democratic directions.

What are some of the lessons of this literature on technological change for policy studies? First, these scholars all agree that technology and policy development are intertwined and interact continuously, as renewable energy coalitions and official policymaking communities adjust to one another, in processes that usually resemble something of a feedback loop, or a synergistic or symbiotic relationship. From a sociotechnical systems view, policy is an integral component of the structure and function of all energy systems, and not a separate domain influencing technological development from the outside. This perspective suggests that it is hard to get a full picture of the dynamics affecting renewable energy policy without a close analysis of both the policy and the technology, and how the two subsystems interact over time. It also then recommends a longitudinal approach to the analysis of policy change, since these dynamics unfold in iterative processes usually over decades.

Not only do policy processes cross time, they also unfold across multiple layers and levels of political systems, and government institutions. The closing sections of this chapter will examine how Denmark's national policies interact with politics at local levels. And I will return once again to the interaction of technological infrastructure and policy change in the final chapter, considering how Denmark's transformation of its grid facilitated the trajectory of more recent policy schemes and energy planning.

5.4 Denmark's winning record

Danish lawmakers must get a kick out of holding press conferences. They regularly get to announce that they've made significant progress in addressing core issues on the country's policy agenda, and at least compared to the American context of perpetual gridlock, these commitments are often quite breathtaking in their ambition, generating headlines not only in Copenhagen, but around the world. An example of this frequent phenomenon in Danish politics can be seen in 2021 documentary film *70/30*, which follows leaders of the governing coalition as they negotiate a landmark climate law. In one scene, the camera watches from outside a glass-paneled conference room where representatives of the various political parties are engaged in horse trading aimed at reaching a compromise. Late at night, Climate Minister Dan Jørgensen emerges from the conference room, beaming, to meet a gaggle of waiting reporters, and publicly announce that the parties have agreed, in principle, to reduce domestic carbon emissions 70% below 1990 levels by 2030. Celebrations ensue.

But that wasn't the end point of the policy process, and it was only the midpoint of the film—climate activists remained unhappy that the agreement didn't go further and put an immediate end to North Sea oil extraction. Street protests continued, as did parliamentary negotiations, there were further setbacks, breakthroughs, and details ironed out. What Jørgensen successfully negotiated in 2020 was a legally-binding framework agreement, which would require the government to meet broad targets, but stayed mum on how to get there. A lot of hard work remained in the next legislative session to hammer out the specific policy mechanisms that would be used to meet the designated targets. When I last visited Denmark in 2022, those negotiations over the details were ongoing.

This example is typical of the approach successive Danish governments have taken to policymaking in general, and to energy policy specifically, for decades. Long-term planning is the foundation of that process. Lawmakers try to find consensus on broad principles, pass those framework agreements into law, and then haggle over the details of how to deliver on those commitments. As Kristine van het Erve Grunnet, a longtime lobbyist for the utility sector, explained to me, this process facilitates policy progress by creating certainty that all political parties are on board with the general policy direction, which then encourages discussions about the best means of achieving those shared goals. (18) Danish politicians have also intentionally sought the broadest agreements possible, including all parties in negotiations, even opposition parties, and settling for whatever proposal will achieve the widest buy-in from across the political spectrum. This approach is one of the main explanations for the appearance of policy stability in Denmark. The framework agreements ensure that even after an election and a change of government, the overall direction of policy will remain unchanged, no matter which parties are in power.

According to Rasmus Helveg Petersen, a member of Danish parliament, the *Folketing*, since 2011, this effort to reach compromise agreements with participation from all parties has been the default model of policymaking in Denmark post-World War II, not only on energy policy, but also on defense, criminal justice, education, infrastructure and numerous other issues. Petersen described this consensus-oriented approach as “dead boring,” but also “completely vital” to the success of the wind industry. Companies in the sector “haven’t been planning up to the end of the election, they’ve been planning up to the end of the energy agreement,” he explained. “They have a longer horizon because of these broad coalitions we’ve made on our energy policy. Without that, the rest would not have happened.” (19) Ida Auken, a member of parliament since 2007 and a former Minister for the Environment, remembered the industry lobbies sending “a very clear message” in the most recent rounds of negotiations that they wanted lawmakers to reach a broad, long-term agreement, in order to give the, certainty as they planned their investments. (20)

While this deliberative democratic tradition has deep roots in Scandinavian culture, the dominance of coalitional politics in Denmark today is largely a structural effect of the party system. The country’s proportional representation electoral model regularly allows ten or more parties to win seats in the *Folketing*. That pattern began in the December 1973 election, when widespread social unrest, exacerbated by the oil embargo, resulted in a disastrous showing for the four establishment parties—the Social Democrats, the Conservatives, the pro-business liberal party Venstre, and the social liberal party Radikale Venstre—and five new parties entered Parliament. (Van Est 1999, 72) Party politics in Denmark have been tumultuous ever since, with the party fortunes often shifting drastically from election to election. When I met with Petersen in summer 2015, he found himself freshly (and temporarily) out of office after his party, Radikale

Venstre, showed unusually poorly in that spring's election. That year, the right-wing Dansk Folkeparti rode a wave of populism and anti-immigrant sentiment then cresting around Europe to a surprise second place finish, polling only behind the Social Democrats, and playing the role of kingmakers in the center-right governing coalition that emerged. But in the next election, support for the Folkeparti cratered, as a newly-formed populist party, Nye Borgerlige, ate into their vote share, and emerged as the sharpest skeptics of the country's green agenda. This churn in parliamentary representation is typical in Denmark. Smaller parties disappear from the political scene entirely, new parties emerge, parties frequently rebrand and merge. This game of musical chairs also helps explain why the Green party in Danish energy policy, despite the widespread public popularity of an environmental agenda. In 1989, the Greens merged with Communist party to form the Red-Green Alliance, which since then has tended to focus its policy agenda more on Red proposals than Green ones. There also isn't much of a lane for a green party in Denmark, since sustainability initiatives and the energy transition are broadly supported by all parties, with the Social Democrats leading the charge. No one party has cornered the green portfolio, and no large parties have been able to dominate that political agenda. After the most recent parliamentary election in 2022, twelve different parties won seats in parliament (plus four additional parties representing Greenland and the Faroe Islands, both Danish territories), with only the Social Democrats earning more than 20% of the vote. Post election, the parties sort themselves into broadly left-leaning, social democratic "red" and right-leaning, liberal "blue" coalitions to form governing and opposition blocs, though it is not unusual for some of the smaller parties in the middle of the ideological spectrum to hop between the red and blue teams, and both blocs tend to cater more to the centrist than the more extreme wings of their coalitions. The need to form minority governing coalitions encourages dealmaking, reducing partisan polarization over policy, and disincentivizes interest groups from hitching their wagon to any particular government or political faction. For example, corporate and industry leaders in Denmark are usually more ideologically-aligned with the liberal blue coalition, yet the energy sector's lobbying association remains assiduously politically neutral, and works to maintain lines of communication to all parties. In fact, the association's staff tend to work most with whichever parties find themselves in the opposition, since without ministry staff at their disposal, those parties are more in need of the legislative subsidies lobbying organizations have the expertise to provide. (21)

New rounds of policymaking commence with each election. The energy plans that have formed the backbone of Danish energy policy since the 1970s originate in the electoral campaigns. As Petersen explained, if a politician or party wants to pursue a specific agenda in the next round of energy planning, they outline the proposal in detailed policy plans that make up the party platforms, and put the issue before voters. The 2019 election, which was widely viewed as the climate election, spurred on by a wave of youth protest, offers a good example of this plebiscitary approach to setting the policy agenda. When the social democrats triumphed over the liberals that year, they were perceived as having won a strong mandate to pursue climate action, and faced intense public pressure to follow through on their campaign promises, which led directly to the adoption of an aggressive 70% emissions reduction target in the 2020 climate law. Issues on which the parties do not campaign are treated as settled policy. When I talked to Rasmus Helveg Petersen in 2015, he had just lost control of the climate ministry, but he was still celebrating an "unsung victory" because the new government had not found a way to annul the policies he had negotiated while in office, meaning the 2012 energy agreement had been cemented into law for its full duration, and his policies would be maintained until at least 2021. "They're stuck with it, and they have to implement it," Petersen said. (22)

After the election establishes the broad principles that will guide the new government, the formal policymaking process is a collaboration between the political parties, the government ministries, and the state bureaucracy. I met with Morten Baek, then director of the Danish Energy Agency, in the aftermath of the 2015 election which broad a center-right coalition to power behind the leadership of Prime Minister Lars Løkke Rasmussen. Baek characterized the agency as heavily involved in policymaking, in close dialogue with the ministry for energy and climate. He described that relationship between the career civil servants in the agency and the political appointees in the ministry as a "relatively smooth operation," though with its background in grid management, the agency tended to be a little more conservative in seeing the challenges to implementing the renewable energy transition, compared to the more youthful and aspirational politicians. But the agency staff had enormous amounts of experience and technical expertise, giving them a key role in drafting legislation. With the 2015 election setting the 2012 Energy Agreement in stone, the agency was hard at work preparing the detailed laws that would be needed to realize the goals in that framework agreement, as well as preparing technical analyses to inform the next energy agreement, which would set the trajectory for the decade of 2020-2030. It was "inconceivable" that there wouldn't be a new agreement, Baek said, the question was merely how broad and ambitious it would be (as it turned out, quite ambitious). The agency's role was to present lawmakers with a range of scenarios to choose from, including a heavy wind energy scenario, a heavy biomass scenario, and a reference scenario that retained coal in the energy mix. The agency also enjoys a lot of leeway in policy implementation, for example, in running the tendering process for new offshore wind farms—which has, on occasion, embroiled them in hot-button political fights over who gets to build wind projects and where, as I discuss in Chapter 6.

In addition to working closely with the energy ministry to ensure their policy designs are consistent with the minister's agenda, the finance ministry is also involved in the drafting process, and fulfills a function similar to the White House Office of Management and Budget in the United States. The taxation ministry often weighs in as well, since many renewable energy subsidies operate through alterations to the tax code. One constituency that doesn't have a seat at the table is lobbyists. Baek characterized agency staff as gently dismissive of proposals that came from industry and other outside interests, a sort of, "thanks for the input, but no thanks" attitude. Legislation "in this country, is not prepared by K street," he said. "Once we start writing regulation, it's in-house, and it's a closed process." (23) The interest groups I spoke with seconded that perspective. Kristine van het Erve Grunnet, a lobbyist for the utility industry, said that while her organization was in constant communications with political officials, and often had a good sense of which direction they were leaning, in the final negotiations things can change up until the very last minute. "We are very much outside the door there, you don't really know," she said. (24)

Of course, organized interest groups attempt to influence the political process by a variety of less formal means. One strategy they employ is to message policy priorities and concerns directly to the public and to their industry membership, and asking them to put pressure on politicians. Staffers at lobbying organizations work to maintain regular contact and friendly relationships with civil servants in the energy agency and the relevant ministries. “In general, the politicians in Denmark are very accessible,” said Camilla Holbech, part of the policy team at the Danish Wind Industry Association. It’s a small country, and the political class is even smaller, and as everywhere, leveraging personal relationships and social networks is crucial to getting the ears of decision makers. Holbech mentioned the annual political festival on the island of Bornholm each June as a place where relationships are forged. (25) And much as in the United States, there is a clear employment pipeline in Denmark from government to lobbying organizations. Most of the lobbyists I spoke to had prior experience working in one of the ministries. Grunnet suggested that advocating for policy proposals through the media can be counterproductive, and is more often a last resort, when a policy decision appears to be going against them, and in those instances they are not even attempting to sway policymakers so much as to reassure their membership that the organization is fighting for their interests. (26)

The most important tactic for lobbying groups is to stay ahead of the policymaking curve, to intervene early in the process, and seeding ideas in the hopes that officials will come to see them as their own. Grunnet said her organization began formulating their goals for the 2018 Energy Agreement back in 2014. By the time formal negotiations heat up in parliament, policies develop a life of their own, and are unlikely to see major shifts in direction. By getting involved at the earliest stages of planning at the agency level, it's possible to see more of an impact. "In that room, a lot can happen," Grunnet said. A key strategic decision the industry association made in the initial stages of preparing for the 2018 Energy Agreement was to push for the electrification of the heating and transportation sectors, rather than focus on wind production-specific support schemes. That approach was not popular with all of their members, but the organization succeeded in framing the policy debate in those terms, and electrification became a core element of the final agreement. (27)

A lot of these tactics will be familiar to students of interest group politics, but what I want to call attention to is that very little of the regular activities of these lobbying organizations are particularly adversarial. I do not mean to suggest that conflicts of interest, bitter disputes, and dirty tricks cannot be found in Danish politics—one particularly infamous knife in the back paid unexpected dividends for the wind sector in the 1990s—cracks are visible even within interest coalitions, and a parliamentary process driven by minority governing coalitions invites inter-party bickering. But the Danes seem particularly good at getting all parties around a table to talk through those disagreements and work their way to a compromise everyone can live with. It appears to be a fairly functional example of deliberative democracy at work. The government could use their majority in parliament to ram through their policy agenda if they wanted to, but instead they invite the opposition to the negotiating table, and celebrate when they reach a broad agreement, even though that almost always means they had to give up some of the policy items they wanted included. My sense is that this preference for broad agreements is both a cultural value, and a pragmatic recognition that this approach contributes to the long-term stability of the government's policy achievements. Similar dynamics are apparent in the lobbying. It's perfectly obvious which parties in parliament are most skeptical of the renewable transition (the far right parties). But unlike the United States, where interest groups work primarily with the party that is most supportive of their agenda (Grossman 2013), the Danish energy lobbies are willing to invest in assisting and working to persuade the political parties that are least likely to support their policy goals.

The structure of the lobbying community reflects this propensity to seek alliances rather than vanquish enemies. Historically, the two most important interest groups in the Danish wind sector have been the industry association, DWIA, and the owner's association, DVF. The former represented the turbine manufacturers and the latter traditionally represented smaller producers. These two constituencies have differing financial interests, and often found themselves on opposing sides of debates over policy mechanisms to support wind development. And yet they also have a history of working closely together on shared initiatives, most recently collaborating to fund a campaign to combat misinformation about wind power. The DWIA began as a relative minnow; after forming in the early 1980s, the organization went more than a decade without a full-time staff or an office in Copenhagen. By the early 2000s their shop had grown to three employees. They were seriously outgunned by Dansk Energi, one of the most powerful lobbying organizations in Denmark, representing the fossil fuel and utility sectors. For decades, Dansk Energi pushed to limit government investments in renewables. But in 2022, they decided to merge with the DWIA and the national solar power association to create a new entity, christened Green Power Denmark, representing all sectors of the energy system. To make a comparison to the United States, it would be a little like the

Sierra Club and the American Petroleum Institute combining forces to work on climate legislation. The attitude toward competing interests across the Danish political system seems to be less a fight to the death and more "if you can't beat them, join them." (28)

One other observation about Danish interest group politics that appears at odds with the recommendations of the recent public policy literature on energy transitions is that pro-wind organizations arguably enjoyed more direct influence in policy design when they were younger, smaller, and less organized. Throughout the 1970s and 1980s, renewable energy activists were often consulted on subsidy schemes and technology standards, and their proposals often found their way into government policy. As the wind sector has grown exponentially and become more central to the Danish economy, one would expect a corresponding expansion of its political influence, but that growth has also meant there are more stakeholders weighing in, making it harder for any one voice to be decisive. In fact, there *is* widespread and robust support for wind power among Danish politicians today, but that support is largely internalized in government institutions, rather than a product of external lobbying influence. This state of affairs could be characterized as regulatory capture, but I think that misunderstands the dynamics at work between industry and government. It's not as if politicians and bureaucrats are merely doing the bidding of a powerful special interest. On the contrary, officials claim that when it comes to settling policy details, industry is excluded from those conversations. Support for the energy transition has consolidated through an accumulation of long-term legislation, and all the accumulated knowledge and experience gained in parliament and the ministries and agencies from previous rounds of policy. Today support for renewables is embedded in the platforms of almost all political parties, and has penetrated government in a deeper and subtler way through a cultural shift in the values of elected officials and agency staffers. It would be more accurate to say that, today, the overarching values and policy goals of government officials and industry lobbyists are largely aligned, and they argue over the details of how to implement that shared vision of a sustainable society.

That cultural transformation is, I think, an underappreciated foundation of the policy consensus that emerged around renewable energy in the first decades of the twenty-first century. That cultural shift was gradual and systemic, driven by a confluence of multiple causal factors. Policy was both a cause and an effect of these processes. In the 2010s, lawmakers reaped the rewards of that cultural consensus that had been building for decades, passing two landmark energy agreements that reaffirmed Denmark's commitment to leading the world through the energy transition. In 2012, the government successfully negotiated ambitious pledges to supply 50% of the country's electricity with wind power by 2020, and meet 100% of energy needs with renewable sources by 2050. (Danish Ministry of Climate, Energy and Building 2012) Ninety-five percent of parliament signed on to that agreement, with only the far-right Liberal Alliance dissenting. Six years later, the political parties doubled down on the energy transition, upping the target for 2030 from 30% to 55% renewable energy, pledging to phase out coal and build new offshore wind farms, while simultaneously eliminating the feed-in tariff and reducing electricity taxes. (Danish Ministry of Climate, Energy and Building 2018) This time, parliament approved the agreement unanimously, and perhaps even more surprising, it was negotiated under the leadership of a "blue" coalition government that had stopped wind development in its tracks the last time it was in power. In the United States, it remains inconceivable that policies half this ambitious could pass

Congress during a right-leaning administration, or any administration, let alone with unanimous consent.

But, of course, this consensus in Denmark did not appear overnight, which makes the longitudinal analysis of policy evolution so important for understanding how such dramatic policy victories can be achieved. In many of my interviews with Danish policy actors, an expression that was used repeatedly to describe a specific policy enactment was that it “stands on the shoulders” of work that preceded it. What was being implied is that the relationship between successive iterations of renewable energy policies was quite direct—some advisory committee had issued a report with recommendations, or a regulatory agency had developed best practices, or politicians had agreed to general principles, that were then folded into the design of the next round of policy. That does not mean that support for wind energy grew in a linear fashion, and critically, it does not mean that all forms of wind development benefited equally from what look, at an aggregate level, like increases in government support for the energy transition. How those revisions to policy mechanisms have affected the composition of the wind system will be explored further in the next chapter. What is clearly visible in Denmark is a process of policy learning—with the relevant community doing that learning encompassing pretty much the entirety of the wind energy network, as all parties react to the latest policy regime, updating their proposals and adapting their strategies for the next round of policymaking. It is also important to remember that the policy regime supporting renewable energy development is multidimensional, including not only direct subsidies, but also scientific research, essential investments in basic infrastructure, and regulation and planning at all levels of government. I look more closely at those layers of the policy picture in the sections ahead. Since most of the literature on energy policy focuses on topline statistics about national financial support for renewable energy development and production, I will mostly limit my discussion in this section to those programs.

Since time is a crucial variable, it would be remiss not to mention the importance of Denmark's early start. A first mover in numerous categories—first domestic industry, first feed-in tariff, first to achieve significant grid penetration—the Danes got a jump of a decade or more on almost every other industrial nation in building a wind energy system. That head start imposed costs on government, for sure, but more than paid for itself with numerous other social and economic benefits, not least in building a strong domestic industrial base, helping Danish firms acquire a reputation for global leadership in wind technology that remains a competitive advantage to this day. That Denmark began its energy transition in the late 1970s and only reached 50% grid penetration around 2020 also provides an important data point on the length of energy transitions. Having to overcome the hurdles of a first mover, Denmark's transition may have been slower, especially at first, than it will be for later entrants who have the benefit of learning from Denmark's experiences, and starting with more advanced technology, but those laggard nations may still have decades of catching up to do, in what looks increasingly like it may be a century-long process.

Some of the early Danish support schemes for wind energy and their immediate effects have already been discussed in Chapters 3 and 4. To briefly recap, the 1973 oil embargo was the end of the laissez faire approach to electricity supply in Denmark, and the government passed the first national energy plan that year. At that time, the government had no faith in the prospects for renewable energy, and promoted nuclear power as the solution to the oil shortage. As government debated reactor sites, the public reaction was fierce, and a large anti-nuclear social movement played an important role in sparking grassroots interest in renewable energy, and wind power, specifically. In 1979, after the second oil crisis, an energy ministry was created, and the first subsidies for small-scale, independent wind producers were approved. Those initial investment subsidies were something of an afterthought, as wind power was considered too small to become much of an expense, or much of a threat to the energy establishment.

That narrative is consistent with what public policy scholars predict in the early stages of an energy transition. Stokes, Mildenberger and Aklin and Urpelainen all argue that when novel technologies first appear, entrenched interests like fossil fuel industries and utility companies do not see any danger, and so they don't mobilize opposition to what is considered a niche concern. "Although the external shock does create the political demand for renewable energy, it does not yet present an immediate, salient threat to influential political constituencies that reap gains from the country's reliance on fossil fuels," Aklin and Urpelainen write. "In the short run, experimental policies that allow the growth of renewable energy are simply not threatening enough to the incumbent energy producers and their key customers." (Aklin and Urpelainen 2018, 62) Only once the new producers begin to impinge on the incumbents' bottom lines do these authors expect the old guard to fight back. That is more or less what has been observed in Denmark, though the escalation of tension has been a gradual process. There was always a little friction with the utility companies, which bore the costs and the headache of connecting bespoke machines to the grids they had to manage. But those utilities—which at the time were relatively small and localized firms, often cooperatively or municipally owned, knitted together into two regional associations—willingly connected the earliest turbines of people like Christian Riisager and Torgny Møller, viewing them as something of an experiment and an interesting grid management problem for the engineers to solve. The biggest headache these turbines created, from the utilities' point of view, was that they were usually being installed in rural areas, which required reinforcing the grid far from load centers, a significant inefficiency from the perspective of centralized power distribution. (Jensen 2014, 191)

Grid connections and payments to independent producers became more contentious issues in the 1980s, as the number of turbines quickly multiplied, but throughout the decade the utilities and the small wind energy producers, represented by the owner's association in negotiations, managed to work out informal agreements on standards for grid connection and prices that would be paid for electricity fed into the grid. Those agreements usually struck a balance between the interests of the utilities and the turbine owners. At the beginning, the local utility company bore the full cost of connecting a turbine to the grid, which a 1977 utility commission study estimated at around 80,000 DKK (more than $12,000 USD). (Nielsen 2001, 128) Turbine owners were only paid the cost of the fuel their production offset, but with the addition of the investment subsidies and tax breaks, that was still enough to turn a healthy profit, which Torgny Møller calculated was around 13% the first year of operating his turbine. (Nielsen 2001, 127) Those rules were renegotiated in 1980, increasing payments for wind production to 50% of the price the utilities charged consumers. In exchange, limits were placed on the size of cooperative turbines, and shareholders in a cooperative project were required to live within 3km of the turbine. Utilities were also allowed to negotiate grid connection payments with producers on a case-by-case basis, a system the owner's association later claimed was abused by some companies. (Nielsen 2001, 130-131)

In 1984, the energy agency brokered an updated agreement, which was intended to run for the next ten years, splitting the costs of grid connection evenly between turbine owners, utilities, and the state. The government agreed to maintain the investment subsidies, and the 3km restriction was removed, but turbine shareholders would now have to live within the service area of the utility making the payments. (Van Est 1999, 87)

The restrictions on who could purchase shares in turbines, adjusted repeatedly throughout the 1980s and 1990s, were always a point of contention, and proved to be one of the most significant policy mechanisms for shaping the evolution of the Danish wind network. That there were continuous political debates over that rule is unambiguous evidence that Danish policymakers were consciously thinking about the character of wind development they wanted. If the goal had simply been to cut carbon emissions (not really even on the government radar before the 1990s), or to speed the energy transition, or to support domestic manufacturing, as politicians often said, placing no restrictions on turbine ownership would have boosted all of those agendas. There was ample demand from members of the public, who were snapping up turbines as fast as manufacturers could roll them off the assembly line. Many well-off Danes living in cities saw a safe investment opportunity buying shares in a cooperative windmill, and a way to put their money behind an environmentally-friendly and *folkelig* project, a political agenda popular among the progressive urban professional class. The problem was, those turbines they were buying into weren't being raised in the streets of central Copenhagen, but on the windswept moors of northwest Jutland. The eligibility restrictions placed on purchasing shares demonstrate a direct effort to limit this kind of investment. The regional divide in Danish society is important to understanding this political dynamic. The economic, cultural and political center of Denmark is on the island of Zealand, much of which is occupied by the capital and its suburbs, in the far east of the country. Jutlanders in the rural west are stereotyped as provincials, and they in turn resent what they see as the arrogance and elitism of easterners. That rural-urban divide is particularly salient in intensely social democratic Denmark, where thinking you're better than others is the number one social taboo. So when a doctor, an architect, and a couple of professors from Zealand wanted to build a 20-turbine wind farm along a fjord in the far northwest, the director of the grassroots Organization for Renewable Energy (OVE) complained to the municipal government in Struer that if the project went forward it would block locals from raising windmills in the area, and if rich easterners were allowed to exploit Struer's wind for commercial interests, it risked giving wind power a bad reputation. According to journalist Ib Konrad Jensen, who recounts this incident in his book *Maend I Modvind*, backlash to that large investor-owned wind farm—which did end up getting built in 1985—inspired parliament to formally reimpose residency restrictions on turbine owners, as the politicians reasoned that keeping development small-scale and local would ensure broad popular support for wind energy, and if the people building the projects had to live near them, they would have more incentive to site them wisely and maintain them well. In Jensen's estimation, this political logic was sound. (Jensen 2014, 194). Danes expressly did not want to throw up wind turbines willy-nilly, as they had seen done in California. My sense is that across a wide swath of Danish society, from political elites to the general public, there was not a lot of support for moving fast and breaking things, or for turning a quick buck. Political majorities wanted wind power to grow, but they wanted it done the right way. At that time, at least among the left-wing parties in parliament, the right way meant the cooperative way. This concern with managing an appropriate pace and character of wind development was consistent with a pervasive long-term planning mindset that I still heard being voiced today by everyone from mayors to CEOs, from farmers to members of parliament. What these individuals were often expressing to me was an aesthetic preference for orderliness and craftsmanship, for things being suited to and expressions of their local context, that is deep-rooted in Danish society, and can be seen reflected in everything from its toy manufacturers to its Michelin-starred restaurants.

The turbine manufacturers, for their part, did not particularly care who bought their turbines, as long as they could project a steady stream of business. They were happy to sell ever-larger turbines by the dozens to populate sprawling wind farms, either in the desert passes of California or the gently-rolling fields of Jutland. The utilities presumably had an interest in limiting the growth of wind power, as all of the private capital pouring into cooperative wind projects was putting ever more turbines on the grid, chipping away at their monopoly over the energy system. Whether or not that fear was discussed in the board rooms of the utility associations I cannot say, I have not found much evidence of it being expressed publicly. Whatever their motives, by the mid-1980s the utilities had had their fill of the wind enthusiasts, and made their move to snuff out the threat. Not long after agreeing to the new rules for turbine connections, which were intended to last a decade, the utilities began negotiating in secret with the conservative government, excluding the owner's association from the talks. In December 1985, the government issued new rules requiring all shareholders to live within 5 km of the turbine, a month later the rule was amended to enlarge the boundary to 10 km. The investment subsidy was reduced to 15 percent of the value of the turbine, and the number of shares members could own in cooperative mills was capped at 35% of their personal electricity consumption. All of this was done with the intent of prohibiting financial speculation on wind projects. (Van Est 1999, 89) It must be noted that the industry was leery of this sort of speculative investment as well, since they had already been through that boom-and-bust cycle in California, where the market was in the midst of crashing, wiping out Danish manufacturing firms left and right.

As much as Danes value social equality, they are also most definitely capitalists, and as long as there was easy money to be made erecting wind turbines, someone would find a way to exploit the regulations for their own gain. The most notorious of these schemes was somewhat inadvertently hatched in 1993 by a widower who was moving into town after her husband's death, but wanted to keep her stake in the wind turbine on the farm. Her lawyer realized they could use a loophole in agricultural laws that was designed to let farmers sell non-contiguous fields to one another. A surveyor blocked out a 7x7 meter plot of land around the base of the turbine, and the tiny parcel was then excised from the farm property and registered with the tax authorities to the widower's new residence in town. It's not clear the widower's intent was to pioneer a new scheme for overcoming the residency requirements, but that was the effect, as the idea quickly spread among investors, creating an overnight boom for manufacturers in the mid 1990s. Orders picked up so fast that industry worried about the domestic market overheating, and the utilities fretted about their ability to absorb all this new, highly variable load being fed into the grid. (Jensen 2014, 199-200) While this new investment model was good for the turbine business, it flew in the face of the government's efforts to keep development small-scale and local. After several years of fairly acrimonious debates that spilled out into the press, the government finally managed to close the loophole in 1996, but by then it was too late, investors had plenty of time to ink deals with landowners at choice wind sites before the legal fix went into effect. (Jensen 2014, 201-202) This wave of private investment was rapidly changing the character of Danish wind developments. I described at the beginning of this chapter how small, often family-owned firms like Peter Møller's began to take over onshore development in the late 1990s and early 2000s. The cooperative model had crested, and was beginning a fairly precipitous decline. Whereas cooperatives had usually put up just one or a few small mills, both turbines and wind parks were growing larger. The wind sector was growing bigger faster than either the government or the utilities had wanted, both thanks to policy and in spite of it. The emerging potential of the wind sector offered the nation economic benefits, but also posed serious new challenges for the energy establishment.

The period from the late 1980s and through the early 1990s was probably the low point in the relationship between the utilities and the wind sector. Government policy deserves the lion's share of the credit for dragging the utilities along, begrudgingly. As part of the deal the government had struck with them in 1985, the utilities had agreed to build 100 MW of wind power before the end of the decade. That would have nearly doubled the total capacity on the Danish grid at the time. Left-wing parties in parliament worried this deal would allow the utilities to monopolize the wind sector, a fear that proved decades premature, if not entirely unfounded. (Nielsen 2001, 328) The utility companies were reluctant wind farm developers, only meeting their quota three years after the 1990 deadline. Over that same stretch of time, private developers were installing turbines at twice the rate of the utilities (Jensen 2014, 195), whose lobbies had consistently flexed their political muscle to stifle this surge of new producers. But the concessions they won from government in the 1980s turned out to be the last stand of a system that was being rapidly dissembled. The era of monopoly control of the electricity system was coming to an end. Only after 2000 would the utilities fully embrace wind power, after it became apparent that building the large coal-fired power plants they preferred was no longer politically feasible, and after turbine technology had advanced enough that wind farms were increasingly able to mimic the performance of those centralized power plants.

If the utilities didn't recognize it sooner, by the early 1990s government began sending them clear signals that the political landscape was changing. After national energy plans in the 1970s and 1980s had only projected a small role for wind energy, two plans adopted in the 1990s signaled a new direction, and the beginning a policy lock-in for the renewable energy transition. The first of these plans—Energy 2000, drafted after the publication of the Brundtland Report put climate change on the political agenda—was enacted in 1990 and for the first time set an official target for wind power, aiming to reach an installed capacity of at least 1.3 GW by 2005, which corresponded to about 10% of the expected electricity demand. (Meyer 1995, 23) At the same time, efforts had been underway to secure an updated deal on the rules for grid connection and payments to independent wind producers that the owners' association and the utilities had negotiated back in 1984. In the years that followed, the parties' interests had grown too far apart, and it appeared that handshake deals would no longer suffice. The conservative energy minister, Anne Birgitte Lundholt, had expressed her belief that energy markets functioned most efficiently when free of government interference. That ideological stance from a decade of conservative governments may have given the utilities false confidence that they were in the driver's seat. When it became clear in 1991 that negotiations with the owner's association were going nowhere, the minister threatened unilateral action if the parties could not come to terms. But no deal could be struck, and in early 1992 the industry and utility representatives were summoned to the ministry and informed the political parties had decided to codify the feed-in tariff for wind power at 85% of the consumer electricity price, regardless of who owned the turbine. The residency restrictions were loosened, allowing investors to purchase shares in turbines raised in the municipality where they resided, or an adjacent municipality. Turbine owners would now have to pay the full costs of the substations and low-voltage lines to connect to the grid, but the utilities would be responsible for reinforcing the high-voltage transmission network to accommodate additional wind capacity. (Nielsen 2001, 395-396) The announcement came as a shock to the utility associations, who had not been consulted, and were not pleased with these terms. (Jensen 2014, 197)

A new policy regime was emerging in the 1990s, under the stewardship of a new energy minister who did not seem to care much how wind turbines got built, so long as production kept increasing and emissions kept declining. That minister, Svend Auken, was one of Denmark's biggest political stars, and an unyielding champion of the renewable energy transition—something of a cross between Bernie Sanders and Al Gore. He is widely credited as the driving force who set Denmark on its current policy trajectory. Auken’s biggest political defeat became the wind sector’s biggest political gain, and by losing power, ironically, he ensured the passage of his policy agenda. Auken was chairman of the Social Democrats during the 1990 election, which the party won handily, more than doubling the vote share of the second-place Conservatives. That victory should have put Auken in line to become Prime Minister, but in the most dramatic case of political subterfuge in recent Danish history, he failed to form a governing coalition with the party's traditional allies, Radikale Venstre, allowing the conservative coalition to stay in power another three years. Auken took the blame for the collapse of the red coalition, accused of being too far to the left, and when the Social Democrats won the next election in 1993, he was passed over for party leadership by his former deputy, Poul Nyrup Rasmussen. That political hit job only made Auken a more sympathetic figure to the public. The new government needed Auken’s faction in parliament, giving him carte blanche to demand anything he wanted of the prime minister. What Auken wanted was the environment ministry. A year later, the environmental and energy portfolios were combined into a single ministry, allowing Auken to pursue his climate and renewable energy goals in concert. According to Auken’s close associate Thomas Becker, he had the support of about half of the Social Democrats, and “they were very much in revenge mode” throughout Rasmussen’s nine years in office. Whatever initiatives Auken wanted funded, the finance ministry felt obliged to approve, and he wasn’t shy about using that leverage to steer resources to the growing wind industry, helping it put “fat on the bones.”

Auken provides the best example of how favorable elite ideology can drive an energy transition forward, though even his friends admit there were larger structural factors at work. "He was completely decisive in Denmark and at a European level pushing for alternative energy, and for pushing climate change as a political subject," Becker said. "I wouldn't say he managed the whole thing himself, because it would have come anyhow, but he sped up the process maybe five or ten years." (30)

Becker described Auken as a "grand man" and an "enormous personality" whose passion for the environment and concern about climate change were sincere, so much so that others in government sometimes laughed at his earnestness. He bicycled everywhere, worried about the airline miles he logged, and owned an electric car before anyone else, which his driver hated. Auken saw the energy transition as "a way out of dependency" and "as something that could help saving the planet." (31) That Auken, who died of cancer in 2009, possessed rare political charisma is evident watching the 2011 documentary *Svend*, which his wife filmed during his final years. In the film, Auken comes off as a gentle giant, his face perpetually about to burst into a toothy grin, who seemingly begins every conversation or speech with a joke that splits open the room into a chorus of guffaws. That mixture of unflinching principles and self-deprecating humor made Auken a folk hero. His niece, Ida, who is herself now a leader of the Social Democrats, perhaps characterized her uncle's place in the public imagination best:

> We've spent too much time in the climate discussions on the technical stuff, and we have all the solutions, but we need to think about how to get people on board, and he really knew how to do that. In a way he is as tall as the wind turbines … he and the wind turbine are somehow related almost physically or viscerally in people's minds, they kind of signal the same thing of sticking up and being this little weird country having big leadership, big arms coming out … I can't take a taxi now without people saying, 'I loved your father,' and then I have to tell them he was my uncle. If I post something on Facebook now it will still get thousands of likes if I mention him. (32)

Ida Auken credited her uncle with maintaining the political support for renewable energy during trying years for the wind industry in the 1980s and 1990s.

Of course, Auken was not universally beloved, or he never would have been deposed by his own party. His willingness to promote the growth of wind power by any means necessary was seen by some in the wind community as a betrayal of the grassroots movement. All Auken cared about was carbon math, Preben Maegard complained, and he never really understood the community development model. (33)

The red and green coalition, as the largest bloc in parliament, had already played a decisive role under the previous administration in making sustainable development official government policy with the *Energy 2000* plan. When Auken assumed control of the energy ministry, the new government doubled down on that vision in the fourth energy plan, *Energy 21*, released in 1996, which explicitly called for coal and oil in the energy system to be replaced with natural gas and renewables. "Deliberate efforts are required to develop renewable and energy-efficient technologies, an effort that is not free of costs" the plan stated, "but the government believes Denmark will benefit greatly as a pioneering country in these technologies." The plan set targets of reducing carbon emissions 20% below 1988 levels by 2005, and generating between 12-14% of the nation's energy from renewable sources, including increasing wind capacity from around 600 MW at the time to 5,500 MW by 2030. For the first time, offshore wind targets were included, comprising 4,000 MW of that total. (Sawin 2001, 552) "In Denmark, the future development will be offshore," Auken wrote in a 2002 journal article on Denmark's policies. "There is, in fact, very little space remaining on land for new installations." (Auken 2002, 156)

With a 30-year planning horizon in place, the energy establishment began to see the writing on the wall. After signing on to build 100 MW of wind farms in their 1985 agreement with the government, the utilities agreed to build an additional 100 MW in 1990. In 1996, Auken negotiated another 200 MW of commitments to build onshore wind before 2000. In 1998, he secured a government tender for 750 MW of offshore wind. Auken reasoned that it was politically advantageous to involve the utilities directly in the transition, "to ensure that expertise and commitment to renewable energy is present within power companies." (Auken 2002, 152) That desire to encourage utility-led development, especially offshore, proved prophetic.

Two additional changes to energy policy under Auken's watch had major consequences for the evolution of the domestic wind network: the liberalization of the energy system, and the first rounds of repowering older windmills. Following a 1996 EU directive, Denmark deregulated its energy market after 1999, leading to a major restructuring of the electricity system, and the end of the old vertically-integrated utility monopolies. Power generation, transmission, and consumer service were decoupled, allowing a flood of new entrants to the market. A few years later in 2005, a newly-formed state-run transmission system operator took over control of grid management from the old utility associations ELSAM and ELKRAFT. The influence of the new TSO on grid development over the past two decades, and its consequences for wind energy, will be discussed further in Chapter 6.

Liberalization was also the beginning of the end for Denmark's feed-in tariffs. The policy scheme that had made raising a wind turbine a safe and attractive investment for tens of thousands of Danish families since the 1980s was becoming increasingly controversial among blue coalition politicians, who complained the high costs of these programs showed unfair favoritism to a particular technology, placed excessive burden on state budgets and ratepayers, and risked making Danish industries less competitive on global markets. The government's plan after the reorganization of the energy market was to eliminate the feed-in tariffs entirely. Instead, wind producers would be paid the market price for the electricity they generated, and would also receive tradeable green certificates. But that plan was understandably unpopular with the wind community, as it would spell the end of predictable, guaranteed prices, introducing an entirely new element of risk and complexity to their investments. The provisions of the certificate trading program were fought over for years, before the plan was eventually abandoned. Instead, in 2001 a tax was introduced to consumer electricity bills to fund investments in renewable energy, the Public Service Obligation (PSO). The government would guarantee independent producers a set price for the renewable power they fed into the grid, and cover the difference between that set price and the market price with the proceeds from the electricity tax. It was the continuation of a feed-in system by other means, and did nothing to solve the electricity price problem, as Danes continued paying the highest rates in Europe. Perhaps unsurprisingly, the subsidy scheme remained a point of political contention, and the PSO was soon accused of violating European competitiveness rules. The sticking point was that the PSO taxes were paid by everyone who bought power from Denmark, but directly benefited the renewable producers feeding power into the Danish grid. That gave the Danish wind sector a leg up over potential competitors in other countries interconnected through the European grid, and EU directives required a level playing field for all generators. After a protracted legal dispute, the Danish government agreed to begin phasing out the PSO in 2016. Support for renewable energy development was added as a regular line item in the state budget, potentially exposing future programs to the unpredictable political winds of budget negotiations. In the most recent energy agreements, direct payments for new wind projects are being curtailed sharply.

The controversy over, and eventual abandonment of, the PSO is a good example of one of the many ways national and European policy interact to influence the progress of the energy transition. As a member of the European Union, Denmark has often been constrained by EU policy in its ambitions to subsidize the transition. Seemingly every time a new support scheme is devised, questions are raised about whether it runs afoul of European competitive rules. Just this summer, the government has suspended the approval of all offshore wind farms under its latest "open door" program for just this reason, now 24 of 27 projects being planned might not go forward. (Durakovic 2023) I think it's fair to say the European Commission has created a lot of headaches, and a piled up a lot of billable hours, inside the Danish Energy Agency over the past decade. But the relationship with the European Union has not only been an obstacle to Denmark's renewable energy policies. More often, Danish and European policy agendas are closely aligned on wind energy. It has usually been the Danish delegation out front championing green policies at the European level, and working behind the scenes to implement the European policy frameworks. For many years, it was Svend Auken in those multilateral meetings, and his contributions to the formation of international climate institutions and policy regimes were arguably as significant as his role in advancing Denmark's energy transition. It was Auken who talked Angela Merkel, then climate minister in Germany, into hosting the first COP meeting in Berlin. He was also a leading proponent of the Kyoto Protocol. (34) Auken collected plenty of frequent flier miles to feel guilty about—he frequently traveled the world doing climate diplomacy, trying to gin up international coalitions for climate action. A full examination of howinternational and national climate policymaking interact is beyond the scope of this dissertation—I leave that task to my friends in international relations—out of necessity I am limiting my focus to the domestic context in Denmark. From a sociotechnical systems view, the domestic energy system is of course embedded in and interconnected with the larger European and global systems—legislatively, economically, physically. In the following sections, I will try to point out several of the places where European policy has made a significant mark on the growth of the Danish wind sector—like in the PSO conflict, with grid infrastructure, and in local planning. To vastly oversimplify a story that could be the subject of its own book, my general sense is that Danish policy actors have strategically exploited the European context to advocate for policies that benefit the Danish wind sector. A lot of the key players in Denmark have also filled advisory, lobbying or official roles at the European level. For example, after serving as Svend Auken's right-hand man in the climate ministry, Thomas Becker jumped chairs to run EWEA, the European wind industry's lobbying arm in Brussels. Later he helped organize the 2009 COP conference in Copenhagen, and today he's working on green collaboration across the Nordic region.

Returning to the Danish context, a second lesson of the liberalization process is that it put pressure on the broader government effort to provide financial support for renewable energy development. One of the major policy consequences of liberalization was the slow unwinding of direct subsidy payments. The overhaul of subsidy programs took about twenty years to complete, probably far longer than the likes of Svend Auken would have anticipated. But today wind power projects in Denmark generally have to be viable at market rates, the direct subsidies that remain are fewer and smaller. Depending on who you ask, this development either signals the welcome arrival of wind energy as a serious player in the energy sector, or the end of an era to be mourned. Most of the sources I spoke to in business and government are firmly in the former camp, seeing an industry that has matured and can now stand on its own feet. Ida Auken cited her uncle's work to liberalize the electricity sector as one of his most important contributions to the energy transition, because even though it might seem "weird" for a social democrat—and a notoriously lefty one, at that—to lead the charge for market liberalization, he had the foresight to understand that the long-term growth and stability of the renewable energy sector would require private capital and big business to be involved in the transition. (35) Svend Auken had decided in the 1990s to use his perch in government and his political capital to help wind power get big. He succeeded.

The evidence the wind business had grown up was becoming increasingly visible on the landscape. As the new millennium dawned, the squat little windmills that no longer looked like such attractive investments started to literally disappear from the horizon. The cause of this sudden die-off in the population of first-generation 22 kW, 55 kW and 150 kW turbines was a repowering subsidy introduced as part the 1999 energy laws. The program was created as a concession to the growing backlash over the enormous number of turbines littered all around the countryside. Many Danes I met spoke disapprovingly of the haphazard manner in which the early turbines had been erected, and the rowdy menagerie of experimental designs, with no formal planning process or siting requirements in those years. Svend Auken, ever thinking like a planner, clearly wanted to impose some order on future wind developments, and that policy stance still holds appeal in rural Denmark today, particularly on the populist right, which has long pushed for a reduction in the total number of turbines onshore. Under the terms of the updated subsidy scheme, new turbines connected to the grid could receive a substantial "scrap premium," on top of the feed-in tariff, if they first decommissioned a prescribed capacity of existing windmills. (36) The math worked out to a financial windfall for developers, who began scouring the countryside cutting deals to purchase aging turbines. As the deadline to qualify for the first round of repowering subsidies approached at the end of 2002, hundreds of small turbines were dismantled in a matter of months. Many of the turbines decommissioned in that period were purchased from cooperatives, as I illustrated in the case of Jane Kruse in Chapter 4.

In addition to the subsidy sweetener, private developers were getting pressured at the local level to take down some older mills if they wanted municipal officials to look favorably on their project, and with the stock of available development sites depleted in the windiest areas, it was often necessary to remove existing installations to make room for the newer, larger parks. Because repowering is attractive to both locals and developers for a variety of reasons, as I described at the beginning of this chapter, it has become one of the most common methods of onshore development today. A recent study by researchers at DTU found that 38% of new wind developments in Denmark were repowering projects. (Kitzing et al. 2020) The repowering of the wind energy system was always inevitable, as turbines aged, and as a first mover Denmark was one of the earliest countries to cross that threshold, right about when the actuaries would expect, 20-30 years after the first installations. And since modern developers favor much larger turbines, in the future far fewer will be needed to meet demand. The plans on the books today call for reducing the overall number of onshore turbines from the more than 5,000 currently operating to less than 2,000. Interestingly, this quota was adopted not primarily for technical reasons, but for political reasons, at the urging of right-wing parties in parliament concerned with reducing visual impacts of turbines on rural landscapes.

Repowering should be seen as a natural stage in the life cycles of renewable energy technologies. But because it is a political process, the question for policymakers is how they want to manage it. The effect of the repowering subsidies was to accelerate this process, and favor one style of development over others. Few of the many observers of the Danish case have flagged the significant effects of what looks like a relatively minor, narrow policy tweak on the character of wind energy development in that country. One exception is Preben Maegaard, who always has a keen eye trained on the politics of renewable energy transitions, and their significance for what he hoped would be a democratizing movement of small-scale, grassroots development. “Repowering also led to a decisive change of wind turbine ownership,” he wrote. “The close deadline meant that there was no time to dismantle and sell those otherwise well-functioning turbines.” Entrepreneurs hoping to get their large wind farms approved were in such a rush, they sawed through the towers of the old mills with flame cutters, dropping them like lumberjacks and dragging them away, leaving their severed stumps behind to rot in the fallow fields. It was mostly cooperative turbines that were being lost, because the commercial developers were offering a price to take them down that was too good to refuse, in some cases allowing shareholders to recoup their entire initial investment. With age, maintenance risks grow, and small-money cooperative shareholders are usually less willing to bear those financial risks. When there was an appealing exit strategy on the table, many cooperatives voted to sell and disband. What saddened cooperative members like Jane Kruse was not only the relationships with their neighbors, and with the turbine itself, that were being lost, but the feeling that the venture had been going quite well before a buyer swept in, and could have feasibly continued going well for a number of years more. Most of the turbines taken down in the early rounds of repowering, while getting up there in years, were operating just fine. As the pushing-fifty Tvindmill demonstrates, those hardy old mills can run forever. Conservatively, many of the turbines taken downs in the early 2000s could have generated power at least another five years, and with regular maintenance, perhaps much longer. That their premature culling was also endangering grassroots participation in the wind network, Maegaard considered "a heavy loss for democracy." (Maegaard 2014, 595-597)

Whether one favors Auken's or Maegaard's perspective on the changing profile of wind development, it does represent a notable reversal of official government policy on the domestic wind sector. In the 1980s, residency requirements for turbine owners were enacted in an effort to stamp out commercial development, and keep wind projects small-scale and local. By the late 1990s, subsidies like the repowering scheme were sending the development community the opposite message. With gratitude for the historical contribution of the grassroots development model, the small turbines had served their purpose, and their time had passed. They were no longer needed or much wanted on the grid; they were now getting in the way of growth. The professionals had arrived on the scene, and government was counting on them to finish the job. Rasmus Helveg Petersen, climate and energy minister from 2014-2015, was just one of the many Danish policy actors who expressed this attitude to me. "I'm really not into symbolics," Petersen said. "We want it to be industrial scale, and something undertaken by the big professional players … It matters that we make the big guys do it, that is actually important when you want to do this on a scale where you can see a real contribution." (37)

Dating the precise timing of renewable energy "lock-in" is difficult, because there are many possible metrics to choose from. And as I and other scholars have argued, it is a very gradual process, with few decisive punctuation points. If lock-in is measured in terms of grid penetration, or the maturation of turbine technology, or industry employment or contributions to GDP, the period from the mid 1990s until the early 2000s looks like a pretty good candidate for the wind system establishing something like lock-in in Denmark. But the closer one looks, the more and nuance can be discerned in the gradual upward trend, I don't get the impression Danish wind businesses have ever felt particularly comfortable or safe in the stability of their industry. In my experience, they are usually busy sounding the alarm about the latest impending crisis. But maybe that is just how lobbyists talk. After its baptism by fire in the California deserts, the Danish wind industry never really settled, alternating between periods of rapid expansion, drought, and decline. Even in the 2020s, the future remains uncertain. After several bad years during the pandemic, progress toward Denmark's wind energy targets has been worryingly flat, a subject I will return to in the next chapter. Just this summer, the industry is facing two new threats—not only the suspension of offshore permitting, but also the discovery of a major mechanical flaws in Siemens' offshore turbine rotors that will likely cost the country's second-largest manufacturer billions, and has cast doubt on the financial outlook for the entire offshore industry. Investors and managers probably thought the sector was past these kinds of widespread equipment failures, which plagued the industry throughout the 1980s and 1990s. At numerous points during the last four decades, manufacturers found themselves in financial jeopardy, and many did not survive. Denmark has also gone through several dry spells when new development cratered. In some cases, the dips in the manufacturing sector were consequences of unfavorable policy environments; the dips in turbine installations in Denmark were almost always driven by changes in policy. One of the most recent, severe and prolonged periods of stasis was from 2002-2009, when a center-right government led by prime minister Anders Fogh Rasmussen took power and immediately announced it was ending plans to develop new offshore wind farms—which at the time were still heavily subsidized by the state—and slashed the premiums for onshore wind projects. For seven years, domestic wind development came to a standstill. “It stopped everything,” onshore developer Jakob Greth told me. (38) The misconception about this policy retrenchment is that the Rasmussen government was not stridently anti-wind, in the way many U.S. conservatives and fossil-fuel interests have become. Rather, as both my sources and other scholars report, the ruling coalition’s main concern was with the costs of the subsidy programs. (Valentine 2015, 101) They were a pro-business bloc, and they were looking at the issue from the perspective of market liberals. They were happy to have the domestic wind industry, but they wanted to see it compete on market terms. Of course, conveniently, those parties’ patrons in the corporate sector were the best-positioned to benefit from market-based policy mechanisms. The debate over the costs of government support for wind power, which has now been running for decades in Denmark, is one of the clearest examples of an opposition of financial interests manifesting as a policy conflict, which the public policy literature predicts is the underlying causal driver of energy transitions. Mom-and-pop wind development shops like Jakob Greth's depended on the continuation of the subsidies to make carrying out new projects financially viable. The manufacturers indirectly benefited from the subsidies as well, by selling more turbines. But larger institutional investors were less wedded to the support schemes, and business interests in other industries suffered from the high electricity prices the tariffs produced. Whatever influence these financial interests had on the Rasmussen government's energy policies, it may have been more of a diffuse philosophical alignment, rather than a coordinated attack on the wind sector, in the way fossil fuel interests in the United States mobilized to sink carbon tax legislation in 2009. The only evidence I have seen of plots to undermine wind energy in Denmark are in the grassroots today, and that interest group coalition is mostly composed of Facebook activists who trade in conspiracy theories. Political elites have been broadly pro-wind since the 1990s, and over most of the 40-year period surveyed in this section, the liberal blue coalition in government has signed on to policies to support the energy transition. Even Anders Fogh Rasmussen's government switched course, reinstating the feed-in subsidies in 2008. My sources suggested the government was feeling pressure—ideological rather than financial—to take a strong pro-renewable stance before the upcoming COP conference, which Copenhagen would be hosting in 2009. Thomas Becker blames the skepticism about wind subsidies during that period on the malign influence of one man, Bjørn Lomborg, whom Rasmussen appointed as something of an energy auditor at a new Environmental Assessment Institute, purpose-made for Lomborg to practice his specific brand of cost-benefit analysis. I already introduced Lomborg's ideas about renewable energy in Chapter 2. He is a prominent climate skeptic and a darling of libertarians. His objections to wind energy, as far as I can tell, are philosophical, and not motivated by some material interest. "He slowed things down for a while," Becker said, "which is tragic, because Lomborg is not a scientist, he's a journalist and nothing else." (39) The Environmental Assessment Institute lasted four years. Lomborg moved to the United States.

The one instance I have seen of an organized interest group campaign against renewable energy policy came a decade later, when large electricity consumers mostly in the agricultural sector, like greenhouses, made the high electricity prices an issue in the 2015 election. That year, the populist parties were the bigger winners, and when the new center-right government led by Lars Løkke Rasmussen took office, they once again trimmed support for wind power. "We experienced them as a government who had spent more time removing incentives for the green transition than promoting them," said Ida Auken of the red coalition. (40) But just as the former Rasmussen government had done a decade earlier, this new prime minister switched course midway through his term in office, passing the most ambitious energy plan yet in 2018. All told, the evidence is relatively weak for the model of interest group combat as the driver of Denmark's energy transition. Yes, Denmark has lobbies. Yes, they are engaged in a perpetual scrap for the spoils of policymaking. But zooming out from the messiness of the day-to-day political spats and the annual adjustments to policy schemes, the broad trend that appears in Denmark is one of widespread support for the energy transition across the political spectrum, even among interests who might be expected to oppose it. There is a reason scholars do not write about Denmark as a case study of a failed transition. It is that broad consensus, and the relative lack of an anti-wind lobby on the national political scene, that is driving the transition forward in the ministries and the agencies, and that needs to be explained. The distributional conflict model does a poor job of capturing how such a consensus emerges.

If the question is how and when support for the renewable energy transition consolidated in official policy circles, I would argue that stabilization was a relatively recent phenomenon. Already in the 1990s, under Svend Auken's leadership, the domestic wind sector was turning a corner. By the end of the decade, the old utility-led model had fractured, and it was clear wind energy was no passing fad. But the future configuration of the energy system remained contested. Auken might have believed that future belonged to renewables, as the best hope of arresting climate change, but in that respect he was out far ahead of most of his colleagues in parliament, dragging government forward on his pet issue. Official policy coming out of Auken's ministry in the 1990s still only projected a minority share for wind in the energy mix, and counted on large biomass and natural gas-burning plants as the backbone of the electricity system, providing baseload to the grid, not to mention leaving petroleum dominance of the transportation system untouched. The utilities were still hoping to get one last giant coal plant approved. The 2000s were an important turning point from an interest group perspective, since that was the decade the utility and corporate sectors embraced wind power, eliminating the last powerful pocket of resistance to the energy transition. Only afterward, in the 2010s, was the vision of a renewably-powered society codified in national energy plans. In that decade, Danish politicians stacked a series of increasingly impressive policy wins—

highlighted by the 2012 and 2018 energy agreements, and the 2020 climate law—setting the country on a clear path to energy independence and carbon neutrality in the decades ahead. Even the temporary setbacks for renewable energy policy after center-right governments took power in 2002 and 2016 could be read as evidence that the green transition was locking in, as the wind community was able to withstand these policy challenges and ultimately reverse them. What is remarkable about the policies enacted in the decade from 2010-2020 is not only that such ambitious targets were set, but also that these agreements were made largely in the absence of the "contentious politics" the public policy literature expects. Most of the sources I interviewed who are still active in Danish politics participated directly in negotiating those policies, and were able to give me firsthand insights into how the deals were achieved.

The blue coalition's blockade of wind development ended in 2008, when Connie Hedegaard was minister for climate and energy. Ida Auken was newly-elected to the Folketing at the time, and remembers sitting in the negotiating room listening to her uncle, Svend, haggle with Hedegaard over wind turbine subsidies down to the last øre. That Hedegaard was a member of the Conservative People's Party did not mean she was anti-wind, on the contrary, she publicly advocated for sustainable development at both the national and European levels. She secured the 2009 COP conference for Copenhagen, and later served as European Commissioner for Climate Action from 2010-2014. Simonsen, who was deputy director at the Danish Energy Agency during Hedegaard's tenure at the climate ministry, credited her leadership with shepherding a broad agreement through parliament in 2008. Both Ida Auken and Anne Simonsen credited the next energy minister, Martin Lidegaard, as the driving force behind the 2012 agreement, which he made his top priority when he took office. Simonsen suggested he intentionally sought a big and broad deal—wanting a splashy policy achievement for his resume. He got the deal, she said, because there was something for all parties in the agreement. The populist Dansk Folkeparti wanted compensation for neighbors of onshore wind projects, and they got it. The center-right Venstre wanted support for biogas, and they got it. (41) The 2012 energy plan forecasted a secure future for the growth of the wind sector, committing to generating 50% of the country's electricity from the wind by 2020. That target was narrowly missed, but wind power's contribution to the electricity mix did top 50% for the first time in 2022. Simonsen credited large industry players like Vestas, the farmers looking to maintain support for onshore wind, and environmental NGOs all pushing for aggressive renewable energy support schemes. According to Rasmus Helveg Petersen, the liberal Prime Minister Lars Løkke Rasmussen was feeling internal pressure from his constituents to show progress on a renewable energy deal in the run-up to the 2011 election, "not particularly because it had climate targets in it, but because it has jobs in it," he explained. "When you look at a map of Denmark and you place all the jobs in wind turbine manufacturing on the Danish map, it coincides with all the places where the liberal party is really strong. There's a lot of mayors out there, a lot of MPs out there." Concern about climate change was a motivation for his own social liberal party, but what brought the right-wing parties to the table was the prospect of more employment in the wind sector. "When you look down those 95 percent [of members of parliament who voted in favor of the argreement], then there's a variety of reasons why you want to enter into this," Petersen said. "And we mobilized all that. We did that on a number of occasions, first to make the agreement and then to preserve the agreement." (42) When a social democratic government led by Prime Minister Helle Thorning-Schmidt took power after their 2011 election, one of their first orders of business was to finalize the energy agreement the following March. In addition to being part of the party's electoral platform, wind industry lobbyists suggested that the final contours of the plan that emerged were also heavily influenced by the recommendations of the Danish Council on Climate Change, an advisory committee comprised of nine academics. (43)

In retrospect, sources across the political spectrum feel the 2012 plan was too ambitious in its embrace of renewables, and mistakes were made that had to be corrected later. A feed-in tariff for residential solar was adopted for the first-time, and the initial rate offered of 2.2 DKK for solar energy fed into the grid proved far too generous, and led to a rapid boom in rooftop solar installations, surpassing the 2020 goal of 200 MW installed in less than a year. Plans were immediately announced to slash the feed-in payments nearly in half, and phase them further downward over the course of several years. The other big regret from the 2012 plan was that the parties were unable to reach an agreement on taxing biomass. Biomass had been promoted as an alternative to coal, and like others renewables exempted from electricity taxes, resulting in a surge in the use of wood pellets to fuel Denmark's combined heat and power plants. While technically a renewable resource, biomass was not a particularly green fuel, since burning wood pellets emits carbon, and much of the lumber was being shipped in from abroad, often from clear-cutting forests in Canada. According to Simonsen, efforts to tax biomass were ultimately removed from the 2012 agreement at the behest of the utilities. (44)

Negotiations on the next energy agreement began in earnest after a second Lars Løkke Rasmussen administration took office in 2015. Ida Auken remembers being embarrassed that Denmark received the dubious distinction of being named “Fossil of the Day” by the Climate Action Network during the COP21 talks in Paris later that year. “We had, in my view, a government very uninterested in the green transition. They had stopped all climate goals,” Auken said. “So we were pushing them very hard to get this deal.” She recalled the left-wing Social Liberals, of which she was a member at the time, and the Socialist People’s Party as leading the charge. “As I remember, the social democrats were not in a big hurry to make a deal,” she said. “I think the Social Liberal party just started negotiating with the government around the Social Democrats, as I remember it, and that kind of got the Social Democrats to get its act together and get the coalition parties together to start to push for this deal.” (45) Auken said it was important that the blue bloc parties came to the negotiating table as well. The right-wing Danish People’s Party wanted a cap on the total of number of turbines onshore, and it was eventually agreed the number would be reduced to no more than 1,850 by 2030. The liberal parties wanted to put an end to the energy taxes. The left-wing parties advocated for more investment in offshore wind. Proposals to build wind farms close to shore, within view of pricey summer houses, were generating public controversy at the time. To secure continued support for offshore wind, the red coalition agreed to build new wind parks farther from the coast, and dropped opposition to the continued extraction of North Sea oil. Ultimately, the parties agreed to wind down the PSO tax that supported renewable development, but also to offer tenders for three new large offshore wind farms before 2030, which on their own would generate more electricity than the entire country consumed. Parliament passed the compromise legislation with unanimous support.

“When we read it now, it seems a little bit small,” Ida Auken mused, reviewing the terms of the agreement in her Folketing office a few years later. (46) The 2,400 MW of new offshore wind pledged in 2018 was not a small number in most contexts—three decades earlier, her uncle Svend had considered 100 MW of onshore wind a big ask. But Ida was understandably unimpressed with her own past achievements, having more recently successfully fought for the inclusion of an additional *five gigawatts* of offshore wind in the 2020 Climate Law. That accelerating ambition is visible in the topline targets of the recent rounds of renewable energy policies—from 14% renewable energy in the 1996 agreement, to 35% in the 2012 agreement, to 55% by 2030 in the 2018 agreement. After pledging to reach 50% wind electricity in 2012, only six years later the government’s new goal was 100% of electricity and 90% of district heating from renewable sources by 2030. (Ministry for Climate, Energy, and Building 2018)

The 2018 energy agreement is indicative of the direction renewable energy policymaking has been trending in Denmark in recent years. Central planners are counting on ever-larger contributions from offshore wind to meet aggressive climate targets, as onshore and nearshore wind remain political lightning rods. Direct taxation to subsidize renewable energy development has been declining, but with the challenge of greening the electricity system largely solved, increasingly, government attention is turning to the heating and transportation sectors. The growing emphasis on electrification across the energy system will indirectly benefit wind and other carbon-neutral generation technologies.

The general trendlines suggest Danes continue to embrace their role as leaders showing the world the path to a sustainably-powered society. Having built wind into a mature and globally-competitive industry, government is turning its attention to the next-generation solutions that will be needed to reach a 100% renewable energy system. The 2020 Climate Law, in addition to going big on offshore wind, also includes investments in experimental carbon capture and power-to-hydrogen technologies, as well as encouraging homeowners to invest in electric heat pumps.

But all of the bold pledges that look great in press releases mask underlying tensions between the political parties, and the slow erosion of the traditional consensus-oriented policymaking process. Remembering the negotiations over the 2012 energy agreement, Rasmus Helveg Petersen said the 95% support in parliament was not as solid as it appeared. “This consensus was not obtained easily,” he said. “There has been brinkmanship … It was a bloody fight, and it very nearly collapsed.” (47) The brinkmanship he was speaking of occurred *after* the agreement was announced, and he spent his tenure as energy minister working to ensure the plan would actually be implemented. Multiple sources I spoke with expressed concern that political polarization was making compromise more difficult in parliament. Anne Simonsen thought the latest energy and climate plans were flimsier than the deal struck in 2012, since the latter had included concrete details on how the targets would be achieved, whereas the most recent agreements have only been broad frameworks, the details of which will have to be filled in later. Simonsen characterized this approach as “less clear, and trying to please everyone, and not actually taking decisions in the negotiation room.” (48) Danish politicians appear to have reached a consensus that the energy system of the future should be powered by renewables, but they continue to fight bitterly over how to best get there. That political dynamic has secured the steady growth of wind installations in recent decades, while simultaneously overhauling the character of domestic wind development. Wind system actors will no doubt be watching negotiations at Christiansborg Palace nervously for the next decade, to see if and how politicians deliver on their ambitious promises for 2030.

Petersen credited the longstanding institutional culture of parliament for helping lock-in commitment to the renewable energy transition. “Minority coalition politics is difficult. You never have the right to say, ‘this is what we’re doing.’ You always have to cooperate,” he said. “Once you’ve completed this process, then things will be implemented … I think we take a lot of the trouble beforehand.” (49) This perspective is at odds with Matto Mildenberger’s prediction that adversarial institutions are more likely to produce transformative renewable energy policies. If the culture of cooperation is fraying in Denmark’s parliament, it remains to be seen whether the progress of the next decade can match the ambitions of the last.

But, of course, institutional cultures and policy coalitions do not emerge out of vacuums, and that is the big shortcoming of traditional policy analyses of energy transitions. While political elites like Svend Auken were important allies, support for renewable energy did not originate in parliament, nor is government the driving force maintaining that support today. When I asked Ida Auken how she explained parliament’s ability to produce unanimous agreements in support of the energy transition, she said that political will came from two main sources—grassroots public support, and industry support. In her telling, energy policy wasn’t being generated out of a conflict between social movements and industrial interests, but through a fusion of those interests:

> I think there’s pride in the Danish population in our wind turbines and this industry … There is big public support overall for Denmark being this green

> leadership country, and the people are aware, we don't anymore have these discussions about whether climate change is real or not, we are beyond that. There is support for the green transition and it's growing even more. It's very clear now that most parties will lose voters if they oppose this. We had all these green technologies that were actually delivering jobs in the whole country so people could see that new industry jobs were in these green jobs, so that really helped, and I think that is probably behind a lot of the public support, because we didn't have that urban-rural split on this, that we've had on so many other things, because the nonurban areas were where the jobs came. (50)

Auken's comments paper over some growing urban-rural divisions that may yet undermine future consensus in support of the renewable energy transition, and it is to those geographic disparities that I turn my attention in the next section. But she is correct that the issue of renewable energy has scrambled traditional political divides, which current public policy theories expect to happen during energy transitions as the result of an external shock, like an oil crisis. In Denmark, the evolution of policy coalitions has been a gradual and largely internal process. The broad consensus achieved in national policy agreements in the 2010s has roots as far back as the 1980s, and represents the culmination of decades of policy learning. The first subsidy schemes were relatively modest, and slowly grew in ambition over time, as support for renewables expanded. By the 2010s, very little institutional opposition to the energy transition remained. Policy was one driver of these political dynamics, bolstering the size and strength of the pro-renewable coalition, but forces outside of government were equally important in generating that widespread support, including technological, industrial, and social developments. These forces did not operate in isolation from one another, and none was sufficient on its own to set Denmark on its current path of rapid decarbonization. Finally, the history presented in the preceding section makes clear that the policy process leading to renewable energy lock-in was not limited to national debates among institutional actors, but played out across multiple levels of governance. I briefly described how European policies shaped the evolution of subsidies to support renewable energy in Denmark from above. Local actors and institutions have been equally important in pressuring national officials from below. Ida Auken joked that the minister who delivered the 2012 energy agreement made the easy decisions about setting targets for growth of renewables, while she was responsible for the harder task of finding places to put all the turbines the deal promised to build. (51) At least with respect to onshore wind development, it is local officials who are charged with making the orders issued in Copenhagen a reality, and municipal processes for siting and permitting wind projects are where conflict over the energy transition is most visible today.

5.5 The local politics of wind development

National policy support has been instrumental in the growth of the wind system in Denmark over decades, creating favorable market conditions for wind entrepreneurs to compete, but as Ida Auken wryly and rightly pointed out, all of those turbines have to be raised somewhere, and usually that means first securing approval from local officials to begin construction. That's often where the trouble starts. Some municipalities are more welcoming of turbines than others, and some developers are better at navigating the local political scene than others. But across Denmark, it has been getting harder and harder to win local approval for new wind installations.

For decades, Denmark was noted for its relative absence of opposition, compared to many other countries that faced stiff public resistance much earlier in their transitions. Some of the older policy studies referenced in section 5.3 point to widespread public support as a key factor in explaining the success of Denmark's energy transition. But local complaints about proposed wind developments have grown noisier and more disruptive in recent decades. This grassroots anti-wind sentiment is widely seen as the biggest current obstacle to the progress of the renewable energy transition. Examining the evolution of the wind sector over five decades makes it possible to address how these social and political dynamics change over time, and ask why opposition arose so late in Denmark.

Both private developers and government officials now expect controversy every time a new onshore or nearshore wind project is announced. So-called NIMBY "Not In My Backyard" protests are a common feature of industrial and energy development around the world, though academics typically contest the pejorative connotation of that expression, and argue that residents are not just being selfish or stubborn, but are often raising legitimate objections about the character of development, and the public's exclusion from the decision making process. (see, for example, Devine-Wright 2011, Batel and Rudolph 2021, Bell et al. 2013) The standard advice for avoiding or overcoming public resistance is for developers and officials to communicate more transparently, to design more inclusive and deliberative planning processes, and to ensure the public benefits directly from development. Both this chapter and the next will give some consideration to the causes of local protests against wind projects, and potential solutions to the problem. In Denmark, there have been attempts at policy fixes at both the national and municipal levels, and it will be possible to make some assessments of how effective those tools are at containing opposition.

My primary objective in this section, however, is to understand how national and local politics interact, and how those overlapping layers of governance translate into the success or failure of individual wind projects. Most policy studies of energy transitions focus on national politics, and rarely drill down to see how government policies are being operationalized at ground level. Those local dynamics have been crucial in the course of wind development in Denmark.

In Denmark, oversight of onshore wind projects is divided between national and municipal authorities. Government agencies in Copenhagen (and also in Fredericia, where the transmission system operator is headquartered) handle the financial sides of development, including taxation and subsidy distribution. Most of the technical decisions about planning, siting and permitting are managed by the municipal governments in the Kommunes. Denmark also has regional governments that are heavily involved in some areas of policy like healthcare, but play a less direct role in the energy system. The network of policy actors directly involved in the energy transition crosses these levels of government, creating opportunities for both conflict and cooperation, divisions of labor and unexpected complications. National policies have consequences for local politics, and vice versa. In practice, communication, policy ideas, policy entrepreneurship, and political pressure flows both ways.

The opportunity to avoid all of these complex political dynamics and the main source of development risk—the neighbors—by planting the turbines in the ocean is one of the reasons both national politicians and corporate managers increasingly favor offshore wind. The farther a park is sited from the coast, the fewer people nearby who have to look at it, which typically mutes public outcry. Circumventing the local planning process has its efficiencies from a project development standpoint; whether it is politically wise is a question I will consider further in the next chapter. Industry lobbyist Kristine van het Erve Grunnet said she thought Denmark did energy planning the "right way" by giving local communities authority over project approval. "That's important," she said. "It's not always easy," but she thought it was the only way to keep the public behind the energy transition. Overcoming public pushback, she argued, came down to whether or not municipal councils could find the "political courage." Local officials told her it was often easier to take a vote to close a school than it was to approve a new wind park. (52)

Because some locales have been more receptive to wind power—or more courageous—than others, Denmark offers a classic case study of what political ecologists call "uneven development." (Smith 1984) The uneven geographic distribution of wind installations is visible on a ma, but this unevenness also has social, political and economic layers. The topography and wind resources are, of course, two important environmental variables that developers calculate precisely when selecting sites to build. But, most everywhere in Denmark is flat enough for some wind power, and some of the regions with the lowest winds have been among the most willing to build large farms. Wind has been adopted so widely, in a country with so little land, that very few places have no experience with turbines, but the density and volume of installations varies widely from one Kommune to another. No municipality has welcomed more wind power than Ringkøbing-Skjern, in western Jutland, which had installed a total of 577 turbines by 2015, or one turbine for every 97 residents. Farther north in Thisted, the relative density of development was even greater, at only 90 humans for every windmill. Meanwhile, Copenhagen Kommune had installed a paltry 34 turbines, or one for approximately every 19,000 residents of the city. Aarhus, the country's second largest population center, looks a little better with 49 turbines installed, one for about every 7,250 residents. But Aarhus Kommune is much less densely built that Copenhagen, and has underperformed its potential as a site for turbine development, a somewhat puzzling state of affairs discussed further below. The national average is approximately one turbine for every 677 citizens. (Figure 5.4)

Northern and western Jutland have seen some of the heaviest wind development. Bordering the North Sea, they are among the windiest regions in Denmark, logical places to build a wind farm. But the steady winds were rarely among the first explanations locals gave me for why wind power had prospered in those areas, and why wind development still enjoys comparatively strong support there today. The first experiments with wind power were in this part of the country, building on its agricultural traditions. The early turbine manufacturers grew out of the local agricultural economy, and are still major employers in many municipalities across Jutland, which creates political support for wind power both in local institutions and with the general public. The long history and familiarity with turbines has sunk deep into the local culture—there is a fondness for wind power, an acceptance of turbines on the landscape, an awareness of the role they play in supporting the community, and the responsibility they are fulfilling to the broader society. This was the kind of language I often heard Danes use to talk about why they supported wind in their community. All of the factors mentioned above collectively create highly favorable conditions for wind development in these regions. It is still not always enough to get projects over the finish line. Local officials almost everywhere in

Denmark—with the possible exception of Rinkøbing—report that onshore wind development is slowing down, in large part due to public challenges to proposed projects. In many Kommunes, new development has ground to a halt, leaving pending proposals in planning purgatory.

The unevenness of wind development in Denmark is also a rural-urban divide of the sort social scientists have long studied. Within a 10-kilometer radius of most every large population center, very few turbines will be found. This geographic split has largely political causes, impacts political outcomes for specific wind projects in many municipalities, and shapes the broader national political discourse about wind energy, with potentially significant consequences for the future of the energy transition. Rural Danes stereotypically don't "mind" wind turbines on the horizon as much as city folk often do. Rural attitudes toward nature are less concerned with keeping it pristine, and are more willing to put it to use in the local economy. The turbines, at least until they grew bigger than jumbo jets, fit well with farming culture and practices, and blended reasonably well into the agricultural landscape. Rural communities reap a lot of benefits from wind power, but they also shoulder most of the direct costs of having to live underneath modern turbines. They don't always mind taking on more of the burden. "I think it's okay to have different obligations in society," said Ikast-Brande Mayor Carsten Kissmeyer. "But I also say to the people in Aarhus and Copenhagen that they have got to pay us." (53) Rural Danes often do mind when outsiders try to swoop into their communities and reap all the rewards for themselves. According to multiple developers and municipal officials I interviewed, projects with strong local ties had a much greater chance of being approved.

The rural-urban divide in Danish wind development has had some unexpected political benefits for the transition, creating a constituency in favor of wind power that would otherwise be unlikely to support an environmental agenda, but on the balance the uneven distribution of turbines has become a political problem today.

There is also an uneven distribution of costs and benefits of wind development *within* rural communities. The nearest neighbors experience the most viewshed and noise impacts, and are often the most vocally opposed. The development model favored today tends to disproportionately lump the benefits on a few people, which Mayor Kissmeyer says “no doubt” exacerbates local conflicts. As numerous interview subjects told me, a local farmer who leases his land might receive a payment of 3 million kroner per turbine from the developer—which must have been about the going rate at the time, since I heard that specific number mentioned a lot—while the next door neighbor doesn’t receive a single øre. These financial windfalls for just one or a few individuals rankle the Danish sense of fairness and social equity. (54) This desire to spread the wealth more evenly among those impacted by a wind project was likely a motivation behind the Dansk Folkeparti, which draws much of its support from rural areas, fighting to require developers to make payments to nearby neighbors in the 2012 energy agreement.

Whatever headaches the effects of uneven development create for developers trying to get a project through the city council, or municipal officials trying to meet the targets in their climate plans, it is a gift for a social science analysis of an energy transition, since it creates within-case variation and allows for fairly controlled comparisons at the local level. Wind developments have been proposed in most municipalities, but some local governments have been much more willing than others to move those proposals forward, and are making better progress toward meeting their renewable energy goals. Denmark, as a nation, still has a lot of work to do to reach its ambitious targets, and the same can be said about a lot of municipalities within the country. If the policy rubber meets the road at the local level, it would useful to know what variables make the difference between success and failure in getting wind capacity approved and built. By comparing Danish municipalities, global, European and national influences can be held constant, since all Kommunes are subject to the same regulatory environment, and while some regions might have various economic advantages over others, wind projects in all municipalities face more or less the same financial opportunities and pressures—broadly, they are operating in the same market and the same business sector. Thus, the observed differences in outcomes should be attributable to local factors. In the remainder of this chapter, I present five brief case studies—two large cities and three mostly rural municipalities—of communities that have had distinctive experiences with wind development, in the hopes of getting a clearer picture of how local politics have shaped the energy transition.

In theory, municipalities in Denmark should also be operating under similar planning regimes when evaluating wind projects, but that ambition has never been fully realized, and the level of effort respective municipalities have made to define a planning apparatus for future wind developments is a pretty good measure of how serious that community is about building more turbines. In January 1994, Svend Auken sent out a communique from the energy ministry directing municipal governments to begin developing plans for wind energy areas where turbines could be sited in their jurisdictions, a requirement that was codified in the 1996 energy agreement. But a 1997 study found that of the 275 municipalities in Denmark, only 36 had formally identified wind energy areas, another 169 had plans in the works. (Nielsen 2001, 407-408) Many municipalities dragged their feet, as selecting specific sites for development was both technically challenging and politically contentious. The planning process was still incomplete in some municipalities when I visited Denmark in 2015 and 2016. Slowly, more and more Kommunes were getting wind energy plans on the books, but the uptick in responsiveness to the national directive was fairly recent, as municipalities started to formalize climate plans only after the COP conference in Copenhagen in 2009. Mobilizing a local government response to climate change usually meant setting some targets for renewable energy production and consumption, which forced a lot of Kommunes to start dreaming up possibilities for wind development, even if making those dreams a reality remained a political challenge.

Aarhus is one of those municipalities that talks a good game on climate, but has struggled to live up to its reputation as a center of wind technology expertise. The country’s second city and the largest on Jutland, central Aarhus is obviously not an ideal place to build large wind firms. However, it is puzzling that no turbines can be found anywhere within ten kilometers of the city center. I have lived in Aarhus, and there are plenty of places one could raise a windmill or a few if sufficiently motivated. Aarhus sits on a large bay, and boasts a large port. The local utility company, nRGI, had drawn up proposals for offshore investments, but those plans were making little progress in 2015. The industrial harbor district would be another good site for a few windmills—Copenhagen has several small arrays in its harbor—and the local bureaucrats had also advanced that proposal, but it was not gaining traction. Furthermore, Aarhus is not a particularly sprawling city; outside the dense urban center, it is easy enough to get into farmland within walking distance of the ring road. The few turbines that have been built in Aarhus Kommune are located in these far rural corners of the municipal borders. There is clearly room for more.

As in many large cities today, there is a lot of institutional momentum within municipal government for action on climate change, and in 2007 the city council set a target of achieving carbon neutrality by 2030. A study by turbine manufacturer Siemens estimated that Aarhus would need approximately 15 wind turbines of 4 MW each, or about 60 MW of new capacity total, and around 3 square kilometers of solar PV to offset carbon emissions in the electricity system. (Siemens 2016) It's not clear where that needed development will happen. Aarhus' wind energy plan states the five approved areas for wind farms are all full. There are currently 16 large turbines operating in Aarhus Kommune, though none have been built since 2001. A handful of tiny household mills were installed after an attractive national subsidy created a mini-boom for mostly 10 kW turbines made by companies like Gaia Wind.

Considering how important the wind sector is to Aarhus, it is surprising that city leaders have not been more open to development within its borders. In 2012, national business magazine *Monday Morning* prepared a glossy report trumpeting Aarhus as a "global wind capital." According to Helle Friis from the mayor's business development team, regional employment in the wind sector had declined slightly, from 14,000 full-time jobs to around 12,000 in the most recent estimates, though many more jobs in the area were connected to the wind industry indirectly through the supply chain and business multiplier effects. City government is keen to maintain their edge as a hub for industry professionals, rolling out the red carpet for delegations of international businesses and policymakers, providing services and resources for newly-arrived foreign workers, and maintaining good relationships with the industry's lobbying associations. (55) The municipality recently helped fund the construction of a gleaming new research and business incubator on the harbor, and trains the next generation of wind professionals at the large local university. The industry jobs in Aarhus skew toward white-collar office workers, which is no accident. Storied manufacturer Vestas decided to move its headquarters there out of concern it would be difficult to attract the talent it needed to rural Jutland. Handsome, leafy, cosmopolitan, and blessed with miles of sandy beaches, Aarhus offers cultural amenities that no other city on the peninsula can match. "We think it has the right facilities—also outside of office hours," Vestas CEO Ditlev Engel said about the decision to relocate. (Mandag Morgen 2010, 28)

It is a bit puzzling that with so many people flying into Aarhus to learn about wind power and work in the wind industry, there wasn't a greater desire to actually see some wind turbines. In Copenhagen, planners have long advocated for siting turbines within the city limits, where they function as highly-visible statements of the nation's commitment to green energy. The officials I spoke to in Aarhus seemed to agree with this notion about the symbolic importance of having turbines in the community, but that had not generated a groundswell of support to build any. "We have not gotten pressure from Vestas or any of the other companies to build turbines in the city, it's not that important to them," said Helle Friis. The mayor's office had advocated for raising wind turbines locally, including at the end of the harbor, but that "doesn't seem possible now." The city council and the technical department were both opposed to new development. (56)

The obstacle appears to be political. The best explanation I received was from Kristian Ditlev Frische of the turbine owner's association, DVF, which is also headquartered in Aarhus. When the city put out a draft proposal for new wind energy areas, "there was a massive response from the public, and the politicians did not expect that to happen, they were very stunned by that," Frische said. The municipality decided to pull back and initiate a new community dialogue about how to meet the climate goals. Frische doubted public support could be drummed up for much new wind development, in large part because of the demographics of the areas most suited to wind farms. The outskirts of Aarhus look rural, but in actuality they are more suburban than agricultural communities. Many of the people living in these areas want to be near the city, and may work in the city, but also want a quiet, natural escape from the bustle of the urban core. A giant wind farm is at odds with their idea of a peaceful country retreat. (57)

One of the few places in Denmark where visitors will see modern wind turbines in urban environments is the capital. Copenhagen Kommune didn't commit to carbon neutrality until 2012, five years later than Aarhus, but since then has been more aggressive in pursuing the development projects to deliver on that pledge. From a siting perspective, Copenhagen would seem like one of the most difficult places in the country to raise wind farms. With about a third of Denmark's population living in the capital region, no municipality has less undeveloped land. Offsetting that shortage of appealing locations is a conducive political environment. Young, highly educated, and progressive, Copenhageners broadly support the need for climate action. Left-wing parties control the city council. Two decades of close experience with turbines has also helped reinforce understanding that wind power and city life can coexist. In 2000, a near offshore wind farm was built through a partnership between a local cooperative and the national utility, and named Middlegrunden, after the shallow shoals onto which the foundations were driven in the narrow strait separating Denmark from Sweden. The farm is easily visible on the approach to the adjacent airport, and dominates the view from Copenhagen's most popular public beach. While that location—the waterway is also busy with both commercial and pleasure boat traffic—would seem to prime the project for public backlash, Middelgrunden has been a hugely-popular triumph, and has become something of an unofficial symbol of the city. "Copenhagers, they're very proud of it." Said Inge Nilsson from the municipal planning and environment department. A 2011 survey commissioned by the city found that 89% of residents supported wind development within the city limits. (58)

A consulting firm hired by the Kommune calculated that building 360 MW of wind turbines could offset the city's entire carbon footprint, and that number was later adopted as the formal target for wind development. Municipal officials are hoping to raise 100 turbines by 2025. Responsibility for finding those projects has been delegated to the municipally-owned utility company HOFOR. (59)

So far, city planners had identified space where an additional 14 turbines could be raised within the city limits. Public reaction to the current proposals had been mixed, and one project that would have erected 4 turbines had to be abandoned because of complaints from conservation organizations and a neighboring municipality. According to Nilsson, making the effort to advance development locally sent a valuable message to residents, to other municipalities in Denmark, and to the wider world. The city had set ambitious targets, and "beacon" projects were needed to demonstrate progress toward those goals. The visibility of renewable energy also helped raise public awareness, which was needed to maintain political support for the transition. It was also politically advantageous in negotiations with other city governments. “When we go out to other municipalities, it’s very important to say we are doing everything we can ourselves within the city,” Nilsson said. (60)

With a goal of installing 360 MW of wind, but room for only 14 turbines locally, the math doesn’t add up for Copenhagen becoming a self-sufficient energy producer. HOFOR was pursuing a dual strategy to address this shortfall. At the time, the national government had three distinct tracks for offshore wind proposals—nearshore, “open door” projects that would have to compete at market rates, and a tendering process for subsidized offshore parks. HOFOR was preparing applications for offshore projects on all three tracks. The company was also approaching private developers and more rural municipalities about buying into onshore projects outside the city limits. Because the city of Copenhagen would own these turbines through the power company, even though they were built elsewhere, the Kommune would get to deduct their production from its carbon account.

This arrangement, predictably, did not go over well in some of the rural areas where HOFOR wanted to put up wind farms. Ikast-Brande, in central Jutland, is one of the municipalities HOFOR reached out to. “I said, we haven’t got any interest,” Ikast-Brande Mayor Carsten Kissmeyer recounted to me. While he wasn’t opposed, in principle, to letting Copenhageners take credit for wind power being generated in his municipality, there would have to be a financial benefit for the local community, and the

Kommune wasn’t going to help facilitate a development that promised no such returns. (61)

The patchwork of wide-open farm fields surrounding Brande has long been hospitable terrain for wind turbines, despite the region’s relative wind-poverty compared to its western neighbors. The Kommune has spun its low average wind speeds as an asset, making it an ideal site for testing the large rotors manufacturers were designing to maximize production in low winds. Brande was also the birthplace of Danish manufacturer Bonus, where pioneering turbine designer Henrik Stiesdal led the engineering team for decades. Bonus was later sold to German industrial giant Siemens, which still operates a large turbine assembly plant in Brande. Wind manufacturing employs about 6,000 people in the municipality today, out of a total workforce of only 22,000. (62) I spoke with multiple local officials who stressed that wind power was not viewed in ideological terms in central Denmark, but instead was primarily thought of as an economic development opportunity. Politically, city government presented a united front—the mayor, city council and local bureaucracy were all supportive of wind power. It was the public that increasingly needed convincing. Government officials wanted the jobs in the wind industry, and wanted to make progress on meeting their obligations to reduce carbon emissions. The public wanted those things, too, city planners said, but fears about the health impacts of living near what were being called “monster mills” were spreading like wildfire. “The local citizens, they don't look on us as experts,” said Lilian Ebbesen from the Ikast-Brande planning department. “They are experts themselves, because they can find any information on the internet.” (63) City planners attributed the spiking public opposition to a variety of factors, including the spread of misinformation on social media. Broader distrust of government was a contributing factor as well, as the public often believed city officials were in the pockets of developers.

At one recent public meeting, 370 citizens showed up to protest a wind project in a village with a total population of less than 600. In another instance, two local farmers wanted to build an array of six turbines, and offered to fund a foundation with 250,000 DKK annually for local initiatives, but that wasn't enough to quiet the neighbors, who felt they were being bought off. A public hearing drew 130 protesters, and the Kommune received 242 written comments opposing the project. I attended one such public meeting held in a hotel ballroom across the street from city hall in Brande. Mayor Kissmeyer sat at the head table with the project developers, and he gave a brief introduction before passing the microphone to the development team for a powerpoint overview of their plans and timeline, including details on the shares that would be offered for locals to purchase. There were about 50 people in attendance, and when the meeting opened to audience questions, it became clear that the developers still had a lot of convincing to do. The mood in the room and tone of the questions was generally polite but tense; no one in the audience rallied support for the project, and no one appeared satisfied with the answers they received from the developers. (64)

In response to the growing public concerns over new wind developments, the city council in Ikast-Brande had placed a one-year moratorium on approving projects, despite having four projects in the pipeline for which technical reviews had already been completed. The only wind project moving forward when I visited was a prototype with a massive 189-meter rotor to be installed at a Siemens test facility. Because of the local manufacturing presence, the Kommune had a separate, streamlined system for permitting experimental turbines that avoided the full public review process.

The planning department was in the midst of updating the Kommune's wind energy plan, and in the updated version had reduced the total number of wind energy areas from 14 to just 7. The planners I spoke to said the process had become much more difficult since 2011, when many municipalities had created their first wind energy plans. Some municipalities tried to avoid the approving a wind plan entirely, while others set strict guidelines that discouraged development.

Ikast-Brande was more serious about trying to find places to site turbines, but the push from within city government was for fewer, larger turbines, which planning officials said was intended to minimize the number of people who would have to live near them. (65) Mayor Kissmeyer said he was not a fan of the current methods for identifying wind energy areas, which amounted to selection by process of elimination. First, the habitat conservation areas protected by European Union Natura 2000 designation areas had to be removed from consideration. Then, forests owned by the state had to be blocked out. Areas of historical or cultural significance are excluded as well. Setbacks for flight paths around a small regional airport had to be included. And finally, there cannot be any homes within a distance of four times the height of the turbines, a distance that grows larger as turbines grow larger.

Kissmeyer was particularly irked by this restriction that a single farmhouse could halt wind development in an area, and wished that local governments had the option to purchase and remove those obstacles by eminent domain. The locations eventually chosen for wind development are essentially whatever is left on the map, the few sites that meet the exacting criteria. Kissmeyer and other politicians I interviewed also complained about the ability of small groups of individuals to file formal objections to new developments, halting projects in their tracks while the complaint is adjudicated, and thought local governments needed better mechanisms to overrule a few noisy neighbors. Kissmeyer argued that a more logical process would be to conduct wind energy planning at a national level, with local input, similar to how the national grid operator plans for high voltage transmission lines. (66) His favored solution for Ikast-Brande was to build a small number of extremely tall turbines in state-planted pine tree farms, which he said lack the biodiversity of mature forests. That idea had actually been proposed by a resident during a public hearing, as an alternative to the unpopular projects currently under development. But that possibility is currently being blocked by a nineteenth-century law that stipulates all the king's forests must be preserved as sources of lumber for shipbuilding. (67)

The preference of many policymakers for ever-larger turbines—"I think they are a little bit more elegant," said Kissmeyer —is somewhat in tension with public fears of "monster mills." (68) But the municipal officials I interviewed expressed universal disdain for the small windmills that had been popping up in recent years. Interest in these household turbines had been fueled by an overly generous feed-in subsidy that parliament had adopted as a means of allowing citizens to participate directly in energy production, recognizing that the growth of the wind industry was imperiling traditional community development models. While there is clearly appetite among homeowners for these turbines, they have also provoked public backlash, since they are noisier than large turbines, and their rotors spin much faster, which catches the eye. "We don't really have much interest in these small mills, there's no power in them," said Ikast-Brande planner Lindy Tanvig. "We do permit them, but we don't encourage it." (69)

Many sources also blame the private development model that has become the norm for onshore wind projects for increasing the public's opposition. "There's not much in it for locals," said Tanvig. (70) Kissmeyer called this system "outdated," saying that developers usually have agreements with landowners long before the municipality approves any wind energy areas for development, and they are looking for the easiest places to build, rather than the most socially desirable locations. He drew a contrast between two wind projects that had recently been proposed in Ikast-Brande. In one, the developer had strong connections in the community, and many locals had made money buying shares in the developer's past projects. The public, he thought, was more supportive of that project. In the second case, an out-of-town developer with no past experience had only struck agreements with the nearest neighbors before submitting a proposal to the municipality. In situations like that, he said, conflict arises. "I am not a fan of this system, to be honest," Kissmeyer said. "The developers are only middlemen. They don't create the possibilities. They don't create anything. They create the projects but they don't create the possibilities." (71)

According to Tine Reimer, a planner in Ringkøbing-Skjern on the western coast, the developers are so afraid of generating controversy that they are often very secretive and reticent to share their plans with the community, a self-defeating strategy that only makes the public more suspicious. Reimer said she advises developers to be more transparent and involve the local community more in their planning, but they rarely listen. "By the time we get a project at the city, it's half finished," she said. "A lot of the design decisions have already been made.” (72) Industry lobbyist Kristine van het Erve Grunnet, and many others, shared this view that developers have often not approached the public in the most effective ways for winning local support. “It takes a lot of coffee, being out there, talking to the people, getting them to understand what is coming their way, seeing what they can get out of it, also,” she said. (73)

Ringkøbing-Skjern is one of the few municipalities where onshore development has continued more-or-less unabated, and at scale. Like Brande and Aarhus, the area enjoys a substantial wind industry presence, with Vestas as one of the major employers, though just as in Aarhus, Reimer said she saw no evidence that the turbine industry put any pressure on local lawmakers to support wind development. Unlike Aarhus, which has hardly built any wind power this century, Ringkøbing-Skjern has installed more than 100 multi-megawatt turbines in just the past decade. This rapid pace of development has been achieved despite the fact that Reimer said political support for wind on the city council had actually declined somewhat. Ringkøbing had long been safe territory for the center-right party Venstre, whose pro-business platform had been friendly to the wind industry, but the party had lost some ground in recent elections, and Reimer estimated the council was now split about 50-50 on the question of wind development. The local community, she said, remained broadly supportive of wind, and although there were always some who raised concerns about specific proposals, she had not seen significant public backlash to the projects that had been built. Local opposition had also not stopped new developments; there were four projects making their way through the planning process at the time we spoke. (74) It surely hasn’t hurt that Ringkøbing has pioneered some innovative approaches to wind development, like the Hvide Sande projects, which planted three enormous 3 MW turbines right on a public beach at the entrance to the city's harbor, within view of the city center, and an adjacent community of summer houses. In many other locales such an arrangement would provoke outrage, but the Hvide Sande project has earned international acclaim, and seems popular with locals. I have seen video of children playing happily in the sand beneath the turbines broadcast on state television. The project was funded under a unique financial arrangement: 80% of the shares are owned by a local foundation that will use the proceeds from the wind turbines to fund much-needed improvements to the harbor. The other 20% of the shares are owned by a cooperative of local residents. Reimer said that while the municipal government places no formal requirements for local ownership in wind projects, the planning department has been trying to make it the informal norm that projects brought to them should include a local element. (75)

She said she has also heard positive reactions from locals to other high-visibility projects, like two rows of large turbines that line the main road out of town. Reimer, who wrote her master's thesis on social acceptance of wind energy in Denmark, thought that the turbines created a sense of place identity, and as locals passed by the project, they associated the windmills with coming home. (76)

5.6 Thinking globally, acting locally

What the preceding vignettes from municipalities around Denmark should make evident is that establishing a supportive national policy framework is not sufficient, on its own, to push a renewable energy transition forward. The best-laid plans cannot be realized without buy-in at the local level. I have described examples of how Denmark's national energy policies, all of which had the intent of spurring on the energy transition, have worked to both encourage and frustrate the adoption of wind power when they collide with local realities. In the scholarship examining Denmark's history with wind power, there has been a lot of discussion about whether a "top-down" or a "bottom-up" development style is preferable. Reframing that question slightly to focus just on the policies needed to stimulate an energy transition, the variation over time and across space introduced in this chapter makes evident that renewable energy policymaking in Denmark has not been unqualified success. While the Danes have made substantial incremental progress in fits and starts over decades, renewable energy development has not proceeded smoothly in all places or at all times. Institutional and policy support is needed at both the national and municipal levels before turbines can start feeding electricity into the grid.

When national and local priorities are aligned, wind development usually moves forward, sometimes with impressive speed. When those imperatives collide, development usually slows or stalls entirely. The changes observed in both Denmark's energy system and its energy policies are best understood as the combined effects of both top-down planning and bottom-up activism. The country's successes with wind energy have been achieved through the efforts of policy entrepreneurs pushing in both directions. There is probably no better example of this dynamic than on the island of Samsø.

Whatever their missteps along the way, Denmark's renewable energy advocates have rarely lacked ambition. In only about two decades, they had silenced the doubters who wrote off wind power as a fantasy or a passing fad. A role for turbines in producing electricity that had been inconceivable in the 1976 energy plan, by 1996 was official government policy. With the progress that had been made, it was becoming possible to dream much bigger. Denmark had proven that, under the right conditions, wind turbines could be dependable, profitable, significant contributors to the electricity mix. The domestic wind sector was increasingly stable, mature, and still growing. How much further could the transition be pushed? Was it possible to power society with only renewable sources? Political elites in Copenhagen were already imagining such a future as they drafted the *Energy 21* plan, which called for a local demonstration of a wholly self-sufficient, renewably-powered community. Svend Auken's energy ministry announced a national competition to select the "Renewable Energy Island." Five islands submitted draft master plans for making the transition to self-sufficiency within the next decade, following criteria drawn up by the Danish Energy Agency. In October 1997—as he was preparing to head to Japan for the signing of the Kyoto Protocol, and likely wanted a splashy headline to signal Denmark's commitment to sustainability—Auken announced that Samsø island had been selected as the winner. (Jørgensen 2007, 7)

Tiny Samsø, measuring only 26 kilometers long and 7 kilometers wide, is conveniently situated near the geographic heart of Denmark, wedged between the three main landmasses of Zealand, Funen and Jutland. Although it is only reachable by ferry, its close proximity to population centers makes it popular with tourists and summer house owners. At the time, the year-round residents numbered a little more than 4,000 spread across several small villages. The aging and declining population was, and remains, the most-discussed social problem on the island. Besides tourism, the local economy has long been dependent on agriculture, and before it became and international beacon for renewable energy development, Samsø was known in Denmark mostly for its potatoes and white asparagus.

According to one source, Samsø was selected as the competition winner, at least in part, because they wrote on their application that there was strong local interest in renewable energy, which wasn't exactly true at the time. (Sperling 2017, 889) There wasn't a lot of money attached to being named the Renewable Energy Island—the intent of the program was that the locals would have to do it on their own. The only direct funding that came from winning the competition was at first a half-time position, which later became a full-time salary, for local project organizer Søren Hermansen. Arguably just as important, it gave Samsø a direct line to the Danish Energy Agency, which was invested in the island's success. The staff contact who administered the Renewable Energy Island program provided expert assistance and steered the community toward other streams of funding they were eligible to apply for. (Sperling 2017, 890) Small grants helped pay for district heating and energy efficiency projects, but the local community would have to provide the rest of the financing themselves.

They would take some convincing, and the project got off to a slow start in the first few years, but island native Søren Hermansen was the right personality for the job. Gregarious, energetic, and quick to laugh, he has become a tireless advocate for community sustainability, at the local, national and international levels. When I visited Samsø, I watched Hermansen emcee a debate between candidates in an upcoming election, and though he wasn't on the ballot, it was clear to me that Hermansen was the most talented politician in the room. To get the Renewable Energy Island project off the ground, he dedicated himself to what he calls "coffee diplomacy," organizing public meetings and sitting with individuals in their homes, trying to convince people to get involved. Hermansen said that when the renewable energy initiative came along, it was fortuitous timing, because the island had been suffering through a severe economic downturn, and was looking to reinvent itself. A local slaughterhouse had recently closed, putting 100 people out of work. “In the city if you lose your job, you can get another,” he said. “Not here, if you lose your job, you are in trouble.” Many locals were searching for a way to make ends meet so they could stay on the island, and were open to taking a risk on something new. The energy development projects, from the beginning, sought to incorporate as much local input as possible, training tradesmen to build, install, and service renewable technologies. Hermansen said the Renewable Energy Island initiatives helped the community rebound, both economically and psychologically. (77)

Another factor that helped mobilize support on the island was that the initiative fit with the rural culture of community self-reliance. It wasn’t within locals’ power to recruit new manufacturing jobs to the island; given their remote location, those types of jobs were unlikely to come back. But raising some wind turbines? That was something they could do. The community had a long history of working together on projects of that scale. They had the land, they were buffeted by sea breezes on all sides, they had the sense of responsibility to one another. “We know about cooperatives here. A lot of hours are worked with no pay. People know about being called to a meeting,” Hermansen said. “Today, this is just a reinvention of the same thing” (78)

When Samsø was named the contest winner in 1997, they produced only 13% of their energy from renewable sources, almost entirely from burning waste straw for heat. (Jørgensen 2007, 44) There were only a few small household turbines on the island. But when the local government put out a call for proposals to build 11 large onshore turbines, they received about 50 applications, which created bad blood among some of the farmers whose proposals weren't selected. Hermansen worked as an intermediary in this process, and talked the farmers whose proposals were ultimately successful into offering 20% of the shares in their projects to the local community. Hermansen claims their example served as the inspiration for the later adoption of that requirement for all onshore wind projects in Denmark. The formation of the cooperative helped salve some of the raw feelings over the selection process, and anyone on the island who wanted to participate was able to buy shares. Even some of the people who had been opposed to the renewable energy initiatives on ideological grounds showed up, saying they didn't support the government meddling in the energy sector, but if the turbines were going up anyway, they were going to invest. Hermansen bought a few shares in the cooperative himself, and said that the turbines had consistently outperformed production estimates, and for as long as they had been covered by the feed-in tariffs, they generated a steady return of between 6-8% most years. As the turbines have aged and the subsidies expired, the economic benefits have shrunk, to maybe a 2-3% annual return. If maintenance costs were higher than expected, in some years there might not be a dividend paid at all. (79) Søren Stensgaard, Samsø's planning director, said his father had purchased three shares apiece for him and each of his three siblings as Christmas presents, "so that's a nice gift that keeps on giving, I get a check every year." (80) For Hermansen, the benefits of local ownership are more political than financial, bolstering community support for living with large windmills. "Local ownership works as a visual safety net. You tolerate noise and whatever nuisance there may be much more when they are your own turbines. Then it becomes a local discussion of how we handle any nuisance factors," he said. (Foresight 2019)

The downsides of the raising the onshore turbines—other than some grumpy farmers who were left out—appear to have been limited for the community, and greatly outweighed by the benefits. Stensgaard said he had not received a single complaint since he started working for the municipality. (81) Hermansen said it hadn't impacted tourism negatively; the tourists come for the sandy beaches and barely notice the turbines. (82)

Increasingly, tourists are coming because they *want* to see the renewable energy projects. One of the farmers who did succeed in building a turbine is Jørgen Tranberg, who has become an unofficial spokesman for the island's energy transition. On the day I visited Tranberg's farm, he was also hosting a group of university students and a camera crew from the state broadcaster. When I arrived, he was feeding his herd of 45 dairy cows. He used to have 150, but couldn't find a younger person to pass the operation off to, so he had to downsize. Wind energy is an increasingly important part of his farm business, generating about 30% of his income, and as much as 50% in a good year. Tranberg, like many lucky farmers around Denmark, has become something of a renewable energy mini-mogul. In addition to wind turbines, he also owns 450 kW of solar, some on his roof, some on his farmland, some in Germany, some in Italy. His sleek modern home, relatively large by Danes' modest standards, has walls of sliding glass in the back that look out directly on the wind turbines. Tranberg said his turbine had been through some major repairs—the generator had to be replaced after only six months, the gearbox broke a few years later. If he could get 25-30 øre per kWh, he thought that would be enough to make the wind business profitable, but with market prices for wind power so low, the financial case for continuing to operate the turbine was getting dicey. Still, he was proud of his turbine, and he didn't want to have to take it down. "I will cry," he said.

He liked having the windmills on the landscape, and as long as they were running “we don’t have to pay Putin for gas.” (83)

Tranberg had also invested in an array of 10 offshore turbines built off the southern tip of the island in 2003. That project also relied on heavy local commitment. It allowed several of the farmers who had been left out of the first round of onshore development to get involved, and just as with the onshore project, 20% of the shares were offered to a local cooperative. This time, the biggest capital contribution came from the Kommune itself. Because the organizers were having trouble lining up sufficient financing, and the offshore project was crucial to meeting the goal of energy self-sufficiency, municipal leaders felt a responsibility to pitch in. The earlier renewable projects had been a success, and Samsø was starting to get a lot of international attention for the progress it was making. The municipality felt pressure to help finish the job. So they took out a loan of DKK 130 million, which Søren Stensgaard thought might be the largest municipal loan per capita in Danish history, and purchased 5 of the 10 turbines. (84) Although the handsomely-situated arc of turbines had been operating for a dozen years when I first visited Samsø, it seemed to be creating a lot of headaches for everyone involved, and I heard jitters from numerous stakeholders about whether the investment would be recouped. The chief complaint had to do with the maintenance costs they were being charged by their turbine supplier, Siemens. It was “terribly hard to work together with Siemens because we are such a small fish,” said Tranberg. (85) In spite of the financial risks, Stensgaard said he thought it had still been a good decision for the municipality to buy into the offshore farm. “We have had an immense gain in the branding of the island as a renewable energy center and it has grown our own self-esteem as well," he said. (86)

With the added production from the offshore turbines, plus investments in several small district heating plants that burned biomass, Samsø declared it had reached the goal of generating 100% of its energy needs from renewable sources right on schedule in 2007. It was another dramatic policy achievement for Svend Auken, precisely the beacon of the renewable energy future he had hoped to create. No other Danish renewable energy project—with the possible exception of Tvind—has been written about as much as Samsø, the renewable energy island. Their potatoes can still be found for sale in every Danish supermarket, and the summer house owners still come to enjoy the beaches, but over the last two decades, a whole new crop of green energy tourists has flocked to the island. Søren Hermansen opened the Energy Academy up the road from the harbor town of Ballen, a nonprofit that employs eight people to educate visitors about Samsø's experiences, and consult with other communities around the world hoping to follow in their footsteps. In addition to the tourism dollars the Energy Academy brings to the island, and the revenue streams the renewable energy installations have created for local farmers and tradesmen, the energy transition on Samsø has generated numerous other, harder to quantify benefits for the community. Hermansen said he thought they had done a better job than many other communities of spreading the wealth from the energy projects, which helped maintain a sense of social equality on the island, something that was increasingly a struggle in many rural communities. The experience of coming together to meet the renewable energy goal had given community members greater collective "decision capacity," and a bigger platform. (87) The eyes of Denmark and the world were now trained on this quiet farming community. Hermansen has accumulated personal political capital as the project's leader, which he uses to preach the gospel of community development to political elites in Copenhagen and beyond. According to Stensgaard, the projects had increased public awareness of the potential of renewable energy. He said in 2015 that Samsø was leading the country in solar installations, and they were also above the national average in adopting electric heat pumps. (88)

The question now is how long the momentum that has been built on Samsø can be sustained. The young people continue to flee to the cities, and with the original investors aging, Hermansen wondered who would lead the next generation of initiatives. What he and his neighbors had accomplished in the early 2000s was getting harder to replicate today, he said, because the market for wind power was less secure than it had been under the feed-in tariff, and the wind turbines were getting so big that the financial risks scared off local investors, an effect they had already seen with the offshore park. He worried about the direction the renewable energy transition was heading, as the wind industry scaled up. "It should be democracy and people," he said. "We think way too much that the government can changes things. They can create a framework. But people change things." (89)

From a more objective analytic perspective, it's clear Samsø could not have achieved energy independence without significant structural and institutional support across multiple levels of government. It is also true that the Renewable Energy Island would not exist without the leadership of individuals like Svend Auken. It is also true that the Renewable Energy Island would not exist without the leadership of Søren Hermansen, and the courage of the many other Samsingers who took personal risks to realize a collective vision. The lesson for policy studies of energy transitions is that all of these actors matter to the outcome, not just the policy elites. Understanding the progress of an energy transition requires attention to the varied layers and distinct networks of participants in the energy system, and how they interact. The lesson for energy policymakers is that they cannot be content with setting bold targets; if they hope to meet those goals, they need to be concerned with how the policy tools they design will be received and acted upon in the local contexts where they are applied.

This prescription, understandably, creates significant challenges for central governments attempting to make rapid progress in transitioning away from fossil fuels. No two communities are exactly alike. Samsø is an unusual case, and the circumstances that led to its rapid energy transition are unlikely to be replicated elsewhere. Hermansen recognizes as much, and when he consults with outside communities working on their own renewable energy projects, he tries to understand the unique opportunities and challenges confronting that community, and what is in the community interest, rather than simply advising them to copy what was done on Samsø. He does always emphasize the importance of involving the local community directly in the transition, "if they are not on board, they will be your worst enemies," he said.

A similar concern about how policy recommendations travel can be raised about the broader Danish case—in many ways that have been discussed in this dissertation, Denmark was an exceptionally favorable locale for wind power to take off. Svend Auken reached that same conclusion in his own analysis of the transition policies he helped write. "The country's success would not be easy to replicate elsewhere, and it certainly would not be easy to replicate in the same manner," he wrote. "In some sense the Danes were fortunate to be in the right place at the right time with the right concept." (Auken 2002, 154)

There will be no universal roadmap for carrying out an energy transition. This doesn't mean that it is impossible to generalize, to identify common patterns or recipes for success, or to learn lessons from others' experiences. Some elements of successful cases will transfer more easily than others.

One consistent theme that emerges from my local case studies is the importance the Danish public attaches to democracy in their attitudes toward wind development. They almost never mean democracy in a Dahlian, procedural sense—in fact, municipalities like Aarhus that have made significant investments in creating deliberative procedures for energy planning have had no success building wind parks. Rather, Danes tend to talk about democracy in a political economic or social democratic sense: they want to see that the costs and benefits of development—financial and otherwise—are being distributed with some degree of equity among the affected parties. When wind projects are perceived as democratic in this sense, they tend to go forward. The public can be mobilized to accomplish the seemingly impossible, as the Samsø case demonstrates. When projects are perceived as benefiting only the few, they tend to face stiff resistance.

What if democracy—judged in terms of how an energy system distributes power across society—is one of the conditions necessary for mobilizing the political support to enact the policies that are themselves so critical for steering the world away from the climate cliff? As the public policy literature reviewed earlier in this chapter argues, systemic shifts unfold over multiple rounds of policymaking, a conclusion strongly supported by the evidence from Denmark, where lawmakers regularly revisited support schemes over the course of more than four decades. The current configuration of the wind network is, from a policy perspective, the accumulated effect of all of those specific policies in all of those years. The prevailing advice in the academic literature about how to "lock-in" policies to support energy transitions is to build coalitions that can exert political force in future rounds of debate. The limitation of these public policy theories that stress institutionalized interest group competition is that they provide no analysis of how to build and sustain those broad-based coalitions. The challenge for Danish policymakers today is that the policies they are pursuing are making it harder to form the very kinds of democratic coalitions that have been so central to their past success. What does it portend for the future of Denmark's energy transition if that democratic character is being lost?

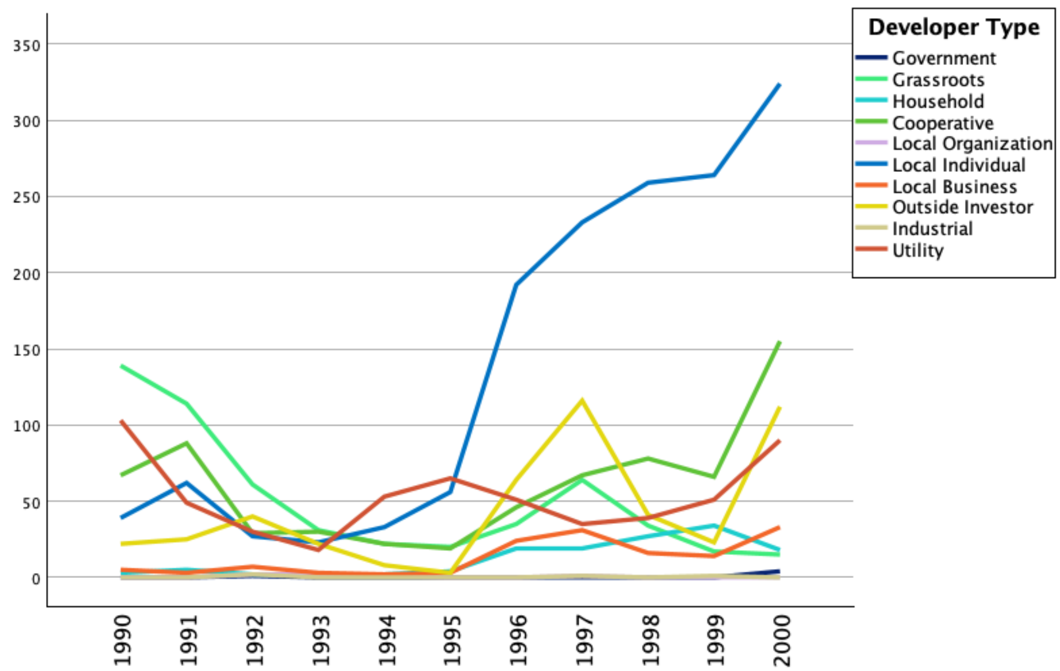

Figure 5.1. The growth of the wind network through the 1990s. The number of new turbines installed, by type of developer.

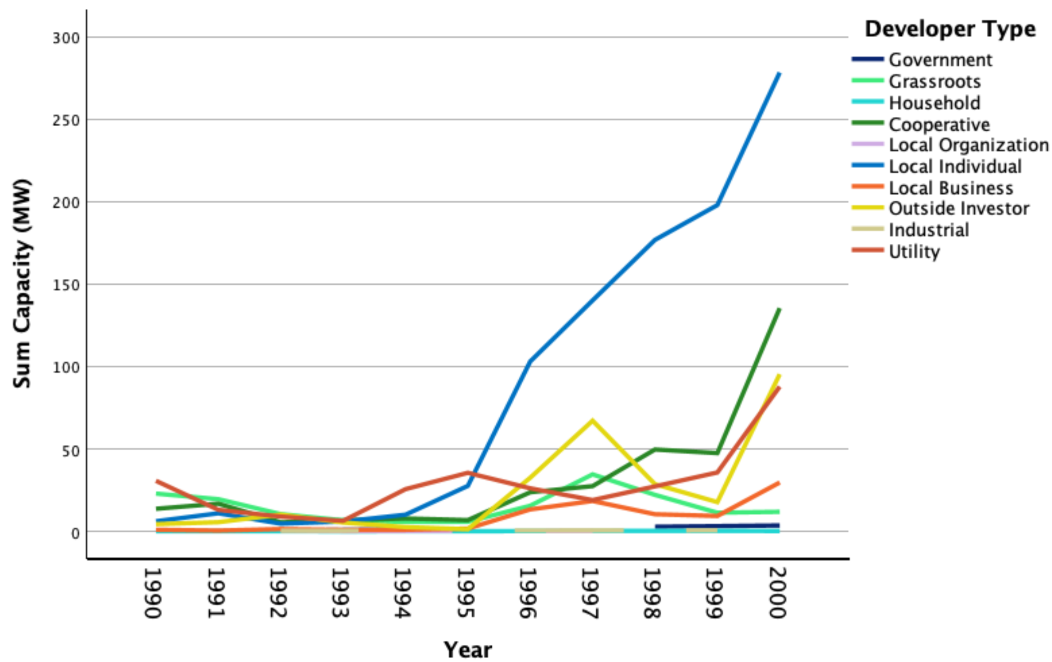

Figure 5.2. The growth of the wind network through the 1990s in megawatts of new capacity installed, by type of developer.

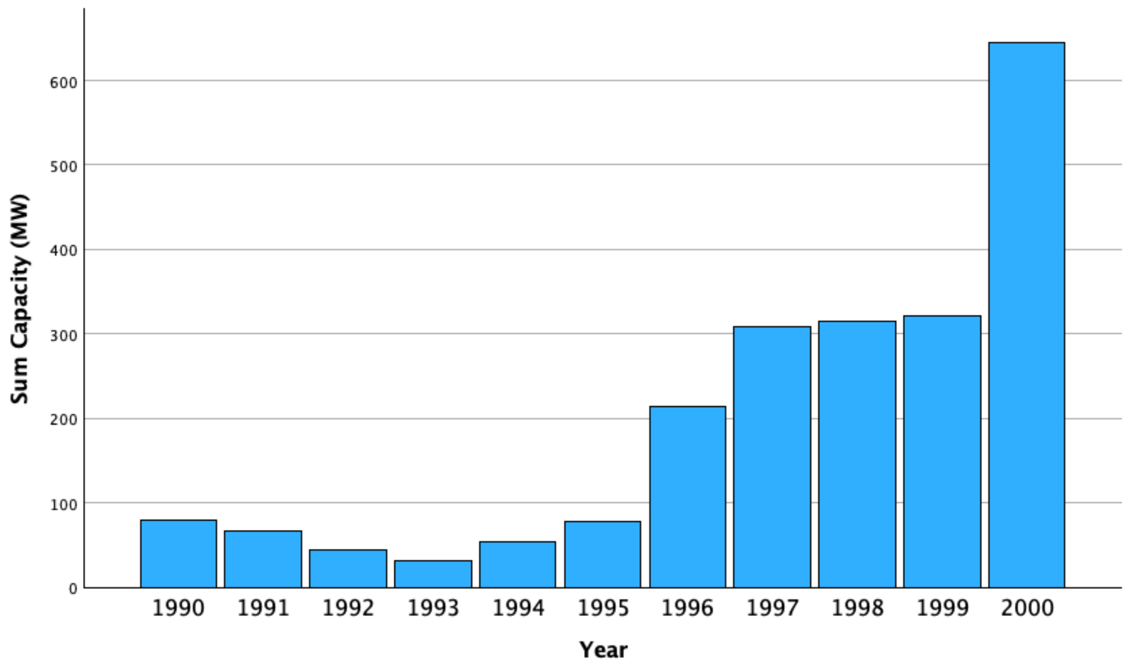

Figure 5.3. Total new installed capacity by year during the 1990s.

Kommune	# of Turbines	Capacity (MW)	Kommune	# of Turbines	Capacity (MW)
Ringkøbing-Skjern	577	466.4375	Hedensted	62	29.671
Norddjurs	247	460.264	Vordingborg	96	26.7125
Esbjerg	291	442.4765	Nordfyns	50	25.284
Lolland	417	414.086	Syddjurs	91	22.3425
Lemvig	284	235.9805	Silkeborg	67	19.6515
Guldborgsund	250	231.355	Faaborg-Midtfyn	56	19.338
Jammerbugt	273	193.02	Kerteminde	30	17.997
Thisted	475	170.7685	Hvidovre	20	17.405
Tønder	307	159.708	Faxe	47	17.0005
Ålborg	289	158.347	Sønderborg	33	15.211
Randers	160	150.91	Skanderborg	54	15.1975
Holstebro	192	138.449	Middelfart	29	14.1585
Skive	299	131.067	Odder	60	14.1415
Vesthimmerlands	313	130.823	Ærø	29	14.095
Herning	157	116.984	Århus	49	13.176
Billund	74	94.439	Stevns	43	13.039
Aabenraa	111	90.158	Odense	19	11.24
Morsø	198	87.3485	Ringsted	25	10.429
Varde	158	77.481	Sorø	21	8.5245
Kalundborg	114	75.5265	Frederikssund	36	7.585
Brønderslev	131	72.841	Lejre	27	7.488
Viborg	106	69.204	Roskilde	31	6.986
Slagelse	133	69.1595	Odsherred	41	6.011
Næstved	119	66.698	Horsens	29	5.625
Frederikshavn	129	66.25	Køge	17	4.735
Vejen	125	65.166	Hillerød	15	4.377
Hjørring	234	64.455	Halsnæs	8	4.16
Holbæk	81	63.129	Allerød	8	3.027
Mariagerfjord	90	59.227	Fredericia	10	2.891
Struer	153	57.0135	Fanø	16	2.695
Langeland	116	51.647	Høje-Taastrup	8	1.776
København	34	51.501	Greve	8	1.401
Vejle	112	45.12	Gribskov	9	0.788
Ikast-Brande	80	45.0975	Unknown	43	0.785
Bornholm	104	43.7635	Dragør	8	0.74
Haderslev	77	42.345	Solrød	4	0.666
Rebild	85	40.75	Egedal	6	0.495
Favrskov	82	37.363	Læsø	3	0.253
Svendborg	72	35.918	Helsingør	5	0.146
Kolding	53	35.602	Furesø	1	0.03
Samsø	34	34.677	Ishøj	1	0.011
Assens	69	33.016	Vallensbæk	1	0.001
Nyborg	52	30.333	**Grand Total**	8673	5593.191

Figure 5.4. Total number of turbines installed and total capacity installed (MW) by municipality from 1976-2015.

Notes

1. From personal communication with Jakob Ferløv Greth, Aalborg, Denmark, June 2016.

2. ibid.

3. ibid.

4. ibid.

5. From personal communication with Peter Malinsky, Copenhagen, Denmark, May 2022.

6. From personal communication with Jens Rasmussen, Hobro, Denmark, June 2016.

7. ibid.

8. ibid.

9. ibid.

10. ibid.

11. ibid.

12. ibid.

13. From personal communication with Jakob Ferløv Greth, Aalborg, Denmark, June 2016.

14. ibid.

15. From personal communication with Jens Rasmussen, Hobro, Denmark, June 2016.

16. From personal communication with Anne Højer Simonsen, Copenhagen, Denmark, May 2022.

17. ibid.

18. From personal communication with Kristine van het Erve Grunnet, Copenhagen, Denmark, May 2022.

19. From personal communication with Rasmus Helveg Petersen, Copenhagen, Denmark, August 2015.

20. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

21. From personal communication with Kristine van het Erve Grunnet, Copenhagen, Denmark, May 2022.

22. From personal communication with Rasmus Helveg Petersen, Copenhagen, Denmark, August 2015.

23. From personal communication with Morten Baek, Copenhagen, Denmark, August 2015.

24. From personal communication with Kristine van het Erve Grunnet, Copenhagen, Denmark, May 2022.

25. From personal communication with Camilla Holbech, Copenhagen, Denmark, May 2015.

26. From personal communication with Kristine van het Erve Grunnet, Copenhagen, Denmark, May 2022.

27. ibid.

28. From personal communication with Per Svendsen, Aarhus, Denmark, June 2015.

29. From personal communication with Anne Højer Simonsen, Copenhagen, Denmark, May 2022.

30. From personal communication with Thomas Becker, over Zoom from Copenhagen, Denmark, June 2022.

31. ibid.

32. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

33. From personal communication with Preben Maegaard, Thisted, Denmark, August 2015.

34. From personal communication with Thomas Becker, over Zoom from Copenhagen, Denmark, June 2022.

35. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

36. See Agnolucci 2007, p. 961, for a detailed breakdown of wind power payments were calculated, both with and without the scrap premium. For the first round of repowered mills, owners were paid an additional 0.17 DKK on top of the regular feed-in tariff of 0.33 DKK, for twenty years.

37. From personal communication with Rasmus Helveg Petersen, Copenhagen, Denmark, August 2015.

38. From personal communication with Jakob Ferløv Greth, Aalborg, Denmark, June 2016.

39. From personal communication with Thomas Becker, over Zoom from Copenhagen, Denmark, June 2022.

40. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

41. From personal communication with Anne Højer Simonsen, Copenhagen, Denmark, May 2022.

42. From personal communication with Rasmus Helveg Petersen, Copenhagen, Denmark, August 2015.

43. From personal communication with Camilla Holbech, Copenhagen, Denmark, May 2015.

44. From personal communication with Anne Højer Simonsen, Copenhagen, Denmark, May 2022.

45. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

46. ibid.

47. From personal communication with Rasmus Helveg Petersen, Copenhagen, Denmark, August 2015.

48. From personal communication with Anne Højer Simonsen, Copenhagen, Denmark, May 2022.

49. From personal communication with Rasmus Helveg Petersen, Copenhagen, Denmark, August 2015.

50. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

51. ibid.

52. From personal communication with Kristine van het Erve Grunnet, Copenhagen, Denmark, May 2022.

53. From personal communication with Carston Kissmeyer, Brande, Denmark, June 2016.

54. ibid.

55. From personal communication with Helle Friis, Aarhus, Denmark, June 2015.

56. ibid.

57. From personal communication with Kristian Ditlev Frische, Aarhus, Denmark, July 2015.

58. From personal communication with Inge Nilsson, Copenhagen, Denmark, May 2015.

59. ibid.

60. ibid.

61. From personal communication with Carston Kissmeyer, Brande, Denmark, June 2016.

62. ibid.

63. From personal communication with Lilian Ebbesen, Ikast, Denmark, June 2016.

64. From personal observation as well as communication with Henrik Vinther, who served as translator. Brande, Denmark. June 2016.

65. From personal communication with Lilian Ebbesen, Lindy Tanvig, and Marie Lyster Nielsen, Ikast, Denmark, June 2016.

66. From personal communication with Carston Kissmeyer, Brande, Denmark, June 2016.

67. ibid.

68. ibid.

69. From personal communication with Lindy Tanvig, Ikast, Denmark, June 2016.

70. ibid.

71. From personal communication with Carston Kissmeyer, Brande, Denmark, June 2016.

72. From personal conversation with Tine Reimer, Ringkøbing, Denmark, June 2016.

73. From personal communication with Kristine van het Erve Grunnet, Copenhagen, Denmark, May 2022.

74. From personal conversation with Tine Reimer, Ringkøbing, Denmark, June 2016.

75. ibid.

76. ibid.

77. From personal communication with Søren Hermansen, Samsø, Denmark, June 2015.

78. ibid.

79. ibid.

80. From personal communication with Søren Stensgaard, Samsø, Denmark, June 2015.

81. ibid.

82. From personal communication with Søren Hermansen, Samsø, Denmark, June 2015.

83. From personal communication with Jørgen Tranberg, Samsø, Denmark, June 2015.

84. From personal communication with Søren Stensgaard, Samsø, Denmark, June 2015.

85. From personal communication with Jørgen Tranberg, Samsø, Denmark, June 2015.

86. From personal communication with Søren Stensgaard, Samsø, Denmark, June 2015.

87. From personal communication with Søren Hermansen, Samsø, Denmark, June 2015.

88. From personal communication with Søren Stensgaard, Samsø, Denmark, June 2015.

89. From personal communication with Søren Hermansen, Samsø, Denmark, June 2015.

CHAPTER 6

VIKINGS: WIND POWER EXPANDS OFFSHORE

6.1 A Community Moves On

On the ferry route from Zealand to Samsø in summer 2016, a strange sight materializes through the morning fog: An eerily still arc of gray wind turbines rises out of the ocean. One tower stands stripped bare, its wings clipped and fallen to the bottom of the Belt Sea.

The nacelle of Samsø Havvind's Turbine #7 had snapped off right where it connects to the tower in a late November gale. The cause was later determined to be a faulty weld at the joint. (Russell 2015) More than six months later, the rotor and nacelle had still not been recovered, while the community worked to determine the project's fate. When I spoke to Søren Hermansen again some years later he said the efforts to repair the turbine had been a "disaster," but for legal rather than technical reasons. According to the contract the community had signed with the state, which owns the seabed, if the park was out of service for more than a year, they would have to restart the approval process. That approaching deadline set off a scramble to find a replacement for Turbine #7. At the time the array had been built in 2002, the 2 MW Bonus turbines were considered state of the art. By 2016 they were antiques, and Siemens, which had purchased Bonus, was no longer manufacturing models that small. The Samsø Havvind shareholders (half municipal government, half local residents) could only purchase a larger turbine, but government regulations stipulated that all turbines in a park had to match, and their permit stipulated a specific turbine size. In late 2017, the Danish Energy Agency approved an exemption to the rules, allowing a new turbine to be installed. Finally, the local shareholders were catching a break, and the regulations were working in their favor. Because a brand new turbine was being connected, rather than merely repairing the old one, it qualified for a new feed-in contract, which only pays the most attractive guaranteed rate for the first 12,000 load hours, which is typically less than half of a modern turbine's useful lifespan. Thanks to the refreshed subsidy, the owners could afford to purchase the replacement turbine.

But the resolution of that crisis did not put to rest concerns about the long-term viability of the partnership that had been building among shareholders since 2015. A general assembly was called in 2018 to vote on an offer from a private developer to purchase the farm. According to Hermansen, a few idealists passionately objected to the deal, but he estimated about 99% of the approximately 400 shareholders voted to sell. A lot of the shareholders were getting older, and were less interested in a risky investment. The offshore farm was sold to Wind Estate, a large domestic development firm that had been buying up old wind projects around the country. Wind Estate had a distinct economic advantage over Samsø residents in operating an aging wind farm. Cooperatives like the ones on Samsø cannot carry debt, and members are jointly-liable for expenses like repairs. As a consequence, they had to maintain expensive insurance policies and service contracts. Those ongoing costs were proving debilitating, especially in the unforgiving offshore environment. Few cooperatives had attempted to build and manage such a large and complicated investment. Wind Estate, Hermansen said, did not take out an insurance policy, and handled maintenance themselves, rather than buying the pricey plans offered by the turbine manufacturer. The company could place a big bet on a large wind farm, and if the turbines didn't operate as expected, write off the loss. At about the same time as the offshore cooperative was disbanded, the members of the onshore cooperative also voted to sell their shares to Wind Estate. (1)

Only a little more than a decade after Samsø had celebrated becoming the first 100% renewably-powered community in Denmark, there were no more cooperatively-owned windmills left on the island. Hermansen did not think it was likely new wind projects would be built there in the future, since government policy increasingly favored gigantic offshore farms. From the government's point of view, it's appealing to have big companies involved in these capital-intensive projects, because they could be financed with fewer subsidies, meaning the government could reach its climate goals at a lower cost. "Local projects are not able to compete with that," Hermansen said. (2)

Jørgen Tranberg and the other farmers on the island still owned their windmills. After riding out several years in which the market prices for wind power were extremely low, Tranberg was inadvertently profiteering off the war in Ukraine, as the resulting energy crisis in Europe had spiked prices, and now he was "smiling all the way to the bank again." Hermansen estimated those onshore turbines could continue running for at least another decade. (3)

The loss of local control over the 20 MW offshore park, which had been so critical to achieving self-sufficiency in the early 2000s, would not endanger Samsø's energy future. Hermansen said they would "easily" replace it with other sources. Solar technology had made rapid strides, and was taking off around Denmark. A planned 130 MW solar farm, to be built on a local farmer's land, was in the final stages of the approval process. "Farmers are getting paid very well to lease out their land," Hermansen said. "They are popping up everywhere." Twenty percent of the shares from that project would be sold to local residents, which he pointed out was the same model on which the wind farms had been built two-and-a-half decades earlier. (4)

Hermansen seemed resigned to this evolution of the wind sector, and the declining importance of local cooperatives in this system. “We as citizens, we helped the process of developing the modern wind turbine to be able to compete with oil and gas and produce electricity at a cost that was lower than fossil fuels,” he said. “So that was part of the ambition 30 years ago, and we have met that now.” He pointed out that Danes were familiar with industries upscaling in this manner; similar developments had occurred in the agricultural cooperatives of centuries past, for example, in the dairy and pork industries. (5) By the 2020s, the Danish wind network was larger than ever, in terms of terawatt hours of electricity generated annually, but also more concentrated than ever.

This consolidation of a business sector, weeding out the smaller players, is precisely what the organizational ecology literature expects to happen in mature industries. It is certainly a typical progression in industrial capitalist societies. But is it desirable? That’s a political question. There is no longer much of a debate in Denmark today that making the transition to renewable energy is both feasible and desirable, those ideas have gained wide currency from board rooms all the way down to classrooms. There remain ongoing debates within the wind network about whether the future energy system should be built offshore or onshore, with “monster mills” or rooftop solar panels, by communities or corporations. Many in the business world and in government see the transformation of the wind sector as both a necessary and beneficial development, since larger firms can throw their weight around and act at scales that are out of reach for most individuals or local communities. Wind Estate purchasing Samsø’s offshore wind farm would seem to be a good example of the benefits of that additional capacity. The locals could not afford to keep running the park on their own, it was too big for them to manage comfortably and efficiently. I do not have any inside information about who was to blame for the failure in Turbine #7, but windmill heads do not typically just pop off and drop into the ocean. It could be argued that the project was unprofessionally managed, and the local owners were out of their depth. Wind Estate has the expertise and the resources to keep outdated turbines of uncertain economic value running. At least for the immediate future, Samsø will still have wind turbines, which will continue feeding clean, renewable power to the grid. On the other hand, companies like Wind Estate are the beneficiaries of political and economic environments that favor their business model. Since the 1990s, politicians like Svend Auken have actively worked to encourage their involvement in the wind sector. It could also be argued that Wind Estate and other firms like them that gobble up aging community wind projects are merely scavengers, picking off the wounded and dying from the herd. Wind Estate did not build the wind projects they have taken over operating. Samsingers did.

There can be no denying that the community development model drove the breakthrough of wind energy into the Danish electricity system in the 1980s. And it is hard to imagine how the exponential growth of the 1990s would have happened without private development jumping into the sector. So both of these technological development styles have played crucial roles in the history of Denmark's energy transition. But will either play a significant role in its future? Or will some new technology emerge?

When scholars of energy policy and policymakers talk about the energy transition, their focus is usually on the aggregate trends—the overall growth of renewable energy adoption, the declining costs of renewable technologies, or the total contribution of wind power to the grid. Since Amory Lovins contrasted “hard” and “soft” energy paths in the 1970s, only rarely have policy analysts drilled down into the distinctions between different approaches to renewable development. Mostly, the policy actors just care about the green gigawatts, they are less concerned with precisely how the carbon emissions are being offset. (6) As I argued in Chapter 2, political scientists have long been uncomfortable getting close to technology. I have tried to make the case that technologies are core components of modern political systems, and that technological change is a key driver of political processes. In the large-scale, long-term systemic change of an energy transition, the manner in which technological infrastructure develops is of particular political importance, in two respects. First, the transition to renewable energy in Denmark, and worldwide, is far from complete. The progress to date must be maintained, and the appetite for additional innovation and investment must be sustained for at least another generation. Both of those ambitions require political will. Humans are still extracting unsustainable amounts of fossil fuels, which have seeped into almost every crevice of modern life. The puzzle that keeps political actors around the world awake at night is how to unwind this reliance on finite and polluting resources, and remake all of the essential, often invisible, systems they fuel, before it’s too late. Solving that multivariate equation is an unprecedented social engineering project. It is a whole-of-society problem that requires whole-of-society transformations, which will need broad-based buy-in to progress. Because engagement and cooperation are needed at every level of society, from the local to the international, it is a profoundly political project.

There's a reason sustainability advocates have a tendency to compare their work to the Apollo missions. The moon landing pales in comparison to the scale and complexity of the breakthroughs that will be needed in the decades ahead. The encouraging news is that the experts have a high degree of confidence this ambitious agenda is technically achievable, they just worry about mustering the support for the efforts that are needed. Scientists and engineers broadly agree that the obstacles to successful climate change adaptation are not chiefly technical, but political. Policymakers are being presented with a menu of technological options for climate action, and have to make choices about their future energy strategies. The paths they choose will have political consequences, both for the successful execution of those strategies, and for the options that will be available in successive rounds of policymaking and successive phases of development. The greatest threat leaders face in completing the transition is that the solutions they pursue will sap the political will to continue the work.

Because Denmark has traveled further along this path than other industrialized countries, it offers an ideal case study of the challenges involved in sustaining momentum. The efforts that have been made in previous decades to advance the energy transition have effected a broad and deep cultural shift. Renewable energy is no longer seen as a curiosity. Across society, the need for climate action is considered urgent. Popular mobilizations pushed climate change to the top of the political agenda in the most recent national elections. Every corporate report I have read loudly proclaims the company's commitment to be leaders in the sustainability transition. These widely-shared green values motivate individuals and institutions to act, which is critically important, since much work remains to be done. Danes have made substantial progress in decarbonizing their electricity system, but have only recently begun thinking about how to make similar efforts in the heating and transportation sectors. Wind power has the potential to play an even greater role as the energy transition expands into these areas. The country's most innovative thinkers are now designing and experimenting with new technologies, such as electrification and hydrogen storage, for sustainably-powered heat and transport. But these prototypes will have to travel a developmental pathway similar to that of wind turbine technology over the past five decades, before they achieve anything close to lock-in. As the preceding chapters have documented, getting to a point where the idea of powering an entire country with the wind seemed realistic was an arduous, expensive, disruptive, and messy process. Will the enthusiasm for sustainability in Denmark today be sufficient to redouble those efforts?

The growth of the wind system, I have explained, has been uneven and intermittent. After the explosion of development in the 1990s, the 2000s was mostly a lost decade for wind power in Denmark. The last decade has been similarly challenging. When I interviewed industry lobbyists in 2015, turbines were producing a little more than 40% of the country's electricity, and they confidently forecasted wind power generation would rocket past the target of 50% by 2020. (7) In fact, growth stagnated in the following years, and the target was missed. The wind share of the electricity mix hit 46.8% in 2019, inched up to 47% in 2020, then dropped to 43.6% in 2021. (Danish Energy Agency 2021, Danish Energy Agency 2022). Only in 2022 did wind energy account for more than half of the nation's electricity consumption for the first time, hitting 53% thanks to a single 604 MW offshore wind farm coming online at Kriegers Flak in the Baltic Sea. Wind production has continued to inch upward, but the growth curve of new installations is becoming noticeably more jagged from year to year, and though total capacity keeps climbing one big leap at a time, the periods when growth is flat are multiplying (see Figures 6.4 and 6.5). The network is becoming more dependent on large offshore wind farms for growth (see Figure 6.6), and onshore development is slowing considerably, raising questions about where the additional capacity will come from to power all the electric boilers and electric cars policymakers are hoping to plug into the grid. The conventional thinking is that the community development model has reached its limits, and can't deliver the kind of scale needed to reach central government quotas. Community wind advocates would counter that their model is the surest means of maintaining public support for the green transition. Even the investor-owned model that was so successful in the 1990s is endangered domestically, as these developers are frequently unable to secure local approval for their onshore projects, and the national government has set its sights offshore, which is increasingly the province of only the world's largest industrial conglomerates. I don't think it is an accident that the relatively small firms focusing on onshore development, like Eurowind Energy (discussed in Chapter 5), are doing more of their business in Eastern Europe today. The current hope among European policymakers seems to be that building a few mammoth offshore wind farms will solve all their energy problems. Some sustainability advocates, like Søren Hermansen, have their doubts about the wisdom of this strategy. "I'm fearful about the system that we are seeing now that is more and more privatized," he said. "It worries me deeply." He pointed to the example of how the liberalization of European energy markets in the 1990s had resulted in an overreliance on Russian natural gas, which set off an energy crisis when Russia invaded Ukraine in 2022, and worried that the trend toward centralizing renewable energy production could similarly weaken the stability and security of Denmark's electricity supply. (8)

Hermansen's worry is a useful reminder that choices about how to construct an energy system are about much more than carbon emissions, spot market prices, and gigawatts installed. Denmark's experience makes it abundantly clear that carrying out a renewable energy transition is never as simple as swapping one fuel source for another. The adoption of wind power has had cascading social consequences—the elevation of sustainability on the domestic political agenda being among the most visible. All infrastructure development has social and political effects, whether intended or otherwise. This is the second sense in which the choice of transition pathways is a politically momentous decision.

If technological change is a political process, then technological development is also an opportunity for political development. Some, but not all, of the actors met in previous chapters were conscious of this connection, and got involved in Denmark's energy transition with explicitly political goals. The question I have been asking in this dissertation is what can be accomplished politically by building a wind turbine?

On Samsø, for example, most of the locals who made the leap into wind energy development in the late 1990s did so out of a sense of community obligation, in an effort to rescue their dying local agricultural economy. When I tried to praise Søren Hermansen for all that had been accomplished on the island under his leadership, he demurred with typical Danish modesty. "I don't know if I'm responsible, but I'm part of it," he said. "Not that I don't want to be responsible, but we are many responsible people who were a part of this. This is the cooperative social dimension of this, that it takes a community to develop projects like this.” (9)

Hermansen said that when he talks with his friends and neighbors on the island, they generally agree Samsø is doing pretty well today, even though the community is still bleeding population, and the local economy has shifted from its agricultural roots. The farmers are maintaining their businesses, but there are fewer of them today, and their operations are more industrialized. There are more summer houses and more tourists, which Hermansen said is not really a source of conflict on the island, because the year-round residents see the benefits these visitors bring—they spend money at local businesses, the ferry service is better. But the two communities do have very different interests in the island, and Hermansen guessed that the summer crowd would not be thrilled about the prospects of raising any new wind parks. “They don’t live here, they live in Copenhagen and they just want peace and quiet on Samsø,” he said. (10)

With less direct public participation in energy development on the island today, I asked Hermansen what, if anything, he thought had been lost. The first thing he mentioned was that sense of responsibility to the community, that obligation to show up to meetings, to place the welfare of the community on one’s own shoulders. “This is what knits society together, that we have important things to do, and take care of,” Hermansen said. “The democratic farming muscle is not as strong as it used to be.” (11)

6.2 Building the Backbone of the Renewable Energy System

I have made an analytic choice in this dissertation to focus my analysis of Denmark’s energy transition around wind development. Singling out this one generation technology makes sense, because historically the growth of wind power has been the driving force behind, and the main contributor to, the transformation of the electricity sector. I argued in Chapter 1 that giving special attention to developers and development helps highlight the political dynamics of energy transitions. While this narrowing of the scope of the investigation has both methodological and practical benefits, from a sociotechnical systems perspective, it is only one element of the larger energy system on which Danish society relies. Even the electricity network is just one element of this energy system, and a full examination of the electricity system would give attention, at a minimum, to the interlinked elements of generation, transmission and consumption. Restricting my analysis only to wind turbines is akin to an ecologist studying the species occupying a specific niche or trophic level, rather than providing a holistic overview of the larger ecosystem of which they are a part. My question is what can be done politically by building a windmill, and technically, the answer to that question is not much, not without a lot of other supporting physical, social, economic and political infrastructure. Humans have employed windmills in isolation for thousands of years to perform tasks such as pumping water and grinding grain. They can also be used to heat buildings, like the Tvindmill and the WF-1 built at UMass Amherst in the 1970s. But today, wind turbines are primarily used to generate electricity, and most feed that electricity to a larger grid. In Denmark, the incentive to generate power for the grid is enhanced by policy, which requires grid operators to accept all incoming generation sources, and pay a fair rate to independent producers (a policy mechanism known as "net metering"), and uses grid interconnection as the mechanism for distributing state subsidy payments. The seemingly simple act of plugging in to the grid is not really so simple at all, and has had numerous consequences—technical, economic, regulatory—for turbine development.

Just as wind turbines are only one component of the larger electricity system, the direct payments to turbine owners are only one of a whole suite of policies that directly and indirectly support renewable energy development. Subsidies are just the tip of the spear in how governments and other institutional actors encourage energy transitions. When policy analysts focus on subsidy schemes, which is the typical approach in the academic literature, they are missing these other critical pieces of the puzzle. The list of policies and institutions that have some influence on the wind energy system is too long to discuss in any depth, so I will just briefly note a few particularly significant examples from Denmark's transition. At the same time Denmark was pioneering modern wind turbines, it also emerged as a world leader in district heating, co-generation, and waste-to-energy technologies, which supply most of the power in major cities today. Even rural communities like Samsø have built smaller-scale district heating plants. These centralized production and distribution networks give policymakers greater influence over the fuel mix, and make it easier to scrub carbon emissions out of the system. They have allowed for controversial decisions like the rapid changeover to biomass at combined heat and power (CHP) plants, which both eliminated the need for coal, and as a renewable fuel also created competition for wind energy as a means of meeting clean energy targets. Today, CHP plants are increasingly investing in electric boilers, which will allow them to buy wind energy from the grid, turn it into steam, and pipe into homes.

Denmark has also made significant investments in wind energy research and development, a fact that is sometimes underappreciated in the policy literature. The country’s wealth of expertise in all facets of the renewable energy value chain is arguably the biggest single factor that continues to make it a global hub for the wind sector today. In Michael Aklin and Johannes’ Urpelainen’s analysis of the Danish case, they conclude that, compared to the United States and Germany, “in Denmark, wind energy R&D did not play such an important role, but the various tax credits, investment subsidies, and regulations that enabled agricultural cooperatives to own wind power created an environment in which the growing Danish wind industry was able to thrive.” (Aklin and Urpelainen 2018, 124) I have already praised these authors in the previous chapter for this quasi-ecological framing of Denmark’s success with wind power, but they are wrong to exclude R&D from the conditions that helped the domestic industry thrive. I am quite confident they are getting this insight secondhand from Matthias Heymann’s well-known 1998 comparative analysis of turbine development in these three countries. But Aklin and Urpelainen are missing Heymann’s point—it’s not that the Danes didn’t invest in R&D, they just did it on a different, “bottom-up” model than the big-budget, state-led research programs in Germany and the United States. A lot of R&D that was instrumental in the development of modern turbine technology was being carried out outside of government in the 1970s, by grassroots organizations like Tvind, OVE, and the Nordic Folkecenter for Renewable Energy, and in the workshops of blacksmiths like Karl Erik Jørgensen (see chapters 3-4). Some of these groups were receiving state funding to support their research efforts. A large amount of the wind research and innovation Denmark is known for today happens in the private sector, but government institutions also have substantial expertise, including in state-funded universities, in the Danish Energy Agency, and at the transmission system operator, Energinet. Turbine manufacturers from India and China have opened offices in Denmark for the specific purpose of tapping Denmark's talent pool.

And, in fact, the Danish state did invest directly in some large turbine demonstration projects, like the Gedser Mill, which provided critical performance data that the first generation of turbine builders used to design their own experiments. Today, the global industry's largest, most advanced (and occasionally most bizarre) turbine designs are tested at two facilities in Risø and Østerild, both run by the Technical University of Denmark (DTU). The Risø campus has been central to the story of Denmark's energy transition from the beginning, and it remains the leading academic center for wind energy research in the world. As noted in the previous chapter, DTU scientists have historically played key advisory roles in crafting Denmark's renewable energy policies, and continue to do so in the present.

Two Risø-led R&D efforts have been particularly impactful in the evolution of Danish wind development. The first was to carry out meteorological analysis of historical wind conditions—first domestically, and then for all of Europe—culminating in the publication of the European Wind Atlas in 1989. This data was an essential tool for private developers in the 1980s and 1990s in identifying the windiest sites to purchase land and raise a wind farm. As big of a deal as mapping European wind resources was, the testing and certification of new turbine models at Risø had an even more direct influence on the specific character of wind projects built in Denmark. I have already discussed in Chapter 3 how the certification requirement to qualify for state subsidies helped the early manufacturers with quality control, giving them a competitive advantage both domestically and internationally. Risø type approval also helps manufacturers with

Danish roots dominate the domestic market, and contributes to supply bottlenecks that frustrate developers. Foreign firms like Suzlon do business in Denmark, but make no effort to sell turbines there, since they can't compete with local companies that have a mixture of business and cultural advantages on Danish soil, and it's not worth the effort and expense trying to make inroads into such a small market. "You cannot sell a Suzlon turbine to the Danish farmers, they go for Vestas or Siemens," said Erik Winther Pedersen, CEO of the Indian manufacturer's Danish subsidiary. "They are very nationalistic." (12) But since foreign manufacturers have not sought type approval for their turbine models, Danish developers also have no choice but to source their turbines from a select group of suppliers. Only Vestas, Siemens, and Nordex make turbines approved for construction in Denmark (the latter two companies are now based in northern Germany, but were founded in Denmark). These limited options can slow down development timelines, when domestic manufacturing is unable to keep up with demand, and pose particular challenges for small projects and small developers, like Jakob Ferløv Greth, who said he is at a competitive disadvantage when trying to negotiate contracts to purchase turbines. (13)

As important as feed-in tariffs and R&D funding have been in promoting the growth of wind energy in Denmark, the backbone of the wind energy system is the grid. The Danish state has poured massive amounts of money into building one of the most advanced electricity grids anywhere in the world, and manages the grid with an eye toward encouraging renewable power generation. These basic infrastructure investments represent easily the largest indirect subsidy to wind energy producers. Grid evolution continues to have major implications for the future of renewable energy deployment, both in Denmark and around Europe.

From the perspective of grid managers, wind turbines can be a real pain. They are relatively small and decentralized generators, compared to traditional fossil-fueled power plants. They only produce energy intermittently when the wind is blowing, which often does not align with the timing of peak electricity demand (people use more power during the day; the wind blows more at night). And because the power output from a spinning turbine rotor is neither stable nor smooth, numerous subsystems have been developed, both within turbines and at the points of interconnection, to ensure electricity production from windmills meets the technical specifications for protecting the grid. When those hardware and software components, like generators and power control systems, are built into turbine nacelles, the added costs are borne by the developers. In Denmark, the subsystems used to connect turbines to the grid, like building transformer substations and running electric cables, have usually been paid for by the utilities or the state. I already described in Chapters 4 and 5 how wind turbine owners and utility companies negotiated interconnection agreements voluntarily during the 1980s, before the breakdown of the talks led the state to require wind developers to pay for the local low-voltage connections, while the utilities were tasked with maintaining a high-voltage network capable of handling all of these distributed inputs. The early investments the utilities made in strengthening the grid provided the necessary technical capacity to absorb and distribute the exponentially growing wind production. Since the 1990s, the state has become much more centrally involved in administering the electricity system, through both energy markets and the grid. This centralization has provoked a series of adjustments and evolutions in wind development in recent decades, and is pushing the future farther offshore. In the remainder of this section I discuss the two most significant developments—the liberalization of energy trading around Europe, and the creation of a national transmission system operator in Denmark.

Liberalization has been part of the broader European integration process, and in the case of the grid, has resulted in the Continent growing more interconnected with each passing year. After Norway's electricity markets were deregulated in 1990, a power exchange was setup between Norway and Sweden in 1996. By 2000, Finland and Denmark had joined the exchange, which today is known as Nord Pool. The spot market has continued to expand, and now also trades in Germany, Austria, the Netherlands, Belgium, France, the United Kingdom, Estonia, Latvia and Lithuania. (Nord Pool) Danish MP Ida Auken called the Nord Pool exchange "the secret behind the whole" energy transition, and she was far from alone in stressing its significance. (14) Without the spot market and the physical grid interconnections that make trading possible, Denmark never would have been able to add so much wind power to its domestic grid. The country now regularly produces more electricity from the wind than it can use. In 2015, wind production exceeded total electricity consumption for 409 hours. (State of Green 2016). For the first-time on September 15, 2019, wind generation exceeded demand for a continuous 24-hour period. (Energinet 2019) Because power cannot be easily stored on today's electric grids, supply must match demand in real time, so all that excess wind energy needs somewhere to go. And the need for on-demand backup generation when the wind isn't blowing has historically been an argument for keeping carbon-emitting gas, coal, and biomass plants online. The Nord Pool exchange helps alleviate these problems in both directions, creating an export market for Danish wind power, and providing essential grid balancing when turbines sit dormant. On less windy days, Denmark is able to import nuclear power from Sweden and hydropower from Norway. The more countries that are incorporated into Nord Pool, the less backup generation is needed on standby, since grid managers can source electricity from abroad to cover domestic shortfalls. While the expansion of the grid has allowed wind power to proliferate, it has not been all good news for wind producers, because it has also created more competition. Wind turbines do not incur any fuel costs to generate electricity—the wind is free—allowing them to underbid conventional generation technologies on the spot market, and often leaving wind farms to compete with other wind farms. “Because renewables are extremely cheap, they push the more expensive suppliers out of the market and, in doing so, depress electricity prices,” Aklin and Urpelainen explain. “As more and more units of electricity are generated by renewable sources, their own profitability decreases.” (Aklin and Urpelainen 2018, 27) In this market environment, the expansion of wind power makes the continued operation of existing turbines and the construction of additional wind capacity a less attractive investment, a problem that seems to be affecting wind producers across the spectrum of development models. Numerous turbine owners I spoke to—including cooperatives, farmers, private investors and utilities—complained that the low spot market prices in the latter half of the 2010s were endangering their participation in the wind sector. According to Denmark’s transmission system operator, “when the west wind is strong, electricity prices plummet,” and reached “rock bottom” (that is, zero) anywhere from 50-100 hours each year. (Karas 2009, 16) In 2009, Nord Pool introduced negative electricity prices in an effort to curb excess power production, leaving turbine owners the choice to either curtail their turbines or pay to keep them running on windy days. (Safarkhanlou 2009, 25) Small producers cannot survive on such terms. As I noted in Chapter 5, Samsø famer Jorgen Tranberg estimated he needed somewhere between 25-30 øre per kWh to keep running his windmill, but at the time he was often getting less than half that amount on the spot market. I heard similar estimates from other turbine owners. Lower market prices favor larger wind farms, which can reduce their unit costs by realizing economies of scale. Liberalization, counterintuitively, has made wind developments more reliant on government subsidies to break even. New turbine installations dropped-off precipitously after the Danish government cut subsidies in 2002 and again in 2015 (see Figure 6.2). Offshore wind farms in Denmark are still centrally planned, and awarded to developers through a tendering process that provides a guaranteed rate to the lowest bidder. Attempts to stimulate offshore development on market terms—both by building close to shore, and through an "open door" permitting scheme—have so far gone nowhere.

The other key institution in administering the Danish grid is the national transmission system operator (TSO), Energinet.dk, which was created in 2005 through the merger of the old utility associations, ELKRAFT and ELSAM, which had previously managed the grids in the east and the west, respectively. Today, the state-owned TSO can run the entire national grid from a single control room at its headquarters in Fredericia. Intermittency is often cited as a limitation of wind power in policy debates, and wind is a highly variable resource, by location, by year, by season, by time of the day. The challenge of trying to harness that resource stably and efficiently is certainly much more complex than ramping a natural gas plant up or down. But from the engineers I spoke to at Energinet, I got the impression it was the sort of technical challenge they relished, and they were confident they had it covered. Intermittency is now seen less as a roadblock to grid penetration and more as a property of the resource to be managed. At headquarters, Energinet grid operators receive three different meteorological reports, four times a day. Forecasts can be off by as much as 30-40%, according to Energinet grid supervisor Lars Fogt Andersen. So at headquarters, grid supervisors are on the phone, about 50 times a day using the Nord Pool market levers to upward and downward regulate the amount of electricity being fed onto the wires. (Karas 2009, 14-15)

Such centralized management of the electricity system is executed with the appearance of ease, I am sure, thanks in part to the expertise and disciplined work of the staff, but also with the aid of world-class grid infrastructure. In a 2014 report, Energinet said it spends annually “in the nine digit range” (I assume they mean DKK) to reinforce the grid, which benefits not only wind turbines, but other renewable technologies like solar as well. Some Energinet projects have provided targeted support to wind developments, especially the large offshore wind farms that are now the favored approach across government. Energinet has built offshore substations, and paid for an undersea cable link to Germany routed through the Kriegers Flak offshore park. Energinet’s involvement in building undersea power cables connecting Denmark to countries across Northern Europe is significantly expanding the reach of energy markets, and changing how the policy community envisions the future of renewable energy development. The TSO currently operates seven undersea power cables connecting Zealand and Jutland to Sweden (twice), Norway, Germany (twice), the Netherlands, and the just-completed Viking Link to the United Kingdom, at 475 miles the world’ longest undersea cable, with a price tag of 1.7 billion pounds sterling, split between Energinet and National Grid. (Energinet, National Grid 2023). Energinet has also recently invested in upgrading the overland high voltage link to Germany that runs up the spine of Jutland. The wind industry sees benefits in all of this grid integration, and has lobbied at the European level for more interconnections. (15) The larger the grid, the bigger the export markets for Danish wind electricity and Danish wind turbines. Access to electricity consumers in more and more countries will continue to allow overbuilding of the domestic wind sector, which has already more than saturated domestic demand on windy days.

Energinet's operations and investments are funded through electricity taxes, which are among the highest in Europe, accounting for about 85% of consumer energy bills in 2014, between the VAT, the PSO, grid payments, and other taxes. (Energinet 2014, 20) Søren Hermansen said the public was generally accepting of high electricity taxes, they are used to paying high taxes for a lot of things, like healthcare and schools, and they can see the results of what they are getting for their tax dollars. Danish public infrastructure, across the board, is extensive, modern, usually well built and maintained, and as a result highly usable and functional. The everyday visibility of these public benefits of government spending are a factor that broadly raises public trust in government, reinforces social democratic values, gives the agencies more leash to pursue ambitious projects, and helps Danes stomach the big tax bills that fund all these investments. This attitude applies to the grid; Hermansen specifically mentioned the burying of cables and the reliability of electric service as benefits of the arrangement. (16) Denmark's grid is one of the most advanced and best-performing in Europe, with better than 99.99% uptimes, Danish homes on average lose power for less than 40 minutes per year. (Danish Energy Agency 2016) Local Danish utilities have also done a lot of work burying low-voltage power lines and equipping buildings with smart meters, which increases the overall efficiency, stability and reliability of the electricity system.

This robust grid infrastructure has encouraged the uptake of large amounts of distributed renewable energy, and just how much that growth can continue is anyone's guess. Per Svendsen, who was communications director at Aarhus utility NRGi and is now a member of the board, thought there would be a limit to how much renewable generation could be added, since eventually it would affect grid stability. But he joked that was a problem for Energinet. From the utility company's point of view, it made no difference how much wind or solar was on the grid. (17) But government goals of electrifying transportation and heating would require bringing even more generation on the grid, and Anne Simonsen worried that plans were not in place for the additional capacity needed to meet surging demand from CHP plants and plug-in vehicles, potentially creating a bottleneck in plans to decarbonize the energy system. (18)

Energinet's official strategic plan for wind energy development is to pursue cutting-edge (and still incubating) electricity-to-hydrogen conversion technologies, promote large-scale offshore wind farms, and press wind and solar to be built on market terms. (Energinet.dk) These goals align with those of parliament, and were likely developed in tandem. Most everyone I talked to in Danish policy circles said they were in communication with Energinet staff in their official roles, including members of parliament, ministers, top-level permanent administrators, lobbyists, and advocacy groups. The impression I got was that these conversations usually went two ways, with politicians asking the TSO's technical experts for input and advice, and for primers on technical details relevant to policy design. Parliament, the ministries, and the energy agency ultimately dictate the direction, and Energinet works to implement the government's agenda. Although Energinet may on paper be more of a technical than a policy agency, it enjoys a relatively quiet but pervasive political influence, as a central node in Denmark's electricity and energy policy networks. The TSO fulfills key facilitating and gatekeeping functions in European energy markets, making it among the most powerful actors in the political economy of the electricity system. It also controls the physical infrastructure and technical standards that form the material backbone of that network's political ecology. Agency staff are in constant communication with other policy actors, and weigh in regularly on policy debates.

Denmark completely overhauled its grid in the last few decades, a process that has only accelerated after Energinet took the reins in the 2005. Once a laggard in electrification, the Danes have caught up with and surpassed most of their peer nations in the capacity and reliability of their grid infrastructure, and are now leading the push to electrify everything. This evolution created and empowered a highly-centralized grid management agency, with both benefits and potential risks for wind development. Centralization has made it easier to connect wind turbines to the grid, and facilitated investments and innovations that have greatly increased the amount of wind power the network can bear. Critically, the far larger and more densely interconnected grid that exists today makes it much easier to manage the natural variations in renewable energy production, making it feasible to plan for even more wind power on the grid in the future without severely disrupting the patterns of modern energy consumption. On the other hand, centralizing grid operation and policymaking in the TSO has created new challenges for wind development. Funneling the hourly regulation of electricity supply through continent-wide trading markets depresses prices for wind power—a welcome lowering of costs for ratepayers and government budgets, but an existential threat to the profitability of some wind projects. The rollercoaster of market prices has been particularly difficult for cooperatives and smaller investors, who have fewer financial mechanisms to absorb the unpredictability of year-to-year returns on their investments. Several of my interview subjects speculated that the TSO-supported trends in renewable development could eventually undercut the government's transition goals. Søren Hermanson is concerned that the trend toward more centralized offshore wind plants, and the slow elimination of the distributed generation model that developed on Samsø in the 1990s and early 2000s, could work to decrease grid security, and make local grid balancing more difficult, since the electricity system would be relying on fewer generation sources and transporting electricity over longer distances, with fewer decentralized plants available to smooth out local fluctuations in demand. (19) Former energy minister Rasmus Helveg Petersen wondered if Denmark's high electricity taxes (paired with declining subsidies for feeding power into the grid) might motivate owners of distributed generation like wind and solar to disconnect from the network in the future, as improving battery storage technologies make the prospects of running a household, or even a business, off-grid increasingly feasible. (20) I have not seen evidence of either of these problems cropping up yet, but either development would endanger the government's agenda of electrifying the energy system.

6.3 The Old Guard Joins the Green Movement

I discussed in previous chapters how the utility sector was initially skeptical of wind power, and clearly was not out front leading the transformation of the electricity system described above. That hesitance to embrace renewable energy persisted surprisingly late into Denmark's energy transition, long after wind technology had demonstrated its viability for large-scale power generation, and decades after political elites had pushed to make a renewably-powered future official state policy. In just the last 10-20 years, there has been a notable shift in both attitude and activity from traditional players in the energy sector. Today, seemingly every corporate report foregrounds glossy photos of executives smiling in front of wind turbines, and proclamations of the company's commitment to being a leader in the green transition. Some of this corporate PR can be written off as greenwashing, and in many utilities the execution of their renewable energy strategies still trails their ambitions. But all of the evidence I have gathered suggests the culture shift inside these companies is widespread and sincere. The largest companies have had the most success completing renewable projects, and have been behind the largest offshore wind farms, which by their sheer size makes them the biggest contemporary developers in the wind sector, and the primary actors government officials are counting on to implement their broad and ambitious policy frameworks. Some of the delays in utility adoption of renewable energy are to be expected—as I have argued repeatedly, energy transition are gradual process, institutions and infrastructure cannot be changed overnight. Planning large-scale energy developments is usually a multi-year process. And since they got such a late start, some utility companies are probably behind the curve in building the internal competency and acquiring the experience that facilitates such projects. At the same time, certain aspects of the utility mindset have been hard to shake, and conflict with traditional approaches to distributed renewable energy development. As much as the wind power revolution transformed the utility sector, the entrance of the utilities is also remaking the domestic wind energy system.

According to Per Svendsen, who has more than four decades of experience in the utility business in Jutland, the impetus for renewable energy development initially came from the left-wing parties in Parliament. At the time of the 1976 Energy Plan, the utilities resented what they saw as government imposing on their area of expertise, and wanted to be left alone to run the grid in the manner they thought best. Svendsen linked this tradition to the rural tradition of community self-reliance. “It was again the cooperative way of thinking,” he said. “We want to decide ourselves, it's our owners, it’s their money, it's their company, and you do not have to interfere with the things we are doing here.” (21) Most local utilities companies in Denmark were then, and still are, cooperatively-owned by their customers. In the 1990s, Svend Auken forced the two regional utility associations to construct one offshore wind farm apiece. “They were not happy about it,” said Anders Eldrup, former CEO of DONG Energy, the country’s largest utility. Eldrup said he remembered attending industry conferences in that area at which managers would state 5% wind power on the grid was acceptable, but any more than that would destabilize the grid. Later, they upped those estimates to 10%, but the general attitude about the limits of renewable energy was the same. “The major obstacle was cultural,” he said. (22)

Svendsen said he started to see attitudes toward wind power change in the 1990s, when his company in southern Jutland constructed a large onshore wind farm, which the engineers felt was an exciting challenge. “We were rather proud of having this wind farm,” he said. “I think many at the time said, ‘okay, it is here to stay, let's try to make a business out of it.’” (23)

Although the resistance to wind power was thawing, the utility companies did not dash headlong into renewable development. Svendsen moved to Aarhus utility ARKE in 1995, which reorganized into NRGi in 2000, and owns the local power lines between 15-60 kV. When I visited their headquarters in 2015, their renewable energy department was only six months old, had a staff of one, and had yet to purchase a single wind project. Everyone in Aarhus who has an NRGi meter connected to their home is a co-owner of the company, which has about 210,000 members. An attempt to incorporate as an A/S was met with a “roar” of disapproval from the public, most of whom wanted to remain a cooperative. Of course, very few of the cooperative members are directly involved in company management or decision making. An elected board of nine oversees the company, while the professional staff runs the day-to-day operations. Homeowner’s financial stake in the company amounts to a discount that is returned on their electricity bills each year. Svendsen said he often gets phone calls from Aarhus residents wondering how they can sell their shares in the company; he informs them they cannot. (24) This cooperative model is a different species than the small neighbor cooperatives that raised so many wind turbines in the 1980s. One example of the lack of direct public participation in the company’s renewable energy programs that Svendsen pointed to was the failure of program allowing customers to pay a premium for green electricity.

“Nobody bought it, nobody,” Svendsen said. “Then we found out there is a very big difference between what they say, and what they do when they have to pay for it.” Most of the utility’s members are just customers, primarily concerned with paying their monthly bill and not thinking much about where their electricity comes from, or at least not willing to pay extra to source the watts they consume more sustainably. That said, NRGi’s forays into renewable energy development have come at the urging of customers, and especially the board, and were not instigated by the professional staff. Svendsen explained that it was not a business decision, but a political influence of the company’s democratic governance structure. “We really have to listen to what the representatives tell us to do. That's why we cannot always have a business approach to all of the things we do,” he said. “I think that's why wind power has been a big part of our daily life, because they want it to be.” (25)

The recent decision to begin looking at renewable energy projects was, in some ways, a return to a more traditional role for the company, owning and operating power plants. When the liberalization process broke up the vertically-integrated monopolies and separated generation from transmission, NRGi sold their stakes in power plants, mostly to Swedish giant Vattenfall, and refocused their core business around retail distribution and energy efficiency consulting. “We wanted to be independent of the power stations. We wanted to buy electricity where it was cheapest for our customers,” Svendsen said. “That's what are dealing with today, trying to make a business out of decreasing electricity [consumption].” He estimated that less than 25% of their business today was traditional utility work. (26)

The company has installed smart meters for customers, and runs a net metering program for rooftop solar. Customers love this program, said Svendsen, who has solar panels on his own home, though he thinks the owners of rooftop arrays should have to pay a fee for grid access and maintenance. The company is clearly not trying to meet it's clean energy goals by encouraging more widespread adoption, but is instead looking to buy into "turnkey" projects managed and built by private developers. NRGi's entire renewable energy division, when I visited, was Jakob Bunsgaard, who joined the company in 2009 from investment banking to work on general business development, and said there were no plans to expand his staff beyond 1-2 additional employees. Although Bunsgaard had no background in the renewable energy sector, he said that shift in the focus of his job was actually more akin to the work he had done in banking, since there renewable energy strategy did not include developing their own projects, but evaluating the financial returns of projects they might purchase. (27) NRGi had allocated DKK 600 million for buying about 100 MW of renewable energy total over a number of years, and Bunsgaard was looking at both wind and solar projects, mostly in the 10-20 MW range, not only in Denmark, but also in Germany, France, Poland and the UK. To date, the company has only bought into a couple of small projects. (28) They could have met a large chunk of their goal with a single large offshore wind farm proposed to be built on Mejl Flak in the Bay of Aarhus, with a planned capacity of 120 MW. NRGi had gotten involved in the longstanding proposal when the development company broad their proposal to the chairman of the utility's board. Bunsgaard said the motivation to invest in the offshore wind farm came from a desire to "bring renewable energy close to the consumer," and make it more visible in Jutland's wind technology hub. "It would be a landmark for Aarhus," he said. Wealthy homeowners along the seashore had loudly protested the plans, but Bunsgaard pointed out that local government did not have jurisdiction over the site, and the national energy agency would give the final approval. Bunsgaard said that when he first took over the renewable energy division, the Mejl Flak took up most of his time and energy, but with the recent drops in market prices for electricity, the business case for the DKK 2 billion project had weakened, and he was now spending less than 5% of his time working on it. (29) The year after we talked, NRGi sold its stake in Mejl Flak to private developer European Energy A/S, which later abandoned the project in November 2021. (4C Offshore) There are still no wind turbines in the Bay of Aarhus.

In contrast to NRGi's lean approach, Denmark's largest utility company, DONG Energy has bet the house on offshore wind power, completely remaking the company over the course of a decade. Anders Eldrup, who was CEO in the early 2000s, is often credited as a leader of the renewable energy transition among the business community, similar to the role Svend Auken played in government. Christina Aabo, who was head of research and development at DONG for a decade, alled Eldrup a "visionary" long-term strategic thinker and a skilled communicator whose political connections were instrumental in building support for the energy transition. (30) Eldrup worked alongside Auken in the 1990s as permanent secretary in the finance ministry. He said the creation of the PSO tax in the 1990s was a critical factor in increasing the power of Auken's energy ministry, since it protected funding for renewable energy during an economic recession. The finance ministry was looking to cut budgets, and the minister at the time found the exploding costs of wind subsidies "irritating." Eldrup said from the perspective of private industry, a stable long-term policy framework was the most crucial condition for investment. If renewable energy funding had remained on the government's balance sheet, rather than being pushed off onto consumer electric bills, political negotiations would have led to frequent changes in subsidy schemes, Eldrup thought. "That would not have been good for industry," he said. (31)

DONG—which stands for Danish Oil and Natural Gas—was primarily an offshore drilling company when Eldrup took over as CEO in 2001. The company had invested heavily in North Sea oil exploration, and had government contracts to extract oil and gas through 2012, but management was concerned about finding new business areas to expand into. Parliament later extended those drilling contracts until 2050, but North Sea production has been declining year-by-year. "The gas will run out before the contracts," Eldrup said. (32)

Renewable energy was not among the options DONG management favored for diversifying their business at the time; Eldrup said he first looked into natural gas and then coal. The first moves made were to acquire fossil-fueled generation stations, and discussions about wind energy came later, on the "same logic, but it was not the first thing we looked at." (33)

Eldrup said the turning point for him came in the lead up to the Copenhagen climate conference, which was being heavily "hyped" in Denmark. Conversations with academics from the United States and United Kingdom, and especially the influence of Al Gore, started to change his thinking about climate change. DONG was also taking a lot of heat from the public and politicians over plans to build a massive coal plant in northern Germany, which would have been the largest in Europe. "Our image in the general public was not very good," Eldrup said. (34)

The growing concerns over climate change at this time not only hurt the company's reputation, but also potentially endangered its business model, occasioning a dramatic shift in strategy from management. At the time, about 85% of DONG's portfolio was fossil fuels, and only about 15% renewables. Eldrup decided he wanted to flip that ratio, and introduced a new "85-15" initiative that became a rallying cry inside the company. In 2009, DONG announced they were canceling plans for the German coal plant, at a significant financial loss. "That was a tough one," Eldrup said. "Not everybody accepted that." But as he explained it, they were also hedging future risks. The business community thought carbon taxes were likely to be introduced, and although that eventuality did not come to pass, Eldrup wanted to avoid the headache of having to take a politically unpopular stance on carbon pricing. By comparison, renewables looked like a simpler investment, since they would indirectly benefit from taxes on fossil generation, and there would be no need to worry about fuel costs. Management also felt confident that policy support for renewables was not going away. "It was more of a business decision," Eldrup said. "The possibility when we look at this new power plant, it will exist for 40-50 years. This would have been by far the biggest investment in DONG's history, should we allocate so many billions to something with all the uncertainties attached to this investment." (35)

The reversal in strategy had immediate benefits for the company's image. Eldrup said their popularity with the public grew, and DONG began to be seen as a more attractive place to work, making it easier to recruit talent from the universities. (36) But the move was not nearly as popular inside the company, especially with the old-guard engineers, who numbered around 500 in the power division, almost all of whom were experts in building and operating coal plants. When DONG created a wind division in 2010, the engineering staff were asked if they would consider transferring to the new department. Eldrup estimated that about half accepted. The other half could have been let go, but instead the company worked out a deal with the large engineering consulting firm Ramboll to take on the staff who were unable or unwilling to adapt to the new direction. (37) Today, the remaining oil and gas division still does not mix with the wind developers. Christina Aabo explained that there wasn't conflict or jealousy between the divisions, they were just different worlds, and hardly knew each other. When DONG invested in offshore wind, they sought synergies with their existing expertise in offshore drilling, but found there were very few overlaps, even the undersea foundations for the platforms were completely different. (38)

This example vividly illustrates the difficulties in bridging the gap between what Danes often refer to as "black" versus "green" engineering cultures. The predominance of the former in the utilities was a major reason for the sector's tardiness in recognizing the business opportunities the energy transition was creating. DONG management discovered that, in order to get their staff aligned behind the new strategy, they first had to clean house.

DONG had acquired its first stakes in wind farms somewhat accidentally, as part of a 2005 merger with the regional utility companies. According to Eldrup, the company was interested in the utilities' central power plants. Their renewable portfolios were thrown in as part of the larger deal to acquire the generation capacity, an afterthought.

“The numbers were so small that they were not reported in our annual reports,” he said. (39)

The Zealand-based utility, E2 (formerly ELKFRAFT) had a pipeline of offshore projects under development that DONG inherited. What was initially a sideline rapidly became the company’s core business after the 2009 strategic realignment. What had been a team of only 50-100 people working on wind energy grew by 2012 to 1,200. (40) By 2015, the wind division had 1,900 employees. (41) A year later it was 2,300. (42) In order to expand, DONG management was directing approximately 2/3 of the company’s capital expenditures to the wind division, which created some tension with the company’s other divisions, which wanted more resources for their own projects. (43)

DONG was taking a large risk bringing project development in-house, a somewhat unusual strategy in a sector where other firms typically subcontract a lot of the technical work. The company simultaneously made the decision to divest all of their onshore wind holdings, and focus exclusively on offshore wind. The managers I spoke to explained that these decisions were a business strategy, intended to create an area of specialty where the company could distinguish itself from competitors. The focus on offshore wind also made sense from technical and resource allocation perspectives, since the two technologies are so different. “Just getting rid of all the onshore, from an operations point of view, support point of view, engineering point of view, in any phase, it is really much easier to focus and concentrate on the competences we need for offshore,” Christina Aabo said. “Handling of authorities, legal frameworks, it's so different on- and offshore. We had a lot of things that were double in our organizations.” (44)

Aabo characterized competition over onshore project development as “rather fierce” around Europe, and continuing to work in that sector would have put them in direct competition with other utilities in countries like Germany and Poland, as well as smaller regional firms.

And even though offshore development is far more technically complex and expensive, from a business management perspective, it was actually simpler than maintaining a large portfolio of smaller onshore wind farms around Europe. Aabo explained that running onshore projects in different countries required decentralized operations and maintenance, whereas offshore wind allowed for the development of clusters that could be constructed and serviced from shared port facilities. The company determined that they would they would have to dedicate the same number of people to “30 MW onshore in Poland as we would use on a 300 MW project offshore.” (45)

That potential for scale offshore was a significant part of the appeal. “It's another supply chain entirely,” Aabo said. “If we wanted to really push on lowering cost of energy, we saw we should focus on offshore and developing that supply chain.” (46) According to Tobias Møller Ruby, an offshore wind specialist at DONG, the company always wanted to purchase the largest turbines they could acquire for their offshore wind projects, since that larger capacity was a critical factor in making the investments profitable. Production from large offshore parks was also more reliable and easier to surveil—they run more like a traditional centralized power plant than an onshore wind farm. (47)

Thus far, the bet on offshore wind appears to be paying off for DONG (recently rebranded Ørsted, after the 18th-century Danish chemist who pioneered electromagnetic theory), which is now the largest and most experienced developer in the world. In recent years, the company has expanded beyond its focus beyond northern Europe to other markets for offshore window, a strategy they would not have considered ten years ago. A newly-established American subsidiary began construction in summer 2023 on what will be the first large offshore wind farm in the United States, off the coast of Massachusetts.

The offshore wind business is not only more centralized from an operations point of view, but also in terms of market players. Ruby said that in 2016 only Siemens and Vestas were producing competitive offshore turbines, and other manufacturers were "far behind." (48) The relatively new market sector was already consolidating in a wave of mergers among industrial giants. Siemens had moved into project development, and to keep up with their chief rival, Vestas announced an offshore wind partnership with Japan's Mitsubishi. General Electric in the United States partnered with France's Alstom to create an offshore wind division, while British Arriva partnered with Spanish manufacturer Gamesa. "You have left 4-5 players that are really, really strong," said Eldrup. "This is no longer a game for small companies." (49)

Understanding the transformation of DONG, now Ørsted, in less than a decade from a state-owned oil company to a worldwide offshore wind concern demonstrates the benefits of adopting an ecological perspective to explanation. The company's evolution grew out of broader shifts in the utility sector and in renewable technologies. It was spurred not only by business considerations, but also by policy pressures and cultural shifts, both external and internal. The decision to focus on offshore development was similarly driven by a mix of financial, technical, institutional and supply chain factors. And the company's experiences illustrate the sharp contrast between onshore and offshore wind—the differences between the technologies are even greater than their similarities, so much so that they should be treated as separate species of energy producers. The context of development places significant constraints on the models that will thrive, and only the largest, most centralized players have survived in the unforgiving offshore environment. As policymakers increasingly plan for future development to occur further offshore, the older models that raised thousands of turbines on land are dying out.

6.4 The Decline of Community Wind Development

As the 2020s began, a new generation of the Auken family was once again hyping "renewable energy islands" as the path to carbon neutrality in the Folketing, though the islands Ida Auken advocated funding would look very different from the one her uncle Svend helped bring to fruition on Samsø.

In May 2022, a delegation of European dignitaries gathered in the western port city of Esbjerg for a signing ceremony and press conference. With European Commission President Ursula von der Leyen present for the occasion, Danish Prime Minister Mette Frederiksen, Belgian Prime Minister Alexander de Croo, Dutch Prime Minister Mark Rutte, and German Chancellor Olaf Scholz all signed the Esbjerg Declaration, pledging to turn the North Sea into the "green power plant of Europe." The four countries committed to building at least 65 GW of offshore wind by 2030, and at least 150 GW by 2050, enough to meet half of the carbon neutrality target for the entire European Union. (The Esbjerg Declaration 2022) The scale of the wind farms being planned, to be built in less than ten years, was mind-boggling. Denmark currently has less than 8 GW of installed wind capacity, connected to the grid over the course of half a century. The most recent, largest, most advanced offshore wind park in the country, at Kriegers Flak, was *only* rated at 600 MW, which is about on par with a nuclear reactor. The Esbjerg Declaration calls for the construction of multiple even larger parks, to be interconnected through several artificial island hubs where grid infrastructure and energy storage technologies would be housed. Already a significant offshore wind port, Esbjerg was poised to become a boom town.

When I met Ida Auken in Copenhagen the next week, she was taking a victory lap. She had been publicly lobbying for the energy islands plan since at least 2017, after she read about the concept in a Danish-language trade weekly, *The Engineer*. She brought the idea to the experts at Energinet, who told her they had already been working on such concepts inside the TSO, though they weren't allowed to take positions on policy. Next, she called up pioneering wind engineer Henrik Stiesdal, who showed her how the undersea cables could be downsized to save costs, and proposed adding energy storage to the islands. (50) Auken's persistent advocacy for the energy islands concept was instrumental in getting it included in Denmark's 2020 framework climate agreement. At the time, Energy Minister Dan Jørgensen praised Auken for fighting for just one energy island in the deal; the governing coalition ultimately successfully negotiated for two islands. Jørgensen joked one should be named "Ida's Island." (Ambo 2021)

In 2021, parliament formalized plans for two artificial islands, each with an initial capacity of 3 GW, one to be built in the North Sea off the coast of Esbjerg, the other in the Baltic Sea of the island of Bornholm. But the ambitious plan has its detractors, and is already encountering setbacks. 2023 has been a terrible year for offshore wind in

Denmark, with widespread mechanical failures leading to temporary closures of multiple offshore parks. In April, the government announced they were postponing the tendering process for the energy islands, after the Danish Energy Agency estimated the costs could be as prohibitively high as DKK 50 billion. The TSO Energinet is now investigating the less-expensive option of building a few large offshore platforms to serve as transmission hubs. (Energinet 2023)

And not everyone is a fan of the government's strategy for meeting its climate targets. Søren Hermansen said that a few places would benefit—namely, Esbjerg and Bornholm—"but if you have winners, then you have losers." This concern about distributing the benefits of wind development unequally was something I heard voiced by multiple interview subjects. Hermansen proposed that if the government was going to sign massive contracts to build a few energy islands, those projects should be followed by a series of smaller commitments to fund distributed generation. He thought it was unwise to try to transport electricity over long distances, which would require building more high voltage transmission lines, which the public hates, and argued that keeping more distributed capacity in locales around the country, coupled with investments in a smarter grid, would allow for better grid balancing, and ultimately cheaper power. (51)

Distributed generation projects have slowly been disappearing from Denmark's wind energy network, and not just on Samsø. The cooperative model of wind development is an endangered species, though cooperatives are currently having better luck with other energy technologies, particularly solar and district heating. And the cooperative approach that has historically been such a distinctive feature of Denmark's renewable energy transition is spreading to other European countries, like Germany, where community organizations are learning directly from the Danish experience. "It's expanding rapidly," said Erik Christensen, a member of the board of REScoop.eu, a network of 1,900 renewable energy cooperatives across Europe. So Denmark's cooperative tradition still has wide appeal, but it is atrophying in the domestic wind sector. Christiansen organized several of the largest and most successful offshore wind cooperatives in Denmark in the late 1990s and 2000s. "This is not going to happen again. When all the old wind turbines are demolished, the utilities will take over," he said. "We are disappearing." (52)

The reasons for this decline are twofold, both the scholarly literature and my interview sources agree. Cooperative wind development has been a victim of its own success. Wind power has grown so rapidly in Denmark, it has largely grown out of the reach of amateur citizen collectives. As discussed in Chapter 5, the funding model of cooperatives, which requires all the development capital to be raised and deposited up front, puts them at a disadvantage against private developers who can debt-finance their projects. And as turbines have grown larger, raising sufficient capital among small shareholders has gotten harder and harder. Cooperatives are also being outcompeted in the wind ecosystem as larger and larger for-profit entities see moneymaking opportunities in renewable energy development. The towering scale of modern turbines creates public backlash from nearby residents, but it fits nicely with utility models of centralized power production, and the capital-intensive developments favored by institutional investors like pension funds.

Considering how much has been written about community wind and Denmark's cooperative development model, there have been surprisingly few attempts to conduct quantitative analyses of who is building and buying wind turbines, despite the fact that the government has been collecting data on turbine owners from the very beginning of the energy transition. So few analyses of these records have been published, I suspect, due to the inconsistent quality of that data, and the arduous work involved in sorting through thousands and thousands of turbine registrations. I am aware of two efforts to classify turbine owners similar to the analysis presented in this dissertation. The earliest study was completed by Hans Christen Sørensen, a founder of the Middelgrunden cooperative and an energy entrepreneur. Sørensen and his colleagues have shown that by the early 2000s, the cooperative movement was already beginning to decline. (Larsen et al. 2005) Their analysis drew on the extensive records of the Danish Wind Turbine Owner's Association (of which Sørensen is a board member) as well as the authors' substantial personal knowledge of the network. Sørensen only had available data up to 2005, and several trends in Danish wind development have intensified in the last decade. This study updates the story to 2015, the last year for which I have full data on turbine owners. Less complete records are publicly-available up to 2022, from which some educated guesses can be made about development patterns in the past few years.

More recently, a 2019 study by Aalborg University planners Leire Gorroño-Albizu, Karl Sperling and Søren Djørup examined “community energy” developments in both the wind and district heating sectors. The authors find that 52% of installed wind capacity had at least some “citizen ownership” in 2016, which they conclude refutes the perception that utilities and private developers are dominating the domestic market. (Gorroño-Albizu et al. 2019, 5) My own analysis suggests they are being overly optimistic about the continued strength of community wind development. The significant flaw in their reasoning is that they are only assessing aggregate capacity on the grid, rather than my preferred method, which is to count only the new installations each year. The aggregate numbers have their own utility—for example, Gorroño-Albizu et al. discover that 75% of large investor-owned turbines built before 1986 were decommissioned after less than the expected lifetime of 20 years, which suggests that these investors might be less interested in the longevity of their projects. Of course, there were very few such turbines raised before 1986. But focusing on new installations paints a more accurate picture of the predominant styles of current development, and thus what the wind network is likely to look like in the future. Gorroño-Albizu et al. later note that 69% of the citizen-owned turbines were installed more than 15 years ago, but offer no comment on that statistic. (Gorroño-Albizu et al. 2019, 6) What it clearly shows is that the citizen-owned turbines are getting old, and fewer such projects are being built today. The authors do present an interesting comparison between wind and district heating technologies. Community-involvement is even more pronounced in the latter, with municipalities or citizen cooperatives owning 96% of Denmark's 407 district heating plants in 2016. They argue the reason these ownership models are so widespread in district heating is that Danish law requires the plants to be operated not-for-profit, making the plants unattractive to private investors. (Gorroño-Albizu et al. 2019, 8)

Both of the existing quantitative studies of Danish wind turbine ownership show similar broad trends to those captured in my analysis—local cooperative and private citizen ownership accounted for most wind development in the early decades of the energy transition, before giving way in the 1990s to increasing amounts of investor and utility-owned projects. The specific totals attributed to each developer type unavoidably differ, in part because the underlying dataset from which all three studies draw is of uneven quality and somewhat imprecise. Considering the data has been collected and managed by several different entities over the course of five decades, the government's registry of wind turbines is remarkably complete; some errors are to be expected in a set of more than 8,000 records. Data collection was a particularly amateur effort in the early years, self-reported on notecards owners voluntarily mailed to journalist Torgny Møller. Since the records only list the tax entity that legally owns the turbine, it can frequently be challenging to sort out exactly who is behind these businesses. Private investors, in particular, often like to hide the true ownership of a project behind shell corporations. When an ownership group includes several distinct developers, such as the Samsø offshore wind farm, it gets even more complicated to account for all of the players in the wind network. And any social scientific typology necessarily draws somewhat artificial lines in the fluid spectrum of observed reality. Close study of the ownership records and the history recounted in this dissertation reveals a wide diversity of owners and development styles. Many individual projects are built for multiple reasons; and owners often blur the boundaries between several categories. As Søren Hermansen told me, everyone comes to wind energy for their own reasons. (53) The analyst is thus often forced to make judgment calls about how to classify individual turbines. Most cases are fairly straightforward and unambiguous, but some can be tricky. I describe in detail the procedures I used to make those judgments in my own data analysis in Appendix A. I employed a variety of cross-checking techniques to limit error, but perfect conformity to the reality on the ground cannot be expected. Gorroño-Albizu et al. stress these same weaknesses of the data in their study. "The large amount of data to be processed and its significant limitations do not enable accurate values but only approximate estimations," they write. (Gorroño-Albizu et al. 2019, 6) I wholly agree that this is the most appropriate way to interpret the results of these data analyses, as informed estimates. There is good reason to have high confidence that these classification efforts are by-and-large accurate, in part because the authors of all three studies had numerous direct contacts in the wind network in Denmark and were able to directly verify many cases. That all three studies illustrate similar broad trends, and that qualitative analysis produces further evidence for these trends, creates even greater confidence they are real—an advantage, I should note, of mixed-methods research designs. Researchers are ultimately most interested in those general trends in development styles, and not the fates of individual wind projects, so some small amounts of random error are not likely to significantly distort the bigger picture.

The most significant difference in the results the three studies report is a consequence of the fact that each invents its own typology, and the categories the studies sort turbines into do not cleanly overlap. Sørensen only distinguished between cooperatives, utilities, and individuals, but in practice the development community is far more diverse than these three archetypes are able to capture, and the category of individuals, in particular, is too broad to provide much definition of or insight into the character of the network. Gorroño-Albizu et al. produce a typology similarly lacking in resolution, mixing together distinctive development styles that should be separated in the same overstuffed box. The more recent study makes its primary distinction between "citizen ownership" and "large investor ownership"—a way of drawing the line that hints toward their preference for local community-based development. The second category does not distinguish between the private developers who become prevalent in the 1990s and the utilities that have more recently dominated offshore development. The authors break the first category down further into “individual” and “collective” ownership, their term for local cooperatives. But there are many types of individuals who own turbines for many different reasons in Denmark; for example, this broad category cannot distinguish between homeowners offsetting their electricity use and large farms that are raising multiple turbines as business investments. The authors somewhat arbitrarily set the boundary between individuals and large investors at owning 10 turbines. I would argue that owning any more than one turbine means the developer has made a substantial capital investment, and is probably turning a tidy profit, and their main motive in raising the turbines was likely financial. The new analysis presented here makes possible a much finer slicing of the development community. I was able to identify nine unique types of developer that are prevalent in the data, from small household turbines, to farmer mills, all the way up to utility megaprojects. A detailed description of the new typology created for the present study, and the manner in which they were coded is provided in Appendix A.

The quantitative data on turbine ownership compiled here supports the hypothesis that community-based, and especially cooperative, windmill ownership has been on the decline in Denmark, as more corporate development models are ascendent. (see Figure 6.3) But it is also clear that the Danish wind network has long been, and remains, diverse, and different models have become more and less prominent during different time periods. In recent years, development styles have also hybridized, as the takeover of the wind network by outside investors provoked a backlash in many Danish communities, making municipal approval of new wind farms almost impossible without at least some local involvement in the project. Coupled with the growing size of wind arrays—which today frequently range from a half dozen to a dozen turbines—this trend led to the rise of mixed developments in the 2000s. It is now common for one or more turbines in an array to be registered to the local resident(s) who own the land on which the turbines are erected, while the majority of the capital is supplied by a professional development firm or a small group of wealthy investors. Additionally, 20% of the shares in each new turbine development must be reserved for residents of the local municipality, as required by a change to Danish law in an effort to preserve some semblance of the old cooperative model, and to mitigate local opposition to wind projects. At many sites around Denmark, this measure has proved insufficient to dull local resistance, and the local shares are often woefully undersubscribed, returning control of the excess shares to the project developers.

Despite a rise in local resistance to onshore wind development, which first became prominent in the late 1990s, the overall growth of the Danish wind network over time has been steady, but somewhat uneven when viewed annually. The slowing of growth in onshore development has largely been compensated for with a growing number of large offshore wind farms, most of which were built after 2000. A range of specific factors, some of which have been discussed in preceding chapters, contributed to more tepid or rapid expansion in specific years. The stopping and starting of subsidy supports schemes has been one major contributor to rapid shifts in development, as discussed in Chapter 5, and as is clearly visible in the quantitative data.

Several trends are immediately apparent from examination of the data represented in Figure 6.3. While there is no scientific relation between the nine categories, they can be loosely grouped on a spectrum from left to right, from developers who favor small and medium-scale projects to those who favor larger projects, from those who favor distributed projects to those who favor centralized projects, from those that require more to those that require less direct community involvement. Although the categories do not always fit cleanly on such a spectrum, and specific projects in these categories may not always exhibit these characteristics, for the sake of trying to spot trends in the makeup of the network over time, the developer categories can be roughly sorted into more "community" based wind projects on the left, and more "corporate" projects on the right.

Although community-based projects—built by the likes of cooperatives and local individuals—are well-represented in most years, their relative influence on the shape of the wind network begins to decline as the weight of new developments shifts toward the "corporate" utility and private investor projects. Utility projects are almost nonexistent before 1990, and spiked sharply in 1990 and 1995. These spikes are somewhat misleading, because of the relatively small average capacities of community developments in those years, but they show the impact these types of companies can have on wind development with just a few large projects. A single offshore wind farm can add as much power to the grid as dozens or even hundreds of cooperative mills. These early spikes are also misleading in that they do not represent a sudden reversal of utility attitudes toward wind power. Rather, the spikes occurred in these years as the utility companies, still skeptical of the long-term viability of wind energy, rushed to fulfill government-mandated quotas for renewable sources in their electricity mix. The data suggests that utility companies truly began to assert their dominance over the wind sector after 2000, and interviews with executives at Denmark's largest utility, described in the preceding section, confirm that wind energy did not take on a central role in corporate strategy until after 2007.

A similarly misleading spike can be seen in household windmills in 2015. Almost 600 of these backyard machines were installed that year, driven by a government incentive program that paid highly attractive rates for the electricity produced by homeowners. The popularity of such projects was artificially inflated by this short-lived program, and the overall contribution of these tiny mills to the country's electricity mix is miniscule compared to the other types of turbine developments. The spike in household turbine purchases also waters down the average turbine size in 2015. When household mills are excluded from the data, a more accurate picture emerges of the exponential growth in turbine size.

Another interesting finding is that the total number of new turbines installed varies widely from year to year, peaking in 2000 with 756 new turbines erected, then cratering in 2005 down to 18 new windmills. (Figure 6.4) These shifts in the pace of new installations are largely responses to broader market conditions, and specifically to changes in government support for renewable energy development. A close examination of policy changes through the decades reveals that these spikes and dips are closely correlated to the introduction or expiration of incentives programs. For example, Danes elected a conservative government in 2002, which remained in power until 2011, and cut almost all support for wind energy development until 2009. The predictable consequence of this retreat in government policy was that very little new wind capacity came online during this period. When the subsidies were reinstated in 2009, the wind business picked back up where it left off on its exponential growth curve.

It is also possible to find clear examples in the data of how, as wind farms have become larger, mixed development styles have become more common within single projects. Gorroño-Albizu et al., for example, note the emergence in recent decades of an innovative model of investing a large ownership stake in a community-based foundation, pioneered on the island of Aerø, which has since spread to other high-visibility projects like Hvide Sande in Ringkøbing. The popularity of these projects is leading more municipal officials ask developers for similar arrangements, as I detailed in Chapter 5. These kinds of examples demonstrate "the capability of adaptation and reinvention of citizen ownership." (Gorroño-Albizu et al. 2019, 7).

Adaptation, in the ecological sense, is exactly the right word for what is going on here. Network actors are constantly responding to changing conditions and new challenges in the energy system, and they are not making those adjustments in isolation from one another. Wind developers are embedded in webs of relationships, and as their strategies and activities change, they exert push and pull forces within the network, altering and reconfiguring those relationships. Over time, new patterns of development, new species of developer, emerge from this tumult. While the metaphor is far from an exact fit, the evolutionary processes at work in these technological systems are analogous to mechanisms of speciation in natural systems. Hybridization is not an unusual mutation—technological systems do not evolve only in response to extreme shocks, in punctuated bursts of activity—but the default state of the system when observed through time. One of the major lessons of this study is that technological systems never stop evolving. They don't settle down, "lock-in," to some mature, permanent, stable, final form.

I will briefly mention three additional hybrid forms of wind development that have appeared at later stages of Denmark's energy transition, two that have had mixed success, and one that offers some promise for the future. When private developers began to enter the market in the 1990s, they were often forced to deed over one turbine in the planned park to each landowner on whose property the turbines would be erected, usually a local farmer. Depending on the size of park, there might be multiple landowners involved, and sometimes developers would also have to sell one of the turbines to the immediate neighbors, to buy their support for the project. Developers obviously do not want to give away their profit margins, so the less of a project they get to keep for themselves, the less motivated they are to pursue it, and the more likely they are to try to build larger wind farms, to make up for those lost returns. The other significant slice taken out of the developer's margins is the requirement to make 20% of the shares available to the public. Crucially, this requirement does not apply to large offshore farms funded through government tenders. In a five-turbine onshore array, it is common to see a local cooperative owning one of the five turbines. But developers have an incentive to minimize these percentages they hand over to local residents—whatever they don't sell of that 20% they get to keep for themselves—and numerous sources I spoke to claimed that many private investment firms used a variety of tricks to try to discourage locals from purchasing shares, such as failing to advertise the sale properly, or making the share price unattractive by inflating project development costs. Whatever machinations are happening behind the scenes, it is an uncontested fact that the cooperative shares in wind projects are frequently undersold.

The other result of that is now readily apparent, as Denmark has several decades of experience with both of these models, is that neither of these hybrids of investor-owned and community-based development is doing much to quell the surge of public opposition to onshore development. Asbjorn Bjerre, longtime director of the Wind Turbine Owner's Association, said that the requirement for selling shares in private parks—intended as a means of involving local communities in wind development—was not enough to quiet local opposition to new onshore installations. The problem, he said, was that many residents moving to rural areas today go there seeking peace and quiet, and do not want to see industrial machinery in their backyard. (54) This new understanding of the countryside as a natural refuge makes locals less inclined to view wind development as a means of meeting a community need, like the farmers and cooperatives of past generations. When I asked Ida Auken if any of the national policies aimed at combatting local opposition to wind development were having an effect, she said, "clearly not yet." Auken thought more planning of wind sites should be facilitated at the national, rather than the municipal level, as a means of stopping a few discontented neighbors from blocking otherwise attractive sites for generating wind energy. (55) Mayor Carston Kissmeyer of Ikast-Brande Kommune felt the same way. (56)

More collaborative approaches to ownership may have success where these other schemes for gaining local support have largely failed, according to Erik Christensen, a co-founder of one of the most visible and popular wind farms in the world, which is also Denmark's largest and most successful offshore wind cooperative, and was built as an innovative hybrid of public and utility ownership. Christensen organized the offshore cooperative with six other Copenhageners, none of whom had any experience in the wind industry at the time. Their startup capital was 50 kroner each, barely enough money to buy a cup of coffee in Copenhagen today. The board members, most of whom are still involved in the project today, collect no fees, and are thanked for their service with a case of wine at Christmas. (57)

From those humble beginnings, the group successfully raised 20 Bonus turbines rated at 2 MW capacity each at Middelgrunden, a shallow shoal in the center of the Øresund strait that separates Copenhagen from Malmo, Sweden. At the time, it was the largest offshore wind park in the world, and it is still operating today. The wind farm is widely admired, both inside Copenhagen and around the world, and has become symbol of the city, printed on everything from tourist brochures to government policy documents.

Christensen explained that the project arose out of anti-nuclear sentiment—the wind farm faces nuclear power plant across the strait in Sweden that Danes have frequently protested—and the city's cooperative housing movement. "We wanted to have a landmark, in front of Copenhagen towards Sweden," he said. "We wanted to show citizens that they can be part of a renewable project." Wind farms were being built mostly in the countryside, and the organizers of the cooperative wanted to make a demonstration that city dwellers could take an active role in the energy transition as well. (58)

The group's initial meetings with the local utility company did not go well. "They said immediately, you are silly, this will never happen," Christensen said. The managing director told them "this will be over my dead body." But they found a more receptive audiences at city hall, and in the Folketing. Svend Auken was enthusiastic about the project. When the mayor's office brokered a second meeting between the cooperative and the utility and company, and made clear that political leaders supported the development, the utility managers quickly changed their tune. (59)

When the project was publicly announced, there was little public opposition, even though the plans called for raising the hulking turbines within the viewshed of well-off coastal neighborhoods, and directly in front of the city's most popular public beach, Amager Strandpark (Figure 6.1). The public popularity of the proposal can partly be attributed to a savvy public relations campaign organized by the cooperative. Copenhagen newspapers gave the project regular, and favorable coverage. Famous actors who were known environmentalists were enlisted as spokespeople. Sigurd Barrett, a puppeteer and musician who hosted a popular children's television show, wrote a song for the windmills. The board members made personal outreach efforts to the few opponents, including a nearby yacht club and a local historic preservation society, even changing the project design to win support. Christensen said that the original plan for the park had called for 3 rows totaling 27 wind turbines, which he admitted would have looked "awful" from shore, but offered the best economic returns. But the organizers drew up a Plan B, a single arc of just 20 turbines, following the line of fortresses built along the harbor to defend against invading Swedes. When Christensen presented this Plan B to the historic preservation society, they acquiesced. This compromise was typical of Danish politics, Christensen said. It typically does not pay to be unyielding and force through a pre-planned vision; project developers have to be willing to adjust and accommodate the views of others. "You have to negotiate and listen, and change your ideas," he said. In this case, that willingness to shift strategies in response to aesthetic concerns raised by local residents proved fortuitous, as the array's elegant design is surely part of its appeal. (60)

The charm offensive worked, and 40,000 Copenhageners paid the 50 kroner to join the cooperative and reserve the right to purchase shares, with more than 8,500 ultimately buying stakes of varying sizes. Peter and Jeanette Malinsky, who live within walking distance of Amager beach, are two of those shareholders. The seven shares they own today had initially been purchased at the urging of Jeanette's ex-husband, who was an engineer and was fascinated with the potential of wind energy. The young couple was not making much money—he was a student and she was a nurse, and had to scrimp and save to come up with the DKK 4,250 per share. "We felt we had a responsibility to think about the earth," Jeanette Malinsky said. "If you just sat on your hands, nobody would develop new ideas." She said she was proud of her role in creating the wind park, even if it hadn't been a particularly profitable financial investment. Annual dividends had averaged between DKK 600-1,000 per year, she estimated, and in recent years, and electricity prices plummeted, more like DKK 300-400. But they clearly see their ownership stake as having a symbolic value beyond the monetary returns. Both Peter and Jeanette said they thought the turbines were beautiful, and loved to look at them when they visited the beach. They always pointed out the wind park to their children when crossing the Øresund bridge on trips to visit family on Bornholm. "Look at the tip of one of the mills—that's yours," they would joke. When we spoke in summer 2022, they were planning to join the annual boat tour out to the wind park offered to shareholders. It would be their first time visiting the turbines they partly owned. (61)

Most shareholders, like the Malinskys, have little direct participation in the day-to-day management of the wind park. According to board member Hans Christian Sørensen, they used to get 300-400 people at their annual assembly, but in recent years attendance had dropped to only about 80. As the turbines have aged, concerns have grown among both shareholders and managers about the project's financial outlook, and plans are actively being made for the future. Sørensen said that the wind resource at the site was "just okay," and in 2016 that production had only been about 85% of what they had projected. Wholesale electricity prices on the NORD Pool market were hovering right around their break-even point, making future operation precarious. The cooperative management had been cutting back on dividend payments and banking funds to prepare for the eventuality of repairs or decommissioning and had about $1 million USD saved. (62) But plans are currently moving forward to repower the park, placing new turbines on the existing towers and platforms, which would be another first—the first repowering of an offshore wind park in the world. That opportunity for a demonstration project, Christensen said, made keeping Middelgrunden in service for another generation more attractive to their utility partners. (63)

Middelgrunden was built as a partnership between citizens and the municipality, in which the cooperative owns 10 of the turbines. The other 10 were purchased by Copenhagen's utility company, which later merged with DONG (now Ørsted), which recently sold its stake back to the new municipal utility company, HOFOR. The two major partners in the project have historically worked well together, though a long-running sticking point for the cooperative was DONG's lack of transparency. Even though their turbines are directly adjacent to one another in the same array, and all of the cooperative's data is published publicly on their website, DONG refused to share the production data from their own turbines with the cooperative board, citing business confidentiality. Otherwise, "It has been very good cooperation," Christensen said. "We are helping each other. It's not a barrier to work with a utility like this." He said a DONG manager had recently called to ask if the cooperative could lend them one of their spare parts, and the cooperative managers happily agreed. (64)

Christensen portrayed the partnership as mutually beneficial, saying he didn't think a company like DONG could complete a nearshore project so close to an urban center on their own, and needed the political cover the cooperative provided. The companies, on the hand, were politically powerful and carried sway with policymakers. He explained how a follow-up project he had helped organize in the suburb of Hvidovre, on a similar model to Middelgrunden, enjoyed a swift approval process, because DONG had a good relationship with municipal officials. So the utility company brought financial resources and political influence to the table, while the cooperative worked to build support among local residents. Christensen said he would "certainly" recommend other cooperatives around Europe pursue this joint development model. (65)

6.5 Conclusion: The Outlook for Democracy in the Energy Transition

Although Middelgrunden has arguably been one of the most successful wind projects in Denmark's history, relatively few other developments have tried to copy its hybrid model of shared citizen and corporate ownership. The general trend is one of declining public participation in the wind sector. After driving the energy transition in the 1980s and remaining major players on the development scene in the 1990s, community-based development models tailed off dramatically after 2000. The number of turbines raised annually by cooperatives ranged from 66 to 92 from 1985-1991, and peaked at 155 in 2000. After 2002, no more than 15 cooperative mills have been raised in any given year. Similarly, the construction of turbines by local individuals on or near their own property was one of the primary developments models in the 1980s and became the dominant one in the late 1990s, also peak in 2000 with 324 new turbines installed. But this style of development has been even more sharply curtailed as onshore development sputtered in the 2010s, reaching a low in 2014 and 2015 of only about 1% of the activity at its peak (see Figure 6.7). The small household mills that had been the first on the market in the early 1980s also became less common as commercial turbine models grew in capacity by orders of magnitude, before seeing a rush of new installations in 2015. This burst of interest in tiny turbines that contribute negligible amounts of electricity to the grid is evidence of the ability of policymakers to shape the character of technological development with the specific policy mechanisms they adopt, as well as of the continued appetite for citizen participation in the wind network. Why did that role for the public in the wind sector begin to disappear after 2000? And what consequences is this change in the composition of the renewable ecosystem having on the progress and politics of Denmark's energy transition?

From the point of view of the business literature, this evolution is not a cause for concern, but a sign the industry has matured and the energy transition is gathering steam. But that was a minority view among the players I interviewed in the Danish wind network; most expressed a sense of loss. When I asked Social Democrat Ida Auken if the public had enough of a role in the energy transition today, she replied:

> No. I don't think they do. One thing is we still have not found out how to get people shares of the renewables on land, how do they feel ownership, how do they feel this is not just a big energy company coming in and running over the local community. How do they feel that we benefit from this, the municipalities benefit, the community benefits. How can they take responsibility in getting these wind turbines up, or these solar panels. For sure that's not solved.

Those themes of local responsibility and community benefits are echoed by many sustainability activists in Denmark, who feel these characteristics of early wind development were key factors in both moving the transition forward, and ensuring that it was carried out in a manner consistent with the country's democratic values.

It is clear a majority of her colleagues in parliament share Auken's views on this subject, as the Folketing has made several explicit attempts to stimulate more local involvement in energy development through policy in recent decades, albeit clumsily. The first such effort was the introduction of the requirement that 20% of shares in onshore developments be reserved for local residents. I discussed above how this policy has often not worked out as intended, and appears to have been ineffective at reducing local opposition in many cases. More recently, parliament has passed generous subsidies for small household turbines and rooftop solar panels. Both programs were so heavily subscribed that they resulted in huge spikes in installations, at significant costs for state budgets. The utilities, as I described earlier in the chapter, are not thrilled about connecting all of this distributed generation without being compensated for maintaining the grid. The small wind turbines are widely disliked by both public officials and residents who have to look at them and hear them on their neighbors' properties. The uptick in solar installations in Denmark has been a more recent, and more welcome, development, though in general planners and grid managers discount the value of these small distributed projects for meeting renewable energy targets, and prefer to make progress in big chunks. It is, from both a planning and an operations point of view, easier to manage a few megaprojects than thousands of personal power plants.

In thinking about technological development as a form of political development, these trends are noteworthy, to some worrying, because wind energy pioneers were actively trying to build something radically new, envisioning a truly alternative energy system. The developments of the last two decades represent something of a retrenchment, and a return to the old model of centralized power production and distribution. The renewable electricity system of the future could end up looking a lot like the coal-fired system of the past, minus the planet-warming emissions. That outcome may be sufficient, even desirable in some ways, if achieving carbon neutrality is all system builders care about, but it is clearly not the only thing that motivates participants in the Danish wind network. If wind development is seen as an opportunity to pursue a broader political and sociotechnical transformation, it could be said the energy transition is losing steam.

This dissertation set out with two primary objectives: First, to understand the processes by which renewable energy transitions progress, in the hopes of gaining insights into how to encourage the expansion of sustainable technologies and move beyond the Age of Oil. Second, I have emphasized the political dimensions of energy transitions, and asked what can be accomplished politically by building a wind turbine? Political theorists have long been skeptical that technological development holds much democratic potential, and have more often feared that industrialization was in direct conflict with democratic values and practices. I have worked throughout this dissertation to try to dismantle that fear of technology as an autonomous, dominating force. I believe the Danish case clearly demonstrates the substantial potential of technological development as a means of political development.

Some critics might dismiss Denmark as an odd, tiny country, a bit player in the global energy system and the fight to slow climate change, making the single-country case study presented here an outlier, the experiences described not easily replicable elsewhere. The flipside of that argument is that the Danish case is uniquely interesting and worthy of attention precisely because it is an outlier; the academic literature universally agrees that it is a case of singular significance for the study of energy transitions. The Danes have traveled farther along the path to sustainability over a longer period of time than any other industrialized nation; they have experimented with a wide range of policies and technological development styles; the outcomes of those efforts have been uneven both geographically and for individual wind projects. All of that makes for an exceptionally rich case, with huge amounts of internal variation across space and time that scholars can probe for patterns and insights. Surprisingly, while an enormous amount has been written about Denmark's experiences with wind power, few scholars have made the effort to present a detailed history of those experiences. The more typical approach has been to briefly consider the Danish case as part of a larger comparative analysis of several countries, and such studies have frequently relied on secondary sources to construct their narratives. The Danes themselves, unsurprisingly, have followed domestic developments intently since the beginning, and have built an impressive scholarly literature documenting the energy transition, much of which is cited in the bibliography and throughout this dissertation. I have frequently credited the planning department at Aalborg University and the Wind and Energy Systems department at the Technical University of Denmark (DTU-Risø) as leading centers of academic expertise on the subject. Scholars like Matthias Heymann and Kristian Hvidtfelt Nielsen at Aarhus University, David Nye at the University of Southern Denmark, and Peter Karnøe at Copenhagen Business School are also among the leading social scientists studying renewable technology transitions. Journalist Ib Konrad Jensen and wind power pioneer Preben Maegaard have published granular accounts of the early decades of the energy transition, though the former is available only in Danish and the latter relies mostly on first-person narratives. All of these Danish authors have been consulted directly and assisted in the preparation of this dissertation; sadly, little of their work has been widely read outside Europe. All of it is worth reading. Yet none of these authors has attempted to write a comprehensive history of the Danish wind energy system. Documenting those historical developments in detail has been a major occupation of the present study, resulting in the most complete, most fine-grained, and most up-to-date history of the case yet assembled.

While that new empirical data should be valuable to students of energy transitions in its own right, this approach has also been crucial to my project's broader scholarly ambitions. The dissertation has attempted to sketch and model a relatively new strategy for social science explanation—political ecology. While ecology is now a buzzword in social science research on the environment and climate policy, as I discussed in detail in Chapter 2, it has been largely ignored in the discipline of political science, and most of the existing literature in related fields demonstrates only a grazing engagement with theories and concepts derived from ecological science. I consider my present attempt at a deeper consideration of what ecology has to offer the social sciences to be still only a first rough and incomplete effort, and hope only to inspire others to think about the potential for further research in this vein. For myself, I expect to continue refining the initial ideas presented here for years to come. I am convinced that as humans grapple with increasingly complex challenges, like global climate change, the perspectives and tools of ecology will become increasingly more relevant, and helpful, than the traditional techniques of positivist social science.

Political ecological frameworks are a particularly good fit for analyses of technological change, given the inherent complexity and materiality of sociotechnical systems. I have adopted a broadly ecological conception throughout this dissertation of what constitutes an explanation, and how to go about building one. Some of those choices will seem unusual, even wrongheaded, from the perspective of mainstream social science methods. Giving an ecological account requires abandoning the linear and reductionist explanatory strategies popular in political science. Rather than dissecting and isolating variables, it favors integration, emphasizes interactions, and focuses on relationships. Individual actors are no longer seen as the drivers of history, but as components of multi-dimensional and multilayered systems. Understanding how these systems are structured and function in practice requires attending to and traversing these different layers of analysis. Longitudinal studies that describe the dynamics of developmental processes are preferred to snapshots of specific outcomes or moments in time. These complex and continuous processes are not easily inscribed into typologies, matrices, or elevator pitches. The evolution of social, technological, and natural systems is continuous, and to the extent the micro-level processes can be organized into series or stages, it is only loosely and approximately so. The drawing of boundaries and the selection of beginning or ending points is unavoidably artificial. I have specifically characterized energy transitions as gradual, long-term, stochastic processes, which is a departure from the punctuated equilibrium and “lock-in” theories popular in the social science literature on innovation, and in the public policy theories discussed in Chapter 5.

One of the benefits of employing ecological tools to examine and explain the course of wind development in Denmark is that it provides fresh perspective on what it means to characterize the energy transition as a success. The close-to-the-ground historical analysis conducted in the preceding chapters reveals wide variation in the achievements and prospects of differing models of development. Tvindkraft keeps churning out watts, but the group’s broader political vision has not spread, though their vision of “letting 100 windmills bloom” has far exceeded what most at the time expected. As it happened, it ended up being thousands and thousands of windmills.

Approximately a thousand patents later, Henrik Stiesdal is still pushing the wind sector in new directions, designing cutting-edge offshore systems that will convert power to hydrogen. On Samsø, Søren Hermansen sounds ready to pass the torch to the next generation, but farmer Jørgen Tranberg doesn’t have to shed any tears over the loss of his wind turbine just yet. The local cooperatives that have been so crucial throughout Denmark’s history with wind energy, and represent one of the more distinctive forms development has taken there, are exiting the wind sector, and moving into other energy technologies. Some of the largest and most well-capitalized private enterprises in Denmark have wrestled control of the wind business from these earlier entrants, and demonstrated the capacity to construct wind farms at breathtaking scale in the cold and deep waters of the North Sea, yet their CEOs still fret continuously about whether and what sorts of development will be financially feasible in the future. All of this constant activity leads to the conclusion that energy systems do not settle into stable equilibria as they mature. If anything, as the data in Figure 6.5 suggests, the pace of wind development in Denmark is becoming more unstable over time. As any energy transition progresses, old forms pass away and new forms emerge; the appearance of hybrids opens innovative pathways for future growth.

Academics have often attributed the success of Denmark's experiments with wind power to a stable policy environment, but the historical record detailed in this dissertation does not provide strong evidence for that claim. Government support for wind energy has repeatedly been described as following a "stop-and-go" pattern, with regular revisions to policies that during some periods have kicked development into overdrive, and during others have dragged it to a halt. The most consistent, and arguably the most important, state investments in supporting the energy transition have been some of the less visible ones, notably the modernization and expansion of the electric grid discussed in section 6.2.

But even if subsidies for wind power have not been consistent in Denmark, the renewable energy network has been unusually stable, compared to other countries, in another, more ecological, respect. As I discussed in Chapter 4, the Danish wind system has historically exhibited, especially in its early decades, a strikingly high density, level of interconnection among network actors, and depth of embeddedness in the local contexts of development. Multiple components and dimensions of the wind energy system overlap and combine in mostly symbiotic ways. This structural configuration has allowed wind development to proceed steadily, and to soldier through setbacks. The resilience of Danish wind energy recommends transition strategies that promote collaboration and sensitivity to the contexts of development. That same degree of integration has not been observed in other countries like the United States, where the hundreds of turbines raised in California in the 1980s have been left to rot in the desert. The tight coupling of the Danish wind community has buffered it from the forces of external shocks like the bursting of the California bubble, the turbine failures of the late 1980s and 1990s, and an unfriendly government in the early 2000s. Companies like Vestas have gone through multiple bankruptcies, but keep coming back. The pace of development hits peaks and valleys, but the accumulated growth inches closer to the government's goals. Individual projects and technological styles come and go, but the network endures.

These observations are just a few of the ways in which an ecological perspective can support political analysis. But I am neither an engineer nor an ecologist, so I will need help, and my own contribution is admittedly only partial, to this larger task of monitoring and managing systemic sociotechnical transitions. As a political scientist, my expertise is in political systems, institutions, actors, and processes. I have been particularly concerned in this dissertation with questions of how democracy influences energy transitions, and whether and how such transitions can yield democratic dividends. In closing, I will attempt to summarize a few key lessons that emerge from the preceding study about the relationship between democracy and renewable energy development.

One of the distinctive elements of the Danish energy transition that makes it such an appealing case for asking these types of political questions is how directly involved the Danish people have been—and not just the state, not just elites, not just technical experts—in the hands-on organization and development of the wind energy system. Political scientists would not traditionally think of raising a windmill as a significant form of political activity. I have tried to argue in this dissertation that it most certainly is. In the preceding chapter I have described how the instrumental role of the Danish people in the energy transition has been slowly declining in recent decades. The direct participation of the public in technology development has had myriad political consequences for Denmark's energy transition and for the broader culture. I will briefly discuss seven of those impacts for which I have found evidence in my historical analysis: Democratic engagement in technology development can 1) catalyze sociotechnical and policy changes, 2) build citizen capacities 3) build organizational capacity, create constituencies and interest coalitions, 4) gain influence in institutional politics, alter the policy agenda and political calculations of officials, 5) change the political culture and the public discourse around renewables, 6) inculcate sustainability values in the populace, and 7) limit and counter opposition to energy development.

I have already noted several times previously that the simple fact of the existence of a mature wind energy system in Denmark is an achievement of note; indeed, it is the premise that launched this investigation. No other country has so quickly and effectively decreased its reliance on fossil fuels. As the empirical analysis throughout this dissertation makes clear, lay actors fulfilled numerous functions at many critical moments in the formation of the wind network, and the progress that has been made toward building a carbon neutral energy system likely could not have been achieved without their input. Community wind enthusiasts engineered the first turbines, made the first connections to the grid, and pushed for government support in parliament. There are, of course, many distinctive features of the Danish environment that made it conducive to early wind development, including its geography and climate, and the absence of a large domestic fossil fuel industry. But one of the most unique characteristics of Denmark's energy transition, compared to other countries, has been the high degree of direct citizen participation in developing, owning and operating wind parks.

Many participants in the Danish wind system view grassroots energy development as a form of democratic capacity building, empowering individuals by teaching them new technical skills and organizational skills, and further extending their political capabilities by uniting them into collectives with their fellow citizens. When I talked to Søren Hermansen about what wind development had accomplished politically on Samsø, he repeatedly returned to the idea that it had instilled in local citizens a sense of responsibility for the welfare of the community, and a sense that they could control their own destiny. Those are deeply democratic ideals. Hermansen said he felt the people were being reduced to customers, rather than owners, of the electricity system. As a mere customer, you can point fingers and complain when a system doesn't work well, but you feel powerless to do anything to change it. Numerous community wind developers I interviewed described becoming more politically conscious and active as a result of their participation in a wind project.

This democratic capacity-building is probably even more important on a collective level than an individual one. The history presented in this dissertation detailed precisely how and where those organizations arose, and how their interests and alliances evolved over time. The grassroots wind community sprouted manner of formal organizations and informal groups and even entire new industries, from the owner's association and the industry association, to the Folkecenter and Samsø Energy Academy, to name just a few examples. All of that organizing strengthened what Søren Hermansen called the "democratic muscle" of those communities, extending their reach and their effectiveness. Many of the nongovernmental organizations and grassroots collectives introduced in the preceding chapters were instrumental in building and sustaining the wind energy network, and spurring Denmark's broader energy transition. A wind project turned out to be a good concrete site around which to organize people, resources and action.

That organizational capacity can also be translated into formal political influence in policy debates and institutional processes, from the local to the international levels. The Samsø Energy Academy is a good example of this effect. Hermansen's work leading the Renewable Energy Island program made him a trusted voice on Samsø, and the Academy has become a central node in the local political community. Hermansen gets regular invites to speak in national policy forums, and lawmakers take his phone calls and listen to his ideas. He travels internationally to speak about the Samsø experience with renewable energy, and advise other communities on how to follow in their footsteps. International visitors flock to the island to see the technologies up close. None of this would have happened if Hermansen had never helped any wind turbines.

And as cases like Samsø, Brande, Ringkøbing, and Esbjerg demonstrate, embracing a technological transition can deliver real material benefits to local communities, especially to those that act early and maintain consistent support both within local institutions and the community-at-large. If politics is conceived as a distributional struggle over who gets what, where, when and how, then one lesson for energy transitions is that those with the most skin in the game are often able to claim an outsize share of the distributional goods of system change.

Public participation in an energy transition also creates positive externalities for society at large. Danes are known around Europe and the world as some of the loudest agitators for climate action, and as one of the societies most committed to leading by example. Domestically, there remains widespread support for renewable energy development, even as resistance has grown at the local level. The culture's embrace of the green transition has been traced, in numerous instances cited in this dissertation, directly to the highly-visible spread of windmills around the country beginning in the 1980s. Today, wind turbines are bearers of all kinds of cultural significations for Danes—they invoke memories of friends and neighbors and family members, they mean jobs and income, they are avatars of modernization and progress, and a point of national pride. When a wind turbine becomes attached to all of these other values and concerns, environmental sustainability no longer feels like such an abstract agenda, divorced from the immediacies of daily life.

Wind development has had an even more direct impact on the social and ecological visions of those who participate directly. Many of the turbine owners I interviewed claimed that their involvement in energy production had made them personally more conscious of both their energy consumption and their social and natural environments. One homeowner on the outskirts of Aarhus who has a small windmill in his backyard said his family actively listens for the sound of the turbine running, partly to detect any unusual noise that might signal the need for maintenance, but also to schedule household chores like running the dishwasher or the washing machine around the weather. (68) Malene Lundén of the Samsø Energy Academy spoke about how her participation in the Renewable Energy Island project made her think more about her own role in sustaining her community on the island, and not just her fellow humans. She said she started to pay attention to the seabirds more than she had in the past. (69) One of the major puzzles with which the literature on ecological democracy surveyed in Chapter 2 has been concerned is how to instill environmental values in political cultures and institutions. The evidence from Denmark suggests building a wind turbine might not be a bad way to work toward that goal.

The chief obstacle to the continued growth of wind energy in Denmark today is not climate denialism, or entrenched interests, but grassroots resistance to new onshore development. For decades, Denmark had been an exceptional case for largely avoiding this plague on wind development around the world. But lately, getting local approval for an onshore wind park has become almost impossible in many parts of Denmark. The longitudinal analysis presented in this study sheds light on the timing of this dispiriting reversal in fortune. Historically, local community-led projects have enjoyed strong public support, and that remains true in places like Ringkøbing today. The evidence of the relative absence of controversy around community wind projects is so widespread that it cannot be accidental. Public outcry over wind installations began to pick up at almost precisely the same time as community development models began to decline. The Middelgrunden offshore park is one of the more dramatic examples of the community effect on public tolerance for the impacts of wind development; built directly in the line of sight of some of the most valuable real estate in the country, it is the sort of wind installation that would be expected to be a magnet for controversy—large, close to shore, highly visible, colliding with the interests of powerful constituencies and creating conflicts for other users and uses of the site. And yet the wind farm is intensely popular. Both the managers and the shareholders expressed their doubts about the economic viability of the project going forward, but for now it is seemingly being kept afloat on its symbolic power alone.

An alternative way of looking at the slackening of public involvement in the wind sector is that as the industry has grown and matured, citizen-led efforts have moved on to new areas and fresh challenges. This was the perspective of both Erik Christensen and Søren Hermansen, neither of whom was too distraught about the senescence of the cooperative model of wind development. Today, Danish citizens have become increasingly active in both the solar and district heating sectors—two areas of the Danish energy system that are relatively underdeveloped compared to the progress that has been made with wind power. Even as it has gotten harder for citizens to participate directly in wind development, the desire to take action on behalf of the environment and democratic values remain strong in the Danish populace.

But Hermansen also felt that with the move away from community-based wind development models in recent decades, a larger project of social development was being sacrificed to the goal of meeting climate targets. "Sustainability is, in my eyes, also a social sustainability project," he said. "If you're not combining the two, and only looking at environmental sustainability, then you are only covering part of the process." Ignoring those social dynamics of technological transitions creates serious political peril. Denmark, like much of the Western world, suffers from a growing rural-urban divide. Hermansen felt the government's energy policies were exacerbating that divide, and that academics and politicians in Copenhagen didn't really understand how rural communities were suffering. They forget about the "NIMBY" opposition they are creating, which he likened to the "yellow vest" protest movement in France. (70) As a recommendation to policymakers, Hermansen proposed that if investments were going to be made in large energy islands operated by utility companies, matching investments should also be made in distributed, community-based generation to help balance the grid and ensure security of supply. In order to facilitate that local development, subsidy schemes would have to be differentiated by the type and location project, since small-scale distributed generators cannot easily compete on market terms with centralized power plants and deep-pocketed corporations. Community-based wind projects should be paid specialized rates in recognition of the unique contributions they make both to the grid, and to maintaining political support for the energy transition, a proposal that has also been endorsed by Gorroño-Albizu et al. (2019).

Hermansen is articulating a more ecological perspective on an energy transition, whereas the Danish government's current renewable energy policies are thoroughly reductionist, aiming to achieve the most efficient reduction of carbon emissions, with efficiency calculated in terms of gigawatts deployed versus dollars spent. These policies have placed the government in a risky situation, depending heavily on the relatively unproven technology of large-scale offshore wind to meet national targets. Recent setbacks in offshore development, along with widespread public opposition to onshore development and growing skepticism about wind turbines in general, imperil the progress that has made Denmark the runaway world leader in the transition to renewable energy, and in wind power, specifically.

The potentially self-sabotaging trajectory of current Danish energy policy calls to mind the "tunnel vision" James C. Scott thought was characteristic of the technocratic management style of highly-centralized modern states. Adopting an ecological perspective would encourage thinking about policymaking more holistically as a multidimensional challenge and ongoing process. One-dimensional metrics can yield highly-misleading conclusions about these multivariate problems, and lead to ill-advised strategies for encouraging the progress and maintaining the stability of transition processes. The safer approach for policymakers is to pursue systemic interventions that are attuned to local contexts (in the fullest socio-ecological understanding of that word), responsive, and adaptable. As Scott argues in *Seeing Like a State*, the technocratic vision can be extremely powerful, particularly with the level of standardization it can achieve and the scale at which it can act. But it can also be brittle, with large and potentially destructive blind spots.

I see evidence in the Danish experience with community wind development of the opposite sort of movement, what I like to think of as an "ecopower," in contrast to the narrow, mechanistic and instrumental logic usually associated with technology. This ecopower entails a widening rather than a narrowing of the scope of vision, and arises from connecting and complicating projects and problems, instead of isolating and simplifying them. It is a property of networks rather than individuals. It bubbles up from the grassroots, rather than filtering down to the masses. It is comfortable with uncertainty and attuned to context. The unfortunate legacy of modern theorists of power like Michel Foucault, and the rest of the critical theory tradition, for that matter, is that they colored contemporary social thought with an unhealthy fear that technology poses an ever-present threat of domination, through state surveillance and other disciplinary mechanisms of social control. The silver lining in this pessimistic portrait of modernity that often gets deemphasized is that Foucault argued political power could take many forms, of which the techniques of modern statecraft were only one recent innovation. In the final years of his life, Foucault started asking what other expressions of political power might emerge in the future. I propose that the ecopower visible in the history of Danish wind development is one of those modes of social action, and one that is substantially more compatible with democracy and environmental sustainability than the alternatives.

The secrets to the rise of wind power in Denmark over the past five decades, as this dissertation has documented in so many discrete instances, have often been creatively unusual, unlikely synergies, symbioses, and collaborations. Model wind developments like Middelgrunden were conceived in the holistic sense advocated above, and can be counted as successes in technical, economic, social and cultural terms. The Middlegrunden wind park also demonstrates the viability of pursuing energy development as a collaboration between citizens, governments, and corporate entities. Project organizer Erik Christensen attributed the effectiveness of the cooperation between those very different groups to the trust, openness and availability that is characteristic of Danish political culture. Where other countries treat politics as an obstacle to achieving sustainability goals, “in Denmark, we do it in another way,” he said. “We don’t consider politicians as enemies. We consider politicians as the instruments of citizens.” (71)

Current academic theories of energy transitions argue they should be understood as distributional conflicts over material resources, as opposed to the older model of collective action problems. It is hard to see much of that sort of interest group competition present in the case of Middelgrunden, or as a driving force in the broader story I have told about Denmark's energy transition. My claim is that energy transitions *are* collective action problems, just not in Mancur Olson's sense of finding ways to overcome incentives to free ride. Rather, the problem of collective action can be given a more ecological connotation, as something akin to what Bruno Latour meant by "convening the collective." (Latour 2004a) My favorite definition of politics, inspired by the likes of Latour, Hannah Arendt, and Jedediah Purdy, is "the art of building a common world." When citizens are empowered to actively share in this common work, they can be said to have established a democratic practice. The real lesson from Denmark is just how much work can get done by working together.

Figure 6.1. Middelgrunden offshore wind farm in 2022, viewed from the public beach at Amager Strandpark in central Copenhagen.

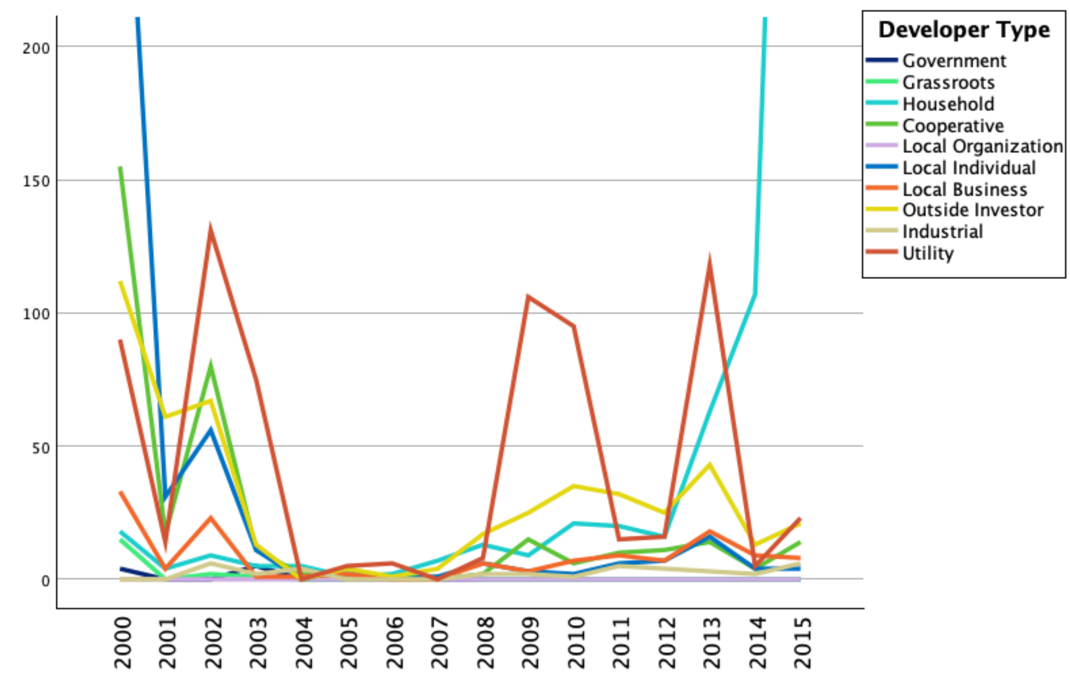

Figure 6.2. The number of new turbines installed annually, by type of developer, 2000-2015

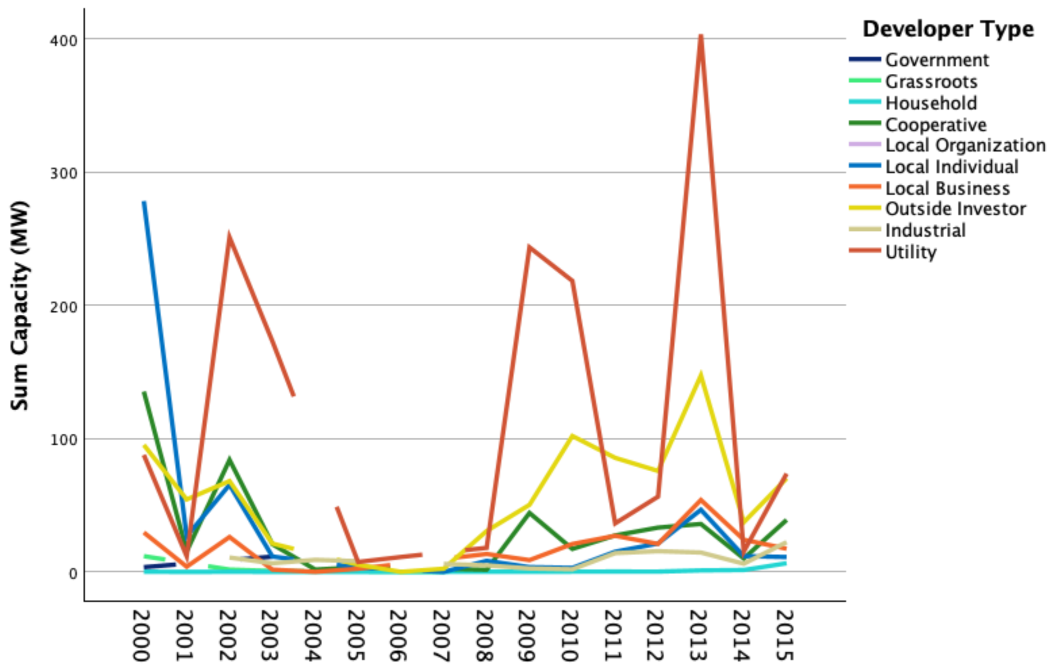

Figure 6.3. New installed capacity categorized by type of developer, 2000-2015

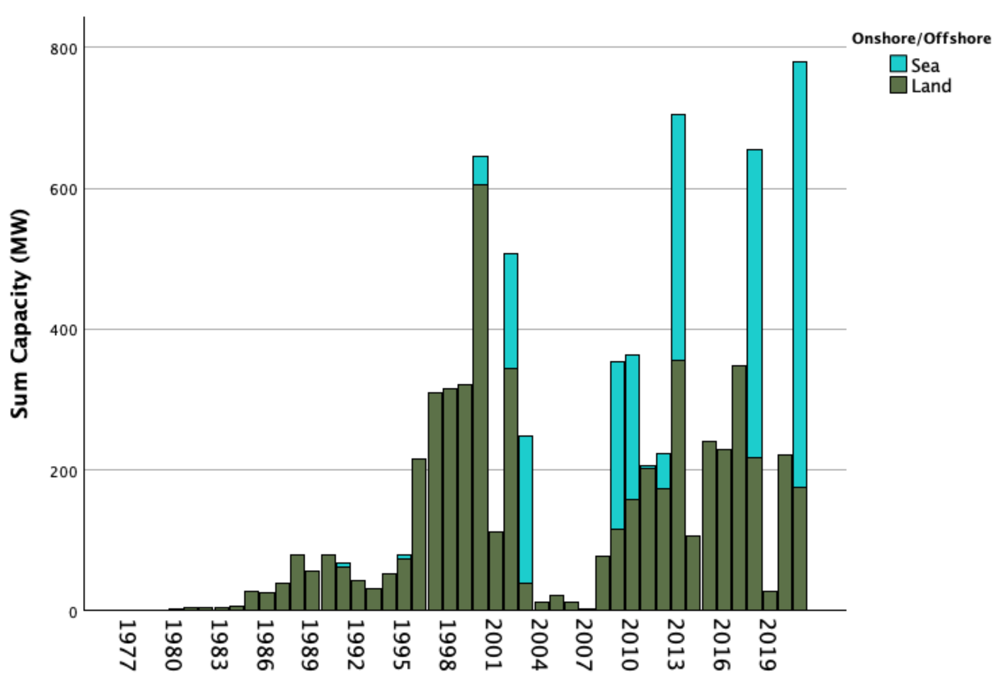

Figure 6.4. New installations grouped by whether the turbine was installed offshore or onshore, 1976-2021. The first two decades of development were almost exclusively onshore, but large bursts of sporadic offshore development begin appearing after 2000.

Figure 6.5. New installed capacity by year, 1976-2021

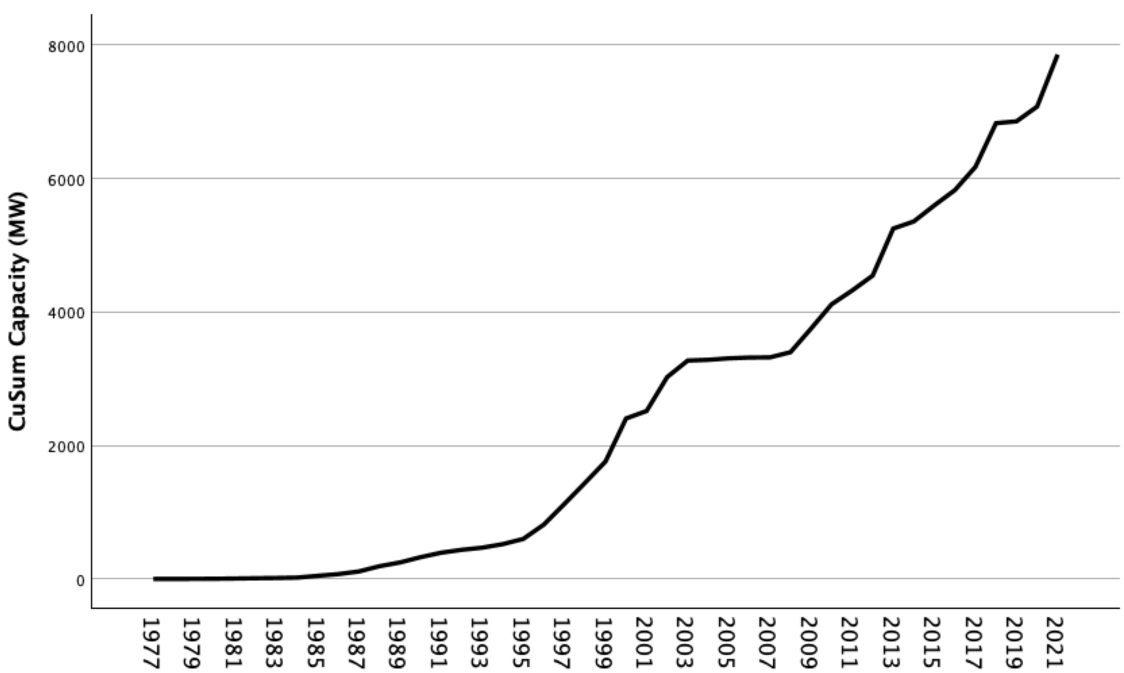

Figure 6.6. Cumulative installed wind energy capacity in Denmark, 1976-2021. Note the repeated pattern of periods of intense growth interrupted by lulls in growth that are becoming more frequent in recent decades.

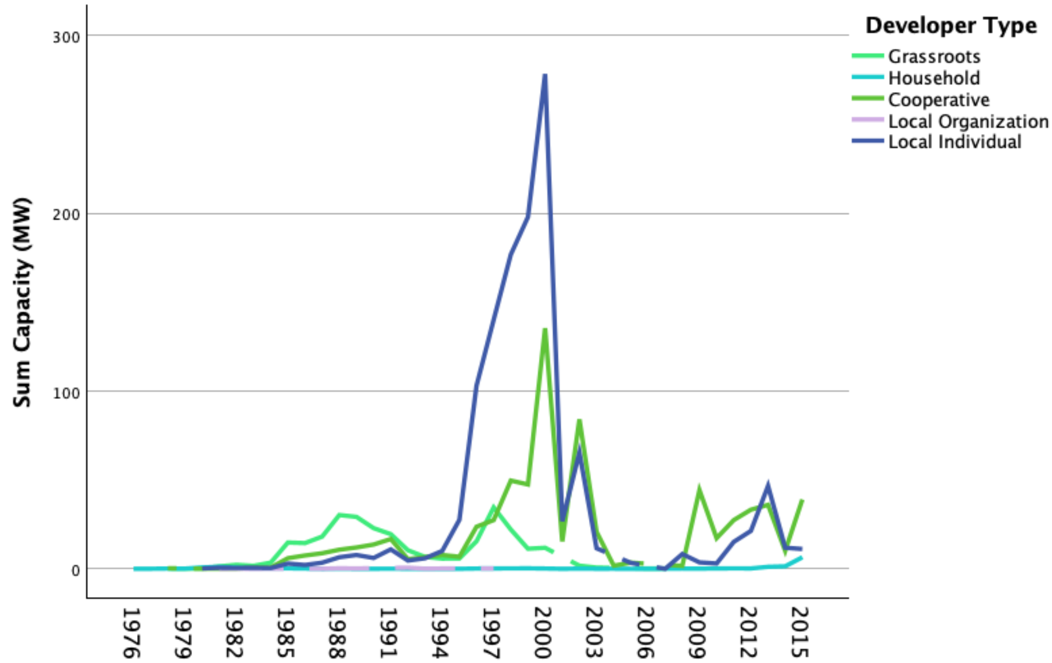

Figure 6.7. New community wind installations, 1976-2021

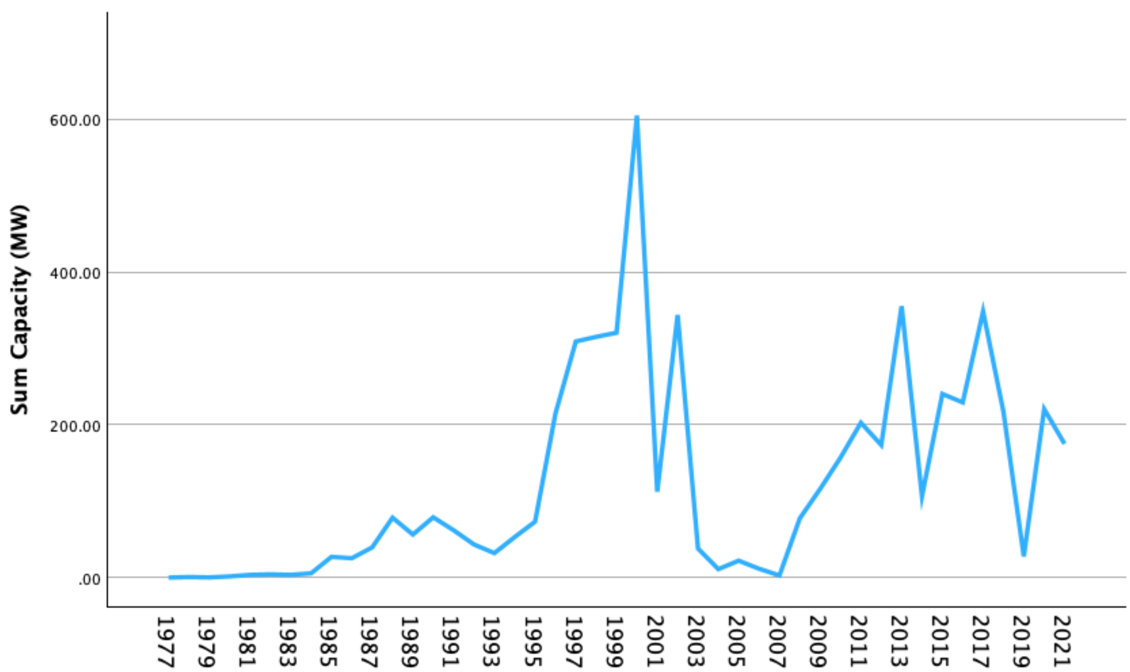

Figure 6.8. New onshore wind capacity installed in Denmark, 1976-2021

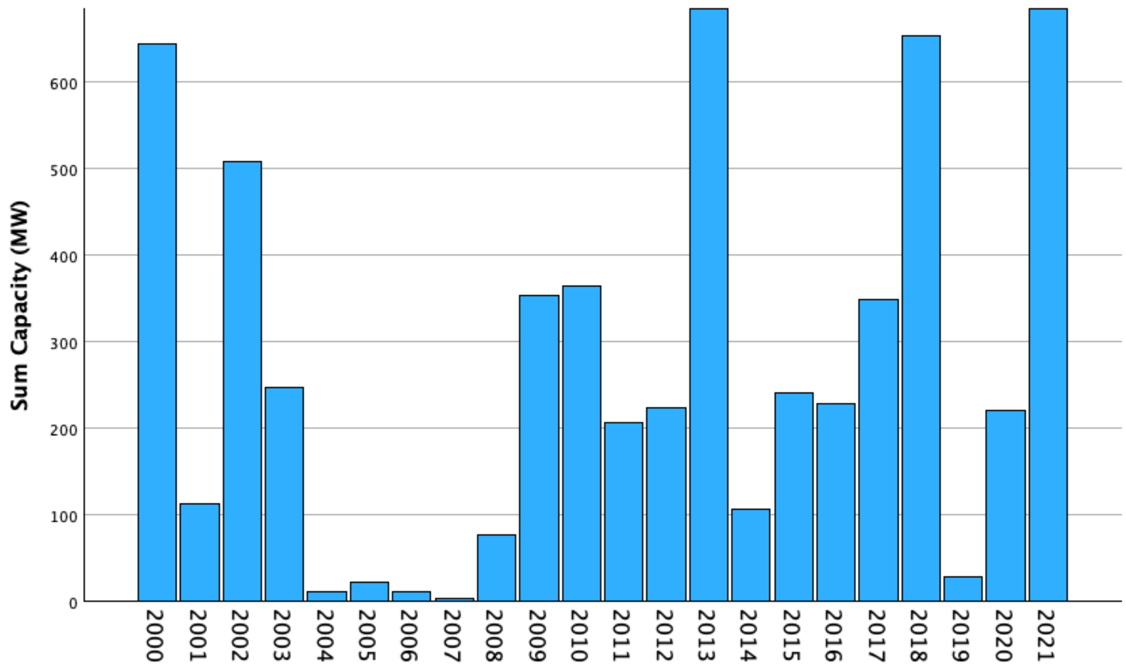

Figure 6.9. New capacity (MW) installed annually, 2000-2021.

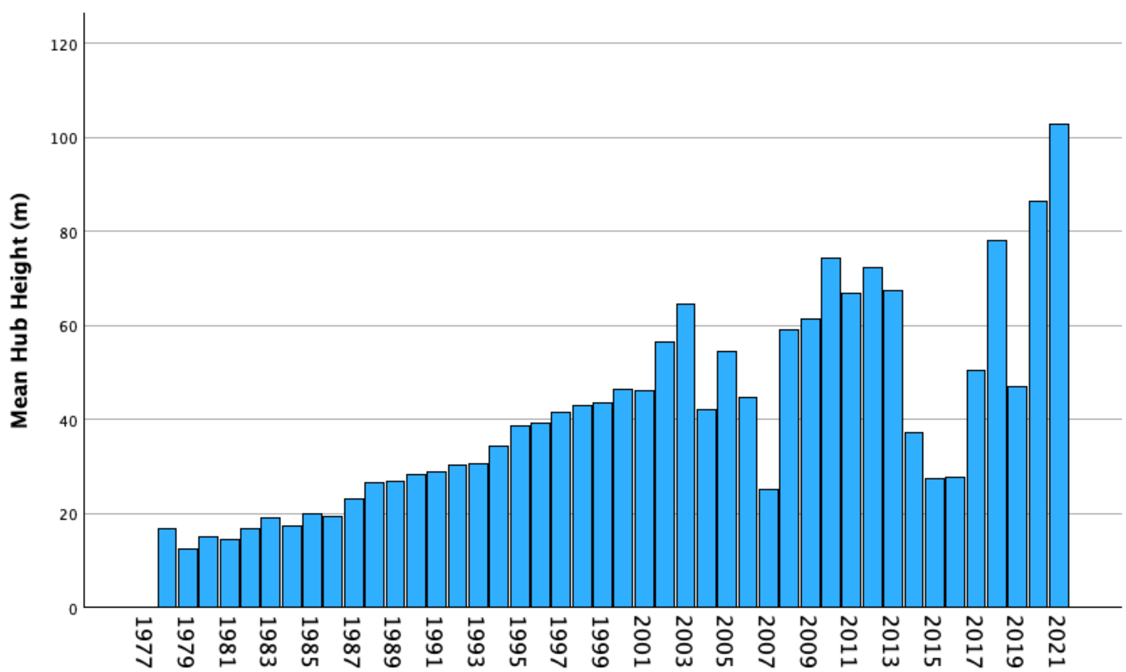

Figure 6.10. Average turbine hub height, 1976-2021.

Notes

1. The above account of the sale of Samsø's wind farms is adapted from personal communication with Søren Hermansen, over Zoom, from Ballen, Denmark, May 2022.

2. ibid.

3. ibid.

4. ibid.

5. ibid.

6. One notable exception is the Department of Planning at Aalborg University, which has tracked the evolution of Denmark's wind energy system closely for decades, first under the leadership of wind pioneers like Frede Hvelplund and Henrik Lund, and now by a new generation of scholars like Karl Sperling. I cite some of their recent studies on the changing character of Danish wind development later in this chapter.

7. From personal communication with Camilla Holbech, Copenhagen, Denmark, May 2015.

8. From personal communication with Søren Hermansen, over Zoom, from Ballen, Denmark, May 2022.

9. ibid.

10. ibid.

11. ibid.

12. From personal communication with Erik Winther Pedersen, Aarhus, Denmark, July 2015.

13. From personal communication with Jakob Ferløv Greth, Aalborg, Denmark, June 2016.

14. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

15. From personal communication with Camilla Holbech, Copenhagen, Denmark, May 2015.

16. From personal communication with Søren Hermansen, over Zoom, from Ballen, Denmark, May 2022.

17. From personal communication with Per Svendsen, Aarhus, Denmark, June 2015.

18. From personal communication with Anne Simonsen, Copenhagen, Denmark, May 2022.

19. From personal communication with Søren Hermansen, over Zoom, from Ballen, Denmark, May 2022.

20. From personal communication with Rasmus Helveg Petersen, Copenhagen, Denmark, August 2015.

21. From personal communication with Per Svendsen, Aarhus, Denmark, June 2015.

22. ibid.

23. ibid.

24. ibid.

25. ibid.

26. ibid.

27. From personal communication with Jakob Bunsgaard, Aarhus, Denmark, June 2015.

28. ibid.

29. ibid.

30. From personal communication with Christina Aabo, Fredericia, Denmark, May 2015.

31. From personal communication with Anders Eldrup, Frederiksberg, Denmark, May 2015.

32. ibid.

33. ibid.

34. ibid.

35. ibid.

36. ibid.

37. ibid.

38. From personal communication with Christina Aabo, Fredericia, Denmark, May 2015.

39. From personal communication with Anders Eldrup, Frederiksberg, Denmark, May 2015.

40. ibid.

41. From personal communication with Christina Aabo, Fredericia, Denmark, May 2015.

42. From personal communication with Tobias Møller Ruby, Gentofte, Denmark, June 2016.

43. From personal communication with Anders Eldrup, Frederiksberg, Denmark, May 2015.

44. From personal communication with Christina Aabo, Fredericia, Denmark, May 2015.

45. ibid.

46. ibid.

47. From personal communication with Tobias Møller Ruby, Gentofte, Denmark, June 2016.

48. ibid.

49. From personal communication with Anders Eldrup, Frederiksberg, Denmark, May 2015.

50. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

51. From personal communication with Søren Hermansen, over Zoom, from Ballen, Denmark, May 2022.

52. From personal communication with Erik Christensen, Hvidovre, Denmark, June 2016.

53. From personal communication with Søren Hermansen, over Zoom, from Ballen, Denmark, May 2022.

54. From personal communication with Asbjorn Bjerre, Aarhus, Denmark, June 2015.

55. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

56. From personal communication with Carsten Kissmeyer, Brande, Denmark, June 2016.

57. From personal communication with Erik Christensen, Hvidovre, Denmark, June 2016.

58. ibid.

59. ibid.

60. ibid.

61. From personal communication with Peter and Jeanette Malinsky, Copenhagen, Denmark, May 2022.

62. From personal communication with Hans Christian Sørensen, Copenhagen, Denmark, June 2016.

63. From personal communication with Erik Christensen, Hvidovre, Denmark, June 2016.

64. ibid.

65. ibid.

66. From personal communication with Ida Auken, Copenhagen, Denmark, May 2022.

67. From personal communication with Søren Hermansen, over Zoom, from Ballen, Denmark, May 2022.

68. From personal communication with Lars Haulrik, Bendstrup, Denmark, June 2016.

69. From personal communication with Malene Lundén, Ballen, Denmark, June 2015.

70. From personal communication with Søren Hermansen, over Zoom, from Ballen, Denmark, May 2022.

71. From personal communication with Erik Christensen, Hvidovre, Denmark, 36.

ibid.

APPENDIX

DATA COLLECTION AND ANALYSIS METHODS

Sources and Methods

Not long after I began learning about wind energy, it became clear to me that I needed to go to Denmark. For several years, I had been asking myself, often in conversation with likeminded peers, versions of the question of how modern societies could meet the challenges of climate change and, specifically, how their utter reliance on fossil fuels could be broken. It turned out a lot of other scholars, activists and policymakers had started asking these same sorts of questions, and over the past decade that discourse has coalesced into a flourishing literature dedicated to the study of what is now usually called the energy transition. In summer 2023, *The New York Times* added a new section to its newspaper with that title. At a conference I attended in summer 2022, a leading public policy scholar argued that the research on energy transitions had grown to a point where the subject merited the attention of disciplinary political science in its own right, and not just as an example of some broader political phenomena or puzzle.

Scholars who study climate change and related subjects often note the novelty of the challenges facing humanity. Building ecologically sustainable societies is clearly a political problem, but with few analogues in historical experience—global in scope, maddeningly complex, implicating all manner of systems and structures and interspecies relationships at all levels of organization. Many of these thinkers lament the weaknesses of the dominant social theories, concepts and methods for unlocking these puzzles, as I detailed in Chapter 2. To treat the environment as just another special interest or issue on the policy agenda is to misunderstand the nature of the challenge, and severely limit the means of attacking it. Taken seriously, environmentalism opens a whole new worldview, on par with the seventeenth-century mechanistic revolution in the natural sciences. It occasions new ways of thinking about the landscape of political activity, about who the relevant political actors are and how they are related, about how power is amassed and exercised. Considering the unfamiliarity of this terrain from the perspective of mainstream social science methodologies, it is not surprising that scholarly interest in sustainability and energy transitions grew first within interdisciplinary communities, and has only belatedly begun to gain the attention of disciplinary political science. I developed an interest in energy politics from a background in sociotechnical systems theory. It might seem counterintuitive that one of the hotbeds of environmental research in the social sciences has been a field dedicated to the analysis of modern science and technology—seemingly the heights of human artifice—but the subjects are more closely linked than initially meets the eye. Social studies of science and technology were already primed to understand and analyze processes of change in systemic terms, and to consider nonhuman entities as core elements and actors in social processes. Technological praxis brings human beings into direct contact with the material world, and is better understood as a means of adapting to and navigating our natural environment, rather than escaping from it. Historians and sociologists have long favored evolutionary models for describing processes of technological change. The more closely I examined energy systems, the more I began to see that they were structured and functioned as ecosystems, and that ecology offered a promising theoretical perspective and toolset for examining how technologies evolve over time. Other scholars of sociotechnical systems, like Bruno Latour, have followed a similar trajectory in their thinking.

In many respects, the research conducted for this dissertation employs fairly traditional social scientific techniques of data gathering and analysis. It is fundamentally a qualitative case study—or, more precisely, a series of interrelated, nested case studies within a shared national context—the most common of social science research strategies, built on a backbone of classic anthropological field methods. The qualitative data is supplemented with the use of basic statistical techniques to capture broader population-level trends. What is distinctive about my approach is how these techniques are combined, and how the data is analyzed to generate conclusions about the observed phenomena. Most social science research strategies rely on logical or statistical inference to break phenomena down into their constituent parts and isolate the effects of causal variables. In Chapter 2, I discussed the limitations of such explanatory frameworks for analyzing socioecological systems, which are composed of webs of multilayered and multidirectional relationships, and are largely unintelligible shorn of context. In search of an alternative that can capture that complexity, this study develops an ecological approach to inference. I am not referring to the statistical techniques of ecological inference associated with the likes of Gary King, aimed at overcoming the "ecological fallacy" of inferring individual behavior from population-level data. (King et al. 2004) There is nothing particularly ecological about these fundamentally positivist techniques. Rather, I draw inspiration from research strategies developed by political and organizational ecologists, and especially field ecologists. I detailed those ecological concepts and methods in Chapter 2, and attempted to apply them to my case analysis in the empirical chapters of the dissertation.

In the writings of ecologists, one of the prevailing themes is a deep awareness of an intimate engagement with place. The study of natural ecosystems has historically relied heavily on sustained, grounded observations conducted at the local sites of interest. The naturalist Aldo Leopold famously argued that it was “inconceivable” to develop an ethical relation toward the land without living in close proximity to it, loving it, having a “vital relation” to it. (Leopold 1966, 261) These insights informed my approach to studying sociotechnical ecosystems. If I wanted to understand the intricacies of how a wind energy system formed and evolved, that perspective would be difficult, probably impossible, to obtain from behind my desk. I would have to log the miles, invest the hours carefully watching and listening, get my hands dirty.

To get an up-close view of an energy transition as it unfolds, there is no better place to go in the world today than Denmark. Anyone who has studied renewable energy development is likely to have at least a passing familiarity with the famed Danish case. Scholars widely regard it as the most successful example of a transition away from fossil fuel dependence to date. In Chapter 1 I detailed the rationale for my case selection. The short version is that Denmark started investing in renewable energy earlier than most other nations, and through sustained effort has made the most progress deploying wind technology, in particular. This long and varied experience with wind power provides data of unparalleled richness, while limiting the scope of the study to a single country makes it possible to hold external conditions constant, and focus on explaining the sources of internal variation. National contexts are so unique—Denmark, for example, is a nation of less than 6 million people, while the United States has a population of more than 330 million—that they pose some serious difficulties for direct country-to-country comparisons. And there are few places in the world where energy transitions have advanced nearly as far as in Denmark. A similar study would be impossible in the United States, where the deployment of renewable power is still at a relatively early stage. It will likely take the United States another two or three decades to catch up to where Denmark is today. While social scientists have already written an enormous amount about Denmark's energy transition (and many of those sources are cited throughout the dissertation), my review of the existing literature revealed that many of those studies relied on relatively thin data, and were relatively dated. I found relatively little analysis of the political dynamics of wind development, and relatively little information about how the wind sector had evolved since the 1990s. Domestic scholars, unsurprisingly, had followed developments more closely, but little of that research was making its way across the Atlantic. The best way to fill in these gaps in the prevailing narratives about Denmark's energy transition was to fly there and talk to the people who were directly involved.

So I secured funding through the National Science Foundation's IGERT program for six months of field study in Denmark in 2015, and later returned in 2016 with support from the UMass Amherst Department of Political Science, and again in 2022 with support from Mount Holyoke College. I selected the regional capital of Aarhus as my base of operations to explore the country, in part to access the renewable energy experts at the city's world-class university and the large network of industry professionals in the area, but mostly as a hub at the geographic center of the country, from which I could easily travel north, south, east and west. All told, I spent about nine months on the ground in Denmark, covering the width of the country from the North to the Baltic Seas, heading as far north as Aalborg and Thisted, and as far south as Esbjerg.

From a logistical perspective, Denmark is an ideal place to conduct the sort of in-depth field study I was attempting. The land-poor nation, which has only about twice the total acreage of the state of Massachusetts, boasts excellent public infrastructure. From my base in Aarhus, I could take trains, buses and ferries to and from meetings anywhere on the main peninsula or islands in a single day. Despite only stepping foot on a few of the largest of the archipelago's 400+ islands, I was able to visit most of the country's major regions and a diverse set of local communities. Denmark's small population and democratic culture also make key actors and institutions unusually accessible, and Danes are justifiably proud of their reputation as a world center of wind technology, so they are usually willing to answer foreigners' questions on the subject. Danish professionals are generally fluent in English, and official documents are typically published in both Danish and English, facilitating communication with non-natives. I did take language classes while living in Denmark, but only succeeded in learning basic phrases, and gained familiarity with common energy-related terminology from reading Danish-language documents.

While in Denmark, I focused on gathering two main types of data—interviews with wind energy actors, and records of wind turbine installations—which I supplemented with field and participant observations, archival materials, and other documents I collected from my sources on the ground. The collection of multiple data sources proved a boon to my analysis, as data points often overlapped and informed one another, allowing me to refine my methods of inquiry, locate confirming evidence, and triangulate conclusions from the available data.

I am mainly a qualitative researcher, most practiced and comfortable with interview techniques. In this respect, my methods are aligned with the existing political science literature on energy transitions, most of which is comprised of interview-based case studies. The historical narrative presented in this dissertation is derived mainly from my interviews with participants in the Danish wind network, who provided me with insider perspectives not available elsewhere, and helped me process-trace developments in the energy transition over time. I employed something of a snowball method for recruiting interview participants, though in truth my aim was to get as complete a portrait of the wind sector as possible, an aim at which I largely succeeded. One of my first goals when I began researching Denmark's energy transition was to sketch the structure of the wind energy system, identifying all relevant actors and institutions. My interviews helped to fill in that picture, but it wasn't long before I stopped hearing new names with which I was unfamiliar, and I grew confident I was aware of all of the major players. By the time I finished my third field visit, I had talked to almost all of them. This approach probably would not have been possible in a larger country, but the Danish wind community is small and many participants know one another personally, so my interview sources were often able to give me multiple perspectives on specific actors and events, and introduce me to additional sources. When I didn't have a connection to a source I wanted to meet, I resorted to cold emails to request an interview, and, remarkably, I would estimate my success rate was close to 50%. All told, I spoke with several hundred individuals about wind power during my time in Denmark, 76 of whom consented to on-the-record interviews. Additionally, I completed about a dozen interviews with academic experts whom I mostly did not quote in the dissertation, though they provided me with important background information and often pointed me to other sources. While I tried to cast my net as widely as possible, it is, of course, not possible to speak to everyone with some connection to the wind industry, which in the Danish case, would constitute most of the population. By necessity, I prioritized some sectors and types of actors over others. I made the intentional choice to limit my scope to the domestic wind sector—which, as I mentioned above, had some analytic benefits—and had relatively few conversations about the larger European and international contexts. In terms of the physical infrastructure of the wind system, I focused my attention on transmission and the turbines themselves. I talked to numerous Danish turbine manufacturers, but made no concerted effort to seek out firms in the component supply chain, which would have complicated my task considerably. Inevitably, I did end up meeting some individuals with experience in the supply chain, as many wind sector professionals have occupied multiple roles throughout their careers. I was also unsuccessful in my efforts to meet with the amateur anti-wind groups in Denmark. I made contact with the most well-known of those organizations, but my requests for an interview were denied. I was, however, able to learn a fair amount about these groups and their activities secondhand from other interview subjects and from published accounts.

I did secure interviews with numerous key actors who have had front row seats, and were often in the driver's seat, throughout Denmark's energy transition, providing me with a wealth of insider information that sets the analysis in this dissertation apart from other accounts of this history. I interviewed multiple wind energy pioneers, senior government officials, corporate CEOs, and leading renewable energy activists. I detailed in Chapter 1 how and why wind turbine developers and developments were a central unit of analysis in my study, as the actors most directly implicated in building the wind energy system. Through the combination of my interviews and my quantitative analysis of turbine registration records, I was able to identify nine distinct major types of wind projects that have been built in Denmark over the past five decades. I managed to conduct interviews with individuals or organizations representing all nine of these different development styles. My return trips helped me flesh out my roster of interviews, filling in gaps or deepening my sources in particularly important areas of the wind network. In 2016, I emphasized increasing the number of project developers I met, as well as expanding my number of municipal case studies, two key sources of internal variation in my analysis. Since my dissertation gives special attention to the political and policy dimensions of the energy transition, my main goal in 2022 was to increase the number of interviews I completed with government officials and other formal policy actors. My final trip to Denmark in 2022 also allowed me to catch up with several sources I had spoken to on previous visits, and collect more longitudinal data about changes they had witnessed since we first spoke.

The interviews I conducted supplied microlevel data that animates the historical narrative recounted in the dissertation, unique first-person perspectives on historical events from actors who participated directly in them, and reflective assessments and analytic insights from longtime observers with expert knowledge of the Danish wind sector. While interviews can yield both fine-grained empirical evidence and wise evaluative judgments, these data points are necessarily subjective, and typically lack precision in their characterization of broader trends. I couldn't interview all of the thousands of Danes who had built a wind turbine during the last half century, and I wanted to get a clearer sense of how representative my interview subjects' experiences were of the domestic wind community as a whole, as well as see if I could find more concrete confirming evidence to support the firsthand accounts I was hearing about how the wind system was evolving.

Quantitative analysis is particularly suited to capturing aggregate trends, usually with greater precision than is achievable through qualitative interviews. When the available data offers more than a snapshot in time, it is possible to describe and visualize large-scale historical processes, and the internal dynamics of evolving systems. In Denmark, fairly accurate and comprehensive calculations about trends in wind development and production over time can be made thanks to a forward-looking and longstanding effort to maintain records on every turbine connected to the domestic grid since the 1970s, collected today in the Danish Energy Agency's Master Data Register of Wind Turbines. In analyzing these official records, I wasn't seeking to put my qualitative interview data to the test, but to thicken it, to add dimension to the case study by examining it through a different lens, and layering those cross sections on top of one another. In one sense, I was using these different data sources to supplement one another. The registry data allowed me to put numbers to questions that were difficult to answer in interviews—just how many cooperative windmills had been raised in Denmark? Which municipalities had been most and least active in wind development? How large, on average, were the projects built at different times and under different development models? How did alternative approaches to turbine development fare over time, when did they grow, when did they decline? Inspired by population ecology, and treating competing development styles as different "species" of wind projects, the registry data presented an opportunity to chart the population dynamics of the Danish wind turbine community. But I wasn't simply analyzing my qualitative and quantitative data sources in isolation from one another; rather, the insights from each data source informed my analysis of the other, and I was weaving the two together in an effort to triangulate answers to my core research questions. So although the use of multiple methods and data sources complicates the study in some ways, and creates additional labor for the investigator, it also buttresses the analysis. Patterns and findings emerge from the comparison of the two datasets that would not have been readily apparent from either in isolation, and the ability to seek out confirming evidence from a variety of data sources enhances confidence in the validity of observations.

The government's wind turbine registry is in some ways remarkably complete, covering the full period of this study, from the time the first turbines were connected to the grid in the mid-1970s until the present day. It offers a fairly comprehensive picture of exactly what machines have been installed in Denmark, where, when, and by whom. There are, however, many known issues with the data quality that have frustrated every scholar I know who has attempted to analyze the registry records. As with any large dataset, there are missing data points, as well as points that are hard to interpret or of questionable accuracy. I mention some of those specific limitations of the data below when they impacted my analysis, and explain how I attempted to resolve those issues. While the registry offers a rich trove of information for skilled and motivated investigators, it is also intimidatingly large and opaque. Interpreting the data correctly can require significant prior expertise on the Danish wind system, and is labor intensive.

The dataset is regularly updated and made available to the public for download on the Danish Energy Agency website, typically with a lag time of about one year before the most recent turbine installations and production data are published. The names and addresses of turbine owners are not included in the publicly-available data, but I was able to secure access to those records up until the year 2015, with permission from the former director of the Danish Energy Agency, on the condition I would keep that information confidential. This single column of data was crucial to my interest in the registry, since the main question I was attempting to answer through my analysis was who owned Denmark's wind turbines. I classified each turbine by the type of developer, in hopes of observing trends in the prevailing styles of development and the population of developers over time. Several other scholars that I am aware of have made similar efforts to use the registry to classify turbine ownership (see my discussion of those studies in Chapter 6), though none with the resolution I have attempted. The wind turbine registry is a popular data source, frequently referred to in studies of Denmark's energy transition, though most scholars rely only on the publicly-available information, and few have tried to introduce their own coding of the data, I suspect due to the intensive effort required to do so. The registry contains more than 8,700 unique records, each representing a single turbine, each of which I had to investigate and code by hand, a task that required hundreds of hours to complete.

While the sheer volume of data that must be processed, without an efficient means of doing so, is certainly an impediment to analysis, the bigger challenge is making sense of the limited information contained in the registry. The data recorded on turbine owners usually amounts to nothing more than the name of an individual or firm, and determining who exactly these people and companies are requires varying degrees of additional legwork. There is also no widely-agreed upon typology of development styles, and each investigator must make their own decisions about what they want to count and how they want to define their categories.

With often incomplete information, and a wide spectrum of individual cases to sort, choices about how to code specific owners are, inevitably, to some degree judgment calls. It would be extremely difficult to make those determinations accurately without some background knowledge about the Danish wind power scene and its players. My field study, documentary research, and interviews all proved extremely useful in helping me evaluate the registry data. In many cases, I was able to recognize specific wind projects and owners that I had either met personally, or learned about in my research. I had traveled to many of the locations referenced in the records, laid eyes on many of those turbines lining the sides of the roads, and that familiarity with the geography proved extremely useful in interpreting the location data in the records. My historical and interview research helped me refine my categories of owner types, and I was often able to lean on sources for additional information that aided the coding of the data. For example, Elsa Brander of the Copenhagen nonprofit Kooperationen was particularly helpful in identifying wind turbine cooperatives. Background knowledge is also needed to recognize data quality issues and to avoid some misleading traps in the records. For example, familiarity with the Danish system for classifying business entities is essential for disentangling the often complex webs of ownership, particularly since private developers frequently hide the true ownership of a project behind shell companies. Turbine owners move, they register their windmills under new tax entities, they sell their turbines to new owners. Some common labels for business entities like *interessentselskab* are attached to very different types of developments. Resolving these ambiguities in the records can be arduous, sometimes impossible, and requires some expertise. For this reason, the tactic of employing additional unskilled coders to check for reliability is not feasible with this dataset.

Instead, I used several techniques to enhance the reliability of my coding and limit errors in classification. As I already mentioned, my qualitative research often made it possible to confirm with a high degree of confidence the specific wind development that corresponded to a particular record. All ownership records were initially cross-referenced with Denmark's central business register (https://datacvr.virk.dk), which contains a range of information about business entities and their principals. These records will often reveal what type of business the turbine owner is in—for example, if they are a farmer, or a landowner, or an investment firm. The business records can be used to pierce holding companies and drill down to the real owners, and to locate evidence of changes in ownership over time. I also relied heavily on maps of Denmark and mapping software to plot the respective locations of turbine installations and their owners. If a farmer raises a turbine in his own backyard, that's a very different approach to development than if he buys into a wind farm on the other side of the country. Finally, in the instances where none of these strategies was sufficient to make a confident determination about the type of development I was looking at, I turned to Danish-language newspapers and renewable energy blogs, municipal records, business websites, and other online resources where I often found additional information about specific wind farms and their owners. In the very rare instances where sufficient information could not be found, I coded the category of turbine owner as unknown.

Most importantly, I followed clear and consistent, predefined procedures for making category determinations, which are spelled out in the description of my developer typology below. I would estimate that more than 90% of cases were relatively unambiguous and could be easily assigned to a category in my typology. Another 5-10% required additional investigation to make a determination, and perhaps 1% of cases were truly ambiguous and either could not be assessed with high confidence or did not fit easily into just one of the developer categories.

That degree of indeterminacy is to some extent an unavoidable artifact of any attempt to fit the diversity and unruliness of empirical reality into a limited schema. One of the fascinating aspects of Denmark's history with wind power is that there have been so many different types of individuals and organizations that have bought into wind projects. There are unusual cases, and there are also many cases that blur the boundaries between multiple categories of developer. In spite of these complicating factors, I was able to identify nine distinctive and common development styles, a significant improvement in resolution from the 3-4 categories of owners used in previous studies. Defining the categories in my typology was an iterative process, drawing on my prior knowledge of Denmark's development history, as well as working from the ground up to capture the variation I was finding in the registry records.

Considering the limitations of the dataset, the challenges involved with coding, and the peculiarity of my classificatory schema, it is best to interpret the results of the quantitative analysis not as precise measurements, but as estimates of general trends. The measurement error is hard to quantify, but it should be assumed there was some error in the underlying data, and there may be some (likely random) error in the coding. However, for the reasons described above, there is little cause to fear systematic bias or widespread misclassification of the data. It is highly likely that the reported trends are generally reflective of the reality on the ground, and my findings from the data are largely consistent with the qualitative evidence and previous quantitative studies. For the purposes of the present study, the limitations in the precision of the data are not especially concerning, since the statistical analysis is being used primarily to describe population-level trends, and not to make causal inferences or claims about individual behaviors.

Developer Typology

Data collected by the Danish Energy Agency makes it possible to identify the owners of almost every turbine that has been connected to the grid in Denmark since 1976, more than 8,700 unique turbines in all. Turbine owners were grouped into nine categories for analysis based on the criteria described below. The range of categories is meant to reflect differences in the scale and distribution of projects (centralized vs. distributed, large vs. small), the primary motives of developers (profit, home economy, environmental activism, etc.), and the level of local involvement, among other distinguishing characteristics. Of course, no typology can fully represent the real diversity of Denmark's windmill projects and owners, and each category must tolerate some variation in the types of developments it encompasses. The fits of specific projects with the available categories were not always perfect, but most turbine developers are easily identifiable as one of these types.

These categories are nominal data, and as such cannot be treated as a scientific scale, though they are arranged here, and in most of the figures throughout the dissertation, roughly in order from more local, decentralized, community-based developments to more centralized, for-profit models dominated by large investors.

Household mill (HOME)

Identifiable by their extremely small output, they typically have a rated capacity of less than 15 kW, though some can be as large as 25-30 kW. These turbines usually only produce enough electricity to offset the consumption of a family home or a small family farm, and that is what they have most often been used to do, frequently in out-of-the-way places where residents cannot benefit from highly-efficient district heating connections, and thus have high energy costs. Most owners are private individuals who raise the mills on their properties, in their backyards. Recently, there has been a surge in public interest in these small turbines, thanks to an overly generous government incentive that ended in 2015. For the purposes of classification, any turbine with a rated capacity of 30 kW or less installed at the owner's private address was considered a household mill.

Grassroots (GRASS)

This large category, particularly prior to the 1990s, reflects inadequacies in the available data, and could be treated as missing data. These turbines are listed in government records as owned by private investment firms (INVEST), but were erected before those firms were established, and in many cases, before such outside investors were able to legally buy into turbine projects. The conclusion that must be drawn is that the firms listed in the government records acquired these turbines from their original owners. It is well-established—and there is plenty of evidence in the records to this effect—that outside investors bought up many of the older, smaller turbines during the 1990s and 2000s in order to decommission them and replace them with newer, larger wind farms. This is likely what occurred in the vast majority of cases that fall into the "Grassroots" category, though in most cases this leaves the identities of the original owners unknown. Danish Energy Agency staff said they do not keep records of previous owners. Given what is known about other projects built during this time period, it can be safely assumed that the overwhelming majority of these windmills must have originally been erected by cooperatives or local individuals, but it is not possible at present to say for certain exactly which of the "Grassroots" turbines fall into those categories.

Cooperative (COOP)

One of the original forms in which wind power developed in Denmark was through associations of neighbors in rural areas. This kind of grassroots voluntary association has been a staple of the "Danish model," and remained prominent for decades, though it has become increasingly endangered as the scale of wind developments grows beyond the reach of small-dollar investors. Cooperatives are owned by their members, who buy shares at a fixed price (often around 3,000-5,000 DKK, or the value of 1,000 kWh produced by the turbine). The members vote on a board that manages the books, and sometimes daily operations. Cooperatives are almost always run as fully-liable partnerships (I/S in the Danish business code). Shareholders will typically net only modest returns.

Local Individual (LOCAL INDV)

Another staple of the early grassroots developments, these private individuals have often been farmers, or other types of rural landowners. They typically invest in a turbine that is erected on their own property, or nearby. Many will go in on a small array with a few neighbors. These buyers have historically had a wide range of motives for raising turbines, from providing energy to a farm, to simply viewing the project as an investment opportunity. Being able to borrow against a farm or enter a lease agreement with investors can provide the necessary start-up capital. For classification purposes, these turbines are registered to individuals, and were only included in the category if that individual's official residence is located in the same municipality (kommune) as the windmill. On some occasions, a turbine is registered to an I/S (partnership) compromised of 2-3 close neighbors or apparent relatives living at the same local address. Those projects were also included in the "local individual" category.

Local Organization (LOCAL ORG)

A relatively minor category of development that includes non-government entities registered as organizations, including schools, social and recreational clubs, service organizations, nonprofits, charitable foundations, etc. The organization must be registered in same municipality as the turbine to be considered local.

Government Entity (GOVT)

A sliver of the overall network, government entities have not frequently invested directly in wind projects. Several municipalities have bought into projects through the decades, and in just a few instances state agencies have run or invested in turbines. More commonly, these government investments have been indirect, filtered through publicly-owned utility companies.

Local Business (LOCAL BIZ)

A diverse category, these locals can be anyone from shop proprietors, registering their turbine through their business, to wealthy local individuals, to for-profit project management firms operating on their home turf. They are grouped together by virtue of being registered as limited-liability businesses in the same municipality as the turbines they own.

Industrial (FABRIK).

A small category, the direct use of wind power for industrial purposes is not widespread in Denmark. The Siemens turbine factory in Brande, which is partly powered by a large turbine on campus, is a prominent example. Unlike other private and utility developments, these projects are often owned by large corporations, but are rarely primarily concerned with generating a financial return. Instead, these windmills are usually intended to offset energy usage at a manufacturing facility, or to meet a company's environmental goals. Test turbines erected by turbine manufacturers for research and development purposes, which are growing to enormous proportions in recent years, are also included in this category.

Outside Investor (INVEST)

The profit-oriented developers who began to flood the market in the 1990s are often private individuals with capital or small firms, but they range up to large companies with experience developing hundreds of turbine projects. They are registered outside of the municipality where the project is built.

Utility (UTIL)

Utility companies long resisted investing in wind power, and did not show much serious interest, beyond doing the minimum to fulfill pledges extracted in government deals, until after 2000. They have since become major players in the Danish wind network, particularly in offshore development, which they currently dominate. The utility companies active in wind power in Denmark are mostly well-known companies, the two largest being DONG Energy (now Ørsted) and Vattenfall, although there are also many regional utility companies. Only known utilities (loosely defined as businesses primarily engaged in electricity generation and distribution) were coded as such.

List of interviews

The following 76 individuals consented to on-the-record interviews to be used for attribution. Consent to be interviewed was usually obtained first in writing by email, and then confirmed verbally before beginning the interview. The interviews were semistructured, and most lasted approximately one hour, although some subjects were interviewed multiple times on separate occasions. The interviews were usually audiotaped, and transcribed afterward from both the tape and handwritten notes. The listed affiliations refer to the subject's professional position at the time the interview was conducted.

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Leire Gorroño Albizu, Project Coordinator, Nordic Folkecenter for Renewable Energy

Stig Balduin Andersen, Offshore Wind Project Manager, HOFOR

Ida Auken, member of the Folketing and former Minister for the Environment

Morten Bæk, Director General, Danish Energy Agency

Thomas Becker, Managing Director, STRING network, former CEO of European Wind Energy Association, former Deputy Permanent Secretary of Danish Climate and Energy Ministry, lead Danish negotiator at COP15 in Copenhagen

Asbjørn Bjerre, Director, Danish Wind Turbine Owners' Association

Elsa Brander, consultant, Kooperationen

Tonny Brink, CTO, Nordic Folkecenter for Renewable Energy

Jakob Bundgaard, CEO, NRGi Renewables

Jamie Chappell, Samsø resident and household turbine owner

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Mike Edds, Senior Manager, Nordex USA

Anders Eldrup, former CEO, DONG Energy

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Lyn Harrison, founder and editor, *Windpower Monthly*

Lars Haulrik, Aarhus resident and household wind turbine owner

Søren Hermansen, Director, Samsø Energy Academy

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Camilla Holbech, Deputy CEO, Danish Wind Industry Association

Bjørn Holmgaard, Senior Project Manager, Wind People

Allan Jensen, Tvindkraft caretaker, Tvind

Britta Jensen, Tvindkraft caretaker, Tvind

Ib Konrad Jensen, journalist and author of *Maend I Modvind*

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Palle Hinze Jensen, Chief Commercial Officer, SE Blue Renewables

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Henrik Stiesdal, Chief Technology Officer, Siemens Wind (retired)

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Per Svendsen, Communications Chief, NRGi

Lindy Tanvig, planner, Ikast-Brande Kommune

Jørgen Tranberg, Samsø farmer, wind turbine investor

Lea Vangstrup, founder, Wind People

Henrik Vinther, Head of Secretariat, Viden Om Vind

Rasmus Windfeld, Head of Press, Siemens Danmark

Robert Zdebski, Sales and Marketing Director, Ogin

I also conducted informal interviews with a number of scholarly experts on the Danish wind sector, and while those conversations were not recorded and are not quoted in the dissertation, they did inform my general understanding of academic perspectives on energy transitions. I am particularly grateful for the assistance and insights of **Benjamin Sovacool, Matthias Heymann, Christian Hvidtfelt Nielsen, Karl Sperling, Frede Hvelplund, David Nye, Bonnie Ram, Niels-Erik Clausen, David Philip Rudolph, Tyler Hansen, and Daniel Nordstrand Frantzen.**

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