Blowing in the wind: A brief history of wind energy and wind power technologies in Denmark

Abstract

This paper explores the history of wind power technologies and the integration of wind energy in the Danish energy system. It does so focusing particularly on historical events, socio-cultural and socio-political changes and priorities that were important on this technological journey. From the first primitive wind turbines in the late 1800s, to the world wars, through the energy- crisis in the 70s, and into the decades of growing environmental awareness and concern, this historical account describes how policy priorities in Denmark gradually translated from the focus on energy diversification, energy efficiency and energy independence to the focus on sustainability and renewable energy resources, with wind energy and wind power technologies at the top of the priority list. Historically, wind power has been - and it still is - popular in Denmark. However, as the modern wind power turbines gradually grew to industrial scale heights, unchallenged support for specific local wind farms could no longer be taken for granted. This paper also touches upon the frequently tacit dilemmas of renewable energy technology planning and deployment, for example issues of environmental justice, wind farm ownership structures, and the role of social psychology for low-carbon energy transition processes. Notably, attention is drawn to the representation biases that may result in the emphasis of wind farm opposition / grievances in the wider wind farm related debates, where resistance to local wind farm projects might derive from minority opposition groups. Insights and lessons learnt from this Danish history of wind power may prove valuable and inspirational for other countries engaging in low-carbon energy transitions.

Keywords

Energy history; Energy Transitions; Renewable Energy; Energy Technologies; Energy Policy

Highlights

- A history of the wind energy sector in Denmark
- Danish energy policy was informed by notions of energy diversification, energy efficiency, and energy independence
- Top-down and bottom-up efforts informed the evolution of the wind energy sector.
- The history of cooperatives and antinuclear sentiments supported wind power.
- Lessons drawn from this Danish case may be valuable and inspirational elsewhere

Contents

1. Introduction

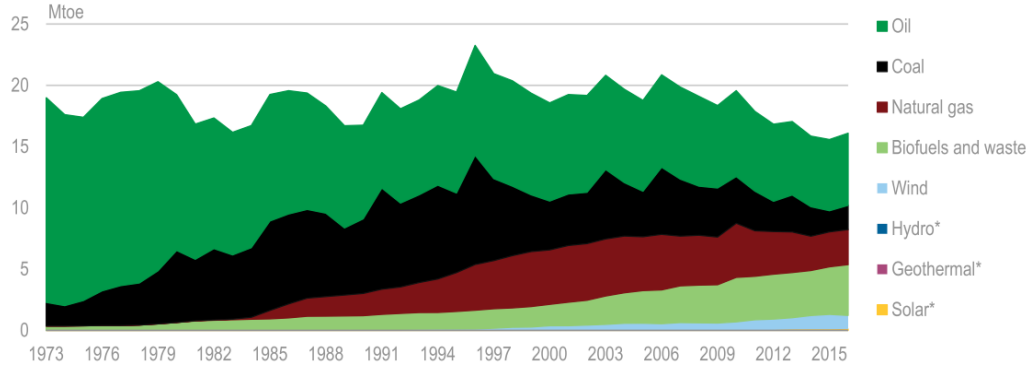
The small Scandinavian country of Denmark is widely known for its innovative energy sector, and it is particularly well known for wind energy and for wind power technologies (Hvelplund et al., 2017; Petersen, 2018; Sperling et al., 2010). Surrounded by the sea, the country is naturally rich in wind resources. Throughout history, Danish people have harvested wind power in various ways. Wind power and wind power technologies have deep-seated historical roots in the country, and historically wind power and wind power technologies have been popular among the Danish public (Araújo, 2018; Danmarks Vindmølleforening, 2015; Meyer, 2007; Sperling et al., 2010). According to national opinion polls they still are (Katinka Johansen, 2019; M. Ø. Johansen, 2017; Megafon, 2015). However, in recent decades wind farm related social and political controversy has become more the norm than the exception (K Johansen & Upham, 2019). The Danish energy system is highly interconnected and flexible, and large amounts of renewable and variable energy (mostly wind power) has been integrated into the system in a short time (IEA, 2017), (see Figure 1). 43.2% of the total national electricity consumption in Denmark was produced by wind power in 2017, and wind power technologies and knowhow are a key national export (Danish Energy Agency [DEA], 2018).

This paper revisits the emergence and the evolution of wind power technologies and the integration of wind power in the energy system in Denmark, focussing particularly on the historical events and changes, policies, socioeconomic and sociocultural dynamics that have proved important on this technological journey. The longitudinal research perspective allows for analysis of the longer-term effects of rationales and policies from the past. Drawing upon this historical account, the paper discusses and reflects on potential insights and lessons learnt valuable for other countries engaging in low-carbon energy transitions. It does so leaving multiple unanswered questions lingering.

The research is guided by the following research questions: 1*) What was the role and importance of national and global historical events and technological advances for the wind energy sector in Denmark? 2) What political priorities and bottom-up initiatives facilitated the emergence and the evolution of the wind energy sector in Denmark? 3) What policy insights and lessons learnt may be drawn from this Danish history of wind power?* In terms of limitations, the socio-cultural and socio-political perspectives of this Danish history of wind power are the prioritised analytical foci, and the longitudinal research perspective inevitably leads to the compromise of less attention to in-depth historical details.[1]

[1] For a more detailed description of the development of e.g. wind power technologies in Denmark, see Petersen (2018).

Figure 1: Total Primary Energy Supplies in Denmark by source from 1973 to 2016



Note: Total Primary Energy Supplies in Denmark by source from 1973 to 2016 *(IEA. International Energy Agency 2017, p.24).* The domestic power system in Denmark is interconnected and flexible, and large amounts of renewable energies have been integrated into the system in a short time (IEA, 2017). The Total Primary Energy Supplies (TPES) in the energy mix vary, and the country is highly integrated into the Nordic electricity market (Araújo, 2018; IEA, 2017). In 2005, the ratio of renewables in the Total National Energy Production (TNEP) was 9.3%, while the 2016 ratio of renewables was 25.3%, and increase largely due to increasing amounts of wind power in the grid (IEA, 2017). The production of oil and gas from the Danish part of the North Sea is declining (International Energy Agency [IEA], 2017).

2. Method

The research methodology of integrative reviewing (IR) is characterised by the use of multiple data-sources, empirical and theoretical literature, and a variance of analytical techniques. This makes for valid and holistic research insights. IR aligns with the critical realist tradition (Jones-Devitt et al., 2017). Empirically, the research draws on expert interviews and interviews wind farm stakeholders, multiyear engagement with a municipal utility and wind farm developer, and participation in wind farm sector events and seminars. In terms of literature, the research draws on energy sector reports, legal and policy documents, news, websites etc.

The paper is organised as follows: Section 3 guides the reader through the history of wind power in Denmark focussing on key historical events, policy priorities and decisions that were important for the evolution of the industry. In this historical light, section 4 touches upon dilemmas of wind farm planning and deployment, wind farm ownership and the importance of socio-psychological phenomena for perceptions of local windfarms among the public. We now turn to the historical account.

3. The History of Wind Power in Denmark

The small country of Denmark has been a frontrunner in the wind energy sector since the formation of the industry (Araújo, 2018; Hvelplund et al., 2017). The following sections describe the Danish history of wind power technologies, from bricoleur-type experiments conducted by visionary individuals, to the mature wind power industry of today with significant international export (see Figure 3). This historical account may help explain how Denmark has become known as a wind power pioneer (Hvelplund et al., 2017).

The first windmills appeared in the twelfth century in Europe, and they were used for grinding grains, cereals and for pumping water from low-lying wetland areas. The first windmills appeared around 1250 in Denmark. For many years, professional millers had the right to grind all corn produced in the parish. This privilege ended with the freedom of trade, however, and the emergence of the steam engine provided a more stable source of energy. For local farmers, the freedom of trade meant that they were now entitled to build, own, and to use private windmills on their farms (Danmarks Vindmølleforening, 2013; Petersen, 2018).

3.1 1900s: Wind Power and Its Role in the Early Electrification of Denmark

Creative and innovative individuals have been of key importance to the emergence of wind power technologies. In Denmark, Poul la Cour was among the most prominent of these early entrepreneurial wind power pioneers. Poul la Cour was born in 1846, and he taught physics and natural science at Askov Højskole,[2] a school for general adult education. In the 1890s, la Cour built a small wind turbine that produced electricity, and because of his ability to produce electrical light from the power of the wind, he was soon nicknamed the Wizard of Askov. La Cour dreamt of how, in the future, the poorer rural populations could benefit from wind energy for warmth, lighting, and the mechanisation of agriculture (Araújo, 2018; Danmarks Vindmølleforening, 2013; Hvelplund et al., 2017; Petersen, 2018).

Poul la Cour and 21 partners established the Danish Wind Electricity Company in 1903, a company that trained 'rural electricians'. These electricians travelled the country and facilitated the establishment of small local electricity plants powered by wind turbines. In this way, La Cour's innovative wind turbine technology was a part of the early electrification of Denmark. In the year 1918, 120 wind-powered electricity plants supplied 3% of the annual national electricity consumption. In 1919, Johannes Jensen and Poul Vinding designed a wind turbine with aerodynamic wings, and in the following years, the Danish State initiated energy efficiency studies of the known wind turbine designs at the time. Wind power research received state support, and wind power related issues were readily debated in the national engineering journal, *Ingeniøren* (The Engineer) (Petersen, 2018).

[2] A Danish 'Højskole' is an educational institution or school that offers non-formal education (mainly for adults) for broad educational purposes. The ideology of the Højskole was to offer general education and inspiration, particularly for rural populations. Højskoler were part of the Danish enlightenment movement. See for example: shorturl.at/AJSV5.

Figure 2: Windmill, 1897

Note: Wind Mill from 1897 designed by Poul La Cour. Photo printed with permission from the Poul la Cour Museum.

In the 1920s, between 20 000 and 30 000 farms had installed small household wind turbines that delivered power for threshing machines, grinders, chainsaws, water pumps, and so on. The first small wind turbines were no longer used with the advent of the diesel/petroleum and later electrical motors, but they did have a small revival during WWII when resources were scarce. However, as energy imports were re-established after WWII, the interest in wind energy and wind turbines dwindled yet again (Araújo, 2018; Danmarks Vindmølleforening, 2013; Hvelplund et al., 2017; Petersen, 2018).

Figure 3: The History of Wind Power

Note: International and national events and policy decisions relevant for the emergence and evolution of wind power. Design: Claus Nielsen, Aalborg University, Copenhagen.

3.2 1940s to 1960s: From Cold War Politics to Economic Upswing

In the 1940s, informed by the experiences of war, the German occupation, and resource and energy scarcity, the Danish Government initiated studies of the national electricity system with the ambition of developing it further. The final report from 1946 concluded that centralised electricity generation was most rational, and coal imports were prioritised. To ease the transport of coal, newly established power stations were mostly located by the sea, and the import of hydropower from Norway was accepted (Rüdiger, 2019a). Importing coal proved challenging in the post war political landscape, however. In 1948, the American aid programme designed to help Europe economically after WWII was initiated, and this aid programme, the Marshall Plan, was administered by the Organisation for European Economic Co-operation (OEEC) (Petersen, 2018).

To receive support from the Marshall Plan from the OEEC, Denmark presented a plan for increased trade with the Eastern bloc by 40% in the years 1948–53. As a response to trade embargoes, the Eastern bloc country of Poland demanded industrial items in return for coal, and the small country of Denmark was 'sandwiched' between restrictions from the Western bloc and the Polish demand for goods (Rüdiger, 2019a). The OEEC economists rightly anticipated the energy import challenges associated with the reconstruction work that was taking place all over Europe after the war, and the organisation hosted a meeting where they discussed the role of wind power as a future and alternative electricity supply.

The Danish State established a wind power committee, and in 1952, this committee applied for Marshall Plan support for wind power related research (Petersen, 2018). In 1956, the Suez Crisis once again emphasised the Danish energy import dependency. Fuel rations were introduced to manage the sparse energy supplies (DEA, 2016). Nuclear power was considered as an alternative energy resource, and the Danish nuclear energy research station Risø was established in 1958. Nonetheless, oil was still easier to transport, and oil required much smaller initial investments; therefore, oil was the final priority (Petersen, 2018; Rüdiger, 2019a). Economic upswing characterised the 1960s. Oil was abundant and inexpensive. People installed oil burners in their houses, motorised traffic increased, industry transitioned from coal to oil, and the demand for oil rose (DEA, 2016; Petersen, 2018; Rüdiger, 2019a).

The world was shocked by the world wars, and the nuclear disaster at Hiroshima and Nagasaki affirmed the atrocious powers unleashed by technological advances. However, rapid industrial, technical, medical, and agricultural developments sparked hopes for the future. Standards of living improved, and so did levels of energy consumption.

3.3 1970s: From Oil Crisis to National Scale Energy Planning

The political approach to ensuring the stability of energy supplies in the 1970s could be described as relaxed, laissez-faire and mostly reliant upon market forces (Rüdiger, 2019a). In the early 1970s, more than 90% of the national energy consumption was imported from the unstable Middle East,

and the 1973 first international oil crisis accentuated the extent of this energy import dependency (Araújo, 2018). The price of oil had doubled six times by the late 1970s.

The Danish Government introduced a series of shorter-term policy initiatives to manage the energy shortage of the oil crisis. Motorised traffic was banned on Sundays. Speed limits were reduced, and street lighting was minimised (Araújo, 2018; Quartz+co, 2015). All members of the Danish public suffered from these immediate restrictions in their everyday lives, and the socioeconomic consequences of the oil crisis were critical: the national economy suffered, and unemployment rates soared. The oil crisis was indeed a 'wake-up call' for Danish authorities, ultimately leading to a series of energy planning initiatives and policies that spanned decades. These longer-term government responses to the oil crises are broadly captured via the headlines *energy diversification, energy efficiency,* and *energy independence* (Araújo, 2018; Rüdiger, 2019a, 2019b; Quartz+co 2015). The Danish Government established the Danish Energy Agency (DEA) and the Ministry of Energy to implement these energy policies in practice. These authorities were to focus on long-term energy planning and policy and diversification of energy supplies in the energy mix, the overarching goal being to reduce vulnerability of the national economy due to energy import dependency (DEA, 2017a; Mortensen et al., 2018; Rüdiger, 2019a).

These authorities developed the first energy plan in Denmark. This 1976 Danish Energy Plan would become a cornerstone for the future and long-term energy policy and planning in the country. The report encouraged the utilisation of waste heat from power plants and industry instead of using oil, it encouraged more energy-efficient heating, and it encouraged the integration of more renewable energy resources in the energy system (DEA, 2016; Energinet.dk & Rambøll, 2015, Rüdiger, 2019a; State of Green, 2018). In 1979, the Danish Energy Policy was ready. This Energy Policy focused on ensuring stable, available and payable energy supplies for all via the overarching strategy of fuel diversification, the harvest of locally available energy resources, minimizing energy consumption and maximizing energy efficiency. 1979 was also the year of the second international oil crisis (DEA, 2017a; Mortensen et al., 2018; Petersen, 2018; Rüdiger, 2019a; State of Green, 2018). The international energy crisis reactivated interest in wind power. In the 1970s, Germany, Sweden, and the US engaged in research and development of modern wind turbines that produced power from wind. In the 1970s, international anti-nuclear movements were gaining momentum.

3.4 Bottom-up and Top-down Initiatives

In Denmark, the anti-nuclear movements were particularly proactive, and widely anchored within society. The anti-nuclear movement actively advocated the integration of renewable energy resources (e.g. solar and wind) in the Danish energy system as an alternative to nuclear. For example, as a response to the official 1976 Energy Plan, a group of independent researchers published an alternative energy plan. These researchers collaborated with the anti-nuclear NGOs, the Organization for Information about Nuclear Power (OOA) and the Organisation for Renewable Energy (OVE). The anti-nuclear movement organized repeated public protests against nuclear throughout the country and collected hundreds of thousands of signatures that confirmed nuclear opposition among members of the public. The anti-nuclear movement was particularly active in 1979, the year of the Danish Energy Policy (Petersen, 2018; M. Rüdiger, 2019b; The Energy Movement OOA, 1994).

During these years, private wind power entrepreneurs tinkered with the emergent renewable energy technology (RET), and in 1978, the largest wind turbine in the world at the time (Tvindmøllen) was erected. Initially, the development of wind power technologies in Denmark was largely based on small private innovators, initiative groups, or small companies that used personal funding at personal risk (Araújo, 2018; Hvelplund et al., 2017; Petersen, 2018). In this way, individual enthusiasts, experts, activists, and non-governmental organisations (NGOs) working *from below* were prominent change agents in the evolution and emergence of Danish wind power technology (Araújo, 2018, p. 180). From the *top down* the Danish State also granted the emergent wind power industry a helping hand: The Government initiated a research programme for larger wind turbines, introduced a feed-in tariff for wind power in 1976, and a 30% subsidy for wind turbines certified from a Danish test centre in 1979. This policy initiative not only linked the certification of wind power technologies to subsidy support, but also promoted collaboration among wind power sector stakeholders and researchers (Araújo, 2018; Danmarks Vindmølleforening, 2013; Hvelplund et al., 2017). In 1979, the then very small Danish company called Vestas commenced the mass production of wind turbines, and the embryonic wind power technologies evolved rapidly (Petersen, 2018; Rüdiger, 2019a).

3.5 1980s: Alternative Visions for Energy Systems and a Public 'No' to Nuclear

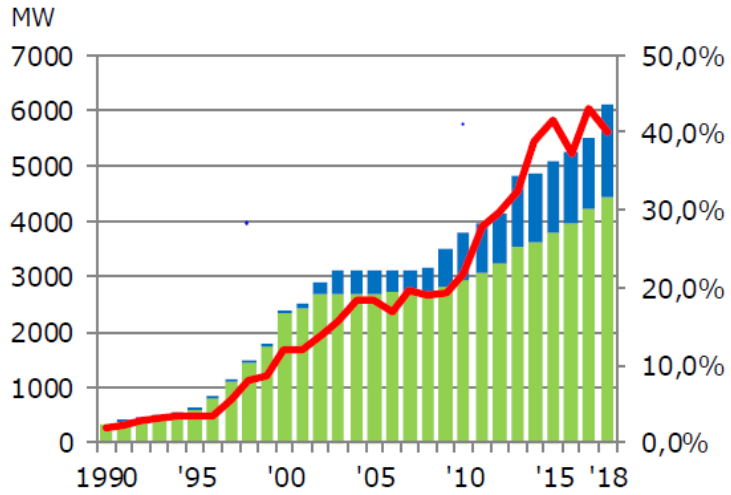
Environmental awareness increased in the 1980s. In Denmark, this growing environmental awareness encouraged multiple alternative suggestions for the future Danish energy system. Bent Sørensen from the Niels Bohr Institute published a suggestion for the future Danish electricity system based on 100% wind power combined with Norwegian hydropower in 1980. In 1981, engineer H. Kiel Jørgensen Femmøller presented a plan for 240 000 wind turbines by the Danish coast. These wind turbines would supply approximately 50% of the total Danish energy consumption. In 1983, a group of researchers published "Energy for the Future – an Alternative Energy Plan". This energy plan suggested radically changing the structure of the electricity supply,

deploying decentralised combined heat and power plants, integrating wind power in the energy system, and reducing electricity consumption overall (DEA, 2016).

As the size of the wind turbines gradually grew, local initiative groups created wind farm cooperatives and jointly financed larger turbines (Araújo, 2018; Danmarks Vindmølleforening, 2013). This growing bottom-up wind farm cooperative movement drew from and relied on decades of organisational experience with cooperatives from within other national sectors, such as the agricultural sector (Grelle, 2012; Petersen, 2018). Utilities also joined in the ranks of wind turbine owners (Araújo, 2018; Danmarks Vindmølleforening, 2013). With the Ministry of Energy as the main investor, the company Danish Wind-Technique was established in 1981 with the aim of producing larger and more efficient wind power technologies. Danish Wind-Technique was challenged economically and technically, however, and therefore Ministry withdrew in 1985 (Danmarks Vindmølleforening, 2013). Offshore wind power technologies were gradually emerging, and in acknowledging the potential for wind power plants at sea, the Ministry of Energy established a committee for offshore wind farms in 1987 (DEA, 2016).

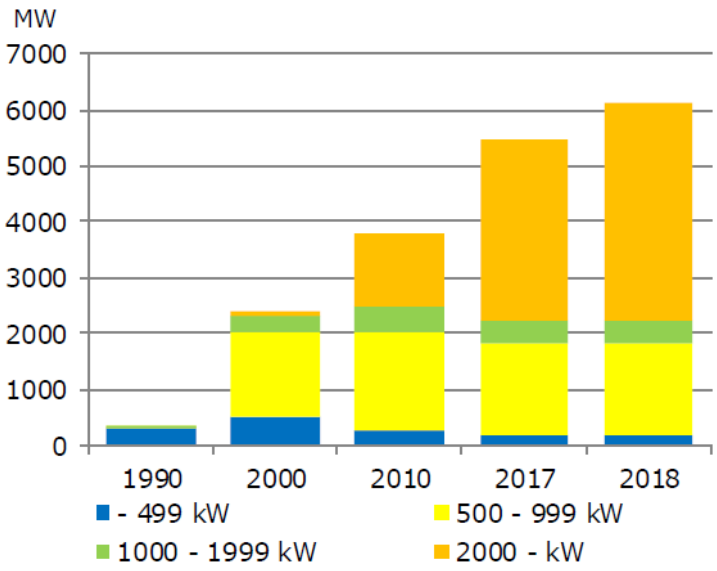
During these years, the sense of urgency bought about by the oil crisis combined with the growing environmental awareness encouraged inventors, environmentalists, scientists, local communities and NGOs to seek alternative sources of energy. Nuclear power was still considered a viable alternative energy resource by some experts and members of the public. However, also informed by the proactive anti-nuclear movements, by the repeated public protests, and by the anti-nuclear sentiments overall, a 1985-86 parliamentary decision finally excluded the option of nuclear power in the Danish energy system (Araújo, 2018; DEA, 2017a; Petersen, 2018; Rüdiger, 2019a; State of Green, 2018). This parliamentary decision emphasized that in the future, the alternatives to imported fuels would be locally harvested energy resources and renewable energy resources.

Figure 4a: Wind Power Capacity and Wind Power Ratio of Domestic Electricity Consumption



Notes: Total wind power capacity onshore and offshore by year. Blue - Total wind power capacity offshore in MW. Green - Total wind power capacity onshore in MW. Red line - Wind power in percent of domestic electricity supplies. Wind power produced 40.2% of the total national electricity consumption in the year 2018, 43.2% of the total national electricity consumption in the year 2017, and 1.9% in 1990. Wind power production varies from year to year depending on the wind resources. Source, DEA (2019).

Figure: 4b Wind Power Capacity by Wind Power Plant Size



Notes: The total number of wind power plants increased by 118 from the year 2017 to the year 2018, and the total wind power capacity installed increased by 631 MW. Throughout the years, the size and the capacity of new wind farms has increased. The tendency is that there are less but much larger wind power plants. From the year 2000, 1260 larger wind power plants (more than 2 MW / 2000 kW) were installed. From the year 2000, 1430 smaller wind power plants (up to 499 kW) were decommissioned. Source, DEA (2019).

3.6 1990s: Growing Wind Turbines and emergent Offshore Technologies

Danish energy politics and environmental politics became intimately intertwined in the 1990s. The Minister of Energy and the Environment from 1993 to 2001, the Social Democrat (A) Svend Auken, initiated a 'green' political turn in energy politics. Mr Auken prioritised green growth and sustainable development (Araújo, 2018) and initiated political plans for greenhouse gas reductions that would also benefit the growing wind power industry. From the mid-1990s, state subsidies encouraged replacing older, smaller and inefficient wind turbines with modern, larger and more efficient wind turbines (Sperling et al., 2010). During these years, onshore and offshore wind power technologies and related industries quickly grew and gained momentum. Rules for wind farm ownership 'were relaxed with liberalization', and so trends in ownership structures of wind farms began to shift (Araújo, 2018, p. 162).

In 1991, the first offshore wind farm in the world (Vindeby Havmøllepark) was constructed off the coast of Lolland, Denmark (Vindeby Havmøllepark: 11 wind turbines; total capacity: almost 5 MW). The Governmental Offshore Commission presented a report that selected five offshore wind farm sites of authority interest in 1995, and in 1998, the Ministry of Environment and Energy mandated the deployment of five offshore wind farms. The total capacity of these wind farms was 750 MW (approximately 150 MW each; Orsted, 2020). The further deployment of onshore wind farms was also encouraged during these years. In 1993, the minister sent a letter to the local councils that encouraged municipal planning of wind farms, and in 1996, the minister instructed power companies to establish onshore wind farms until 2005. The aim was to increase of the existing onshore wind farm capacity of 900 MW. Owners of these wind farms could be either power companies or private investors (DEA, 2016; Petersen, 2018).

The 1980s and 1990s saw a significant increase in wind power capacity in the grid, in wind power technological infrastructures and wind power related technical knowhow (Araújo, 2018; Quartz+co, 2015). As the wind power industry grew and matured, the wind turbines quickly increased in size and efficiency (Araújo, 2018; Quartz+co, 2015), see (Figure 5). By the late 1990s, wind farm cooperatives or individuals still owned most of the 6300 operating wind turbines (Araújo, 2018; Meyer, 2007).

3.7 2000s: Changing Ownership of Wind Farms and the Growing Wind Farm Resistance

Wind power supplied approximately 13% of the total national electricity consumption in Denmark in the year 2000 (DEA, 2016), and the total height of the newest onshore wind turbines exceeded 100 meters at the tips of the wings (see Figs. 4a, 4b and 5).

The environmental focus of the previous years in Danish energy policy changed. The right-wing government in power from 2001 was less supportive of renewable energy resources, and many financial incentive structures supportive of RETs were cut back. In the following years, policy uncertainty and the fluctuating electricity market did not favour the further installation of wind power technologies in the Danish energy system (Araújo, 2018; Sperling et al., 2010). However, wind energy and related technologies and knowhow was now a notable national export. In 2005, the

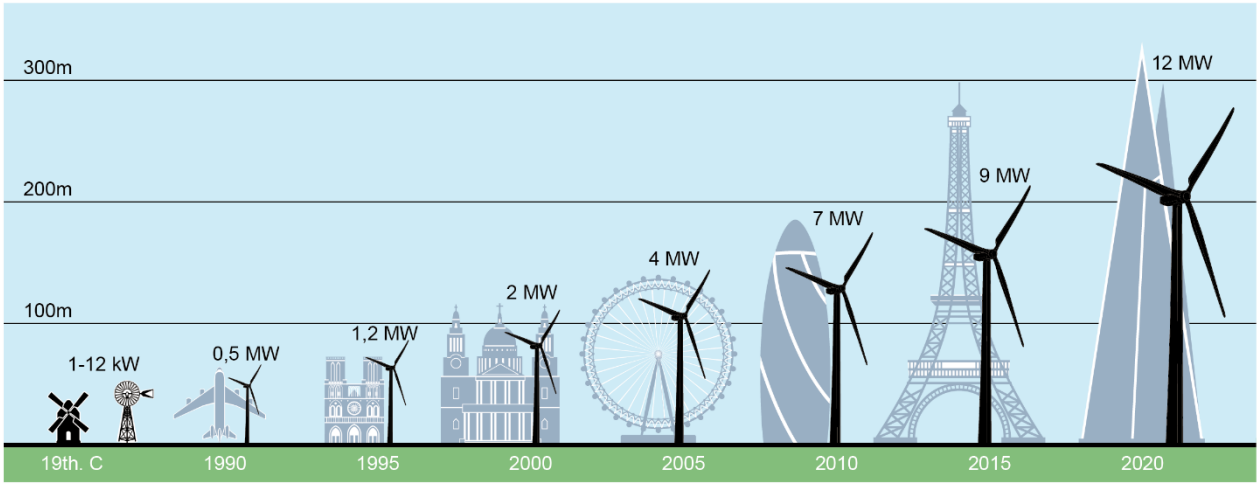
Danish wind energy industry accounted for approximately 70% of the national energy exports and an estimated 40% of the wind energy market globally.

Many of the older, smaller and inefficient wind turbines were decommissioned, and some were replaced with the much larger and more efficient modern wind turbines (see Figure 5). The initial investment costs of these modern wind turbines did not match a typical household budget, or even a wind farm cooperative budget. Unstable and fluctuating electricity prices increased the investment risks involved. As a result, the owners of these modern industrial-scale wind power plants were typically external developers, utilities, private investors or public / private partnerships (Araújo, 2018; Petersen, 2018). Thus, as the turbines and the wind farms grew to industrial scale size, and as the investments and the legal- and technical complexities involved grew accordingly, the role and importance of the wind farm cooperative movement from the early days of wind power in Denmark decreased.

During these years, plans for local wind farms more and more frequently became a source of social and political controversy, and sometimes municipal wind farm planning initiatives lacked political support (Anker, 2016). Resistance to plans for local onshore wind farms became more commonplace, wind farm opposition groups mobilised, and the stories of protests towards planned local wind farms frequently made the headlines (Anker & Jørgensen, 2015; Sovacool, 2013). In other words, as the wind turbines and wind power technologies grew in height, and as the wind power plants gradually became more prominent in the landscape throughout the country, many local wind farm projects faced resistance from a wide range of wind farm stakeholders.

In 2007, a policy shift occurred yet again. In 2008, a broad coalition Energy Agreement was negotiated, and the government once again prioritised RETs and wind farms (Araújo, 2018).

Figure 5: The evolution of wind turbines by year, size and production capacity. Design: Claus Nielsen, Aalborg University, Copenhagen.



3.8 The Energy Agreements and the Renewable Energy Act

The broad political coalition Energy Agreements provide a roadmap and long-term planning guidelines for Danish energy policy, energy planning, and for the ongoing process of low-carbon energy transitions. The Renewable Energy Act (REA)[3] provides the legal framework for planning, deployment and management of renewable energy technologies (RETs), and it gathers all RET related pieces of legislation into one comprehensive legal framework. The first REA was introduced with the 2008 broad coalition energy agreement. According to the Danish Government, the aim of the REA is to promote the harvest and integration of renewable energy resources in the energy system, while at the same time taking into account environmental and socioeconomic factors.

Reflecting the increasing cases of resistance to and social controversy associated with local wind farms, an additional ambition of the first REA was to increase local acceptance of and engagement in local wind farm projects. To this end, it comprised four wind power related policy measures that targeted wind farm 'neighbours', local populations and communities in areas hosting new wind farms (Anker & Jørgensen, 2015, p. 24; Sperling et al., 2010). The four original REA policy measures included the I) loss of property value compensation scheme, II) the wind farm co-ownership scheme, III) green fund/community benefit scheme, and IV) the guarantee fund. As described in Table 1, the four original REA wind farm related policy measures are a combination of community benefit schemes and compensation schemes (Kerr et al., 2017; Sperling et al., 2010).[4] The REA policy measures have been subject to several adjustments throughout the years.

[3] The Renewable Energy Act in Danish: Lov om fremme af vedvarende energi

[4] For a discussion of the REA policy incentive schemes and compensation schemes, see Johansen and Emborg (2018) and Jørgensen (2020).

Table 1: The Renewable Energy Act Wind Farm Policy Measures

1. The Loss of Property Value Compensation Scheme The loss of property value compensation scheme ensures that property owners and potential wind-farm 'neighbours' are compensated financially if new wind-farm projects reduce the value of their property. Claims for loss of property value compensation are free for properties within close proximity to the planned wind farms. For properties located more than six times the total height of the planned wind turbines from the wind-farm site, a fee of 4000 DKK applies. This fee is reimbursed if the compensation is awarded. The developer and wind-farm neighbour may agree upon a suitable compensation fee, or the valuation authority (Taksationskommissionen) may determine the amount. The compensation is the responsibility of the wind-farm developer. The loss of property value compensation scheme also applies to nearshore wind farms.
2. The Wind Farm Co-ownership Scheme Minimum of 20% of wind farms are offered for sale to members of the local public in the form of shares at cost price. The wind-farm shareholders then form a wind-farm cooperative following the criteria set out by the Renewable Energy Act. Citizens must be a minimum of 18 years of age to invest in wind-farm shares. Summerhouse owners must have owned their property for more than two years and not rent the property for commercial purposes to invest in wind-farm shares. The following list indicates those qualified to invest in wind-farm shares: A) Citizens with permanent residency address within 4.5 km of the wind-farm site. B) Citizens who own a summerhouse located up to 4.5 km from the wind-farm site. Shares not sold within the time limit of 8 weeks (for the first round) are then offered to the following: C) Citizens with a permanent residential address in the wind-farm host municipality. D) (For offshore wind farms) Citizens with a permanent residential address in a municipality with a coastline of up to 16 km from the wind-farm project sites.
3. The Green Fund When municipalities host a new wind farm, the municipality could apply for financial support for projects or initiatives that benefit local citizens through the Green Fund. The fund supported projects that strengthened landscape and recreational values, cultural activities, and dissemination promoting the acceptance and use of renewable energy resources in the municipality. The Green Fund generated 88 000 DKK/MW of wind power installed. The Green Fund expired on February 20, 2018.
4. The Guarantee Fund The Guarantee Fund supports preliminary wind-farm project investigations by local wind-farm initiative groups. The Guarantee Fund applies for onshore and offshore wind-farm projects. These wind-farm initiative groups must have a minimum of 10 members, and the majority must be registered by permanent residency address either within 4.5 km of the planned project site or in the wind-farm host municipality. For non-tender offshore projects, the majority of the initiative group must be registered by permanent residency addresses in a municipality with a coastline up to 16 km from the wind-farm project site. The maximum amount granted

from the Guarantee Fund amount is 500 000 DKK/project. If the projects are not completed, reimbursement is not required unless the project is taken over by other people or groups (Energi- Forsynings- og Klimaministeriet, 2018; LBK 119/2018).

Note: The Renewable Energy Act (REA) policy measures for promoting local engagement in and acceptance of local wind farms. For any recent updates of the REA, go to www.retsinformation.dk and search for the REA, Lov om fremme af vedvarende energi.

As plans for onshore wind farm projects increasingly became the source of social controversy, offshore wind power technologies rapidly matured, and the offshore wind energy industry grew. In 2002, the largest offshore wind farm in the world at the time (Horns Rev I) was constructed off the coast of West Jutland, Denmark (Horns Rev I: 80 2 MW wind turbines; total capacity: 160 MW) (Meyer, 2007; Orsted, 2020; Quartz+co, 2015). In 2010, a wind farm off the coast of the island of Anholt (Anholt Havmøllepark) was, again, the largest offshore wind farm in the world at the time. Anholt Havmøllepark generates enough electricity to supply approximately 400 000 households with electricity for a year (Anholt Havmøllepark: 111 wind turbines of 3.6 MW. Total capacity: 400 MW) (DEA, 2016; Orsted, 2020).

3.9 2010s: The Offshore Wind farm Sector Grows

The 2012-2020 broad political coalition Energy Agreement followed in the footsteps of the 2008 Energy Agreement, and it comprised ambitious energy efficiency targets and plans for the integration of more renewable energy resources in the energy system. The 2012 Energy Agreement included plans for nearshore wind farms. The argument for siting these wind farms closer to the cost (nearshore) rather than further offshore was the relatively lower cost of near-shore wind farms (Danish Government, 2012). However, this 450 MW multisite nearshore wind farm tender proved highly controversial among politicians, the experts involved and members of the public (DEA, 2013, 2017b; Johansen & Upham, 2019). The company Vattenfall won the wind farm tender, but public protests, and subsequent legal disputes, delayed the process an estimated three years. Interestingly, the 2018 broad political coalition Energy Agreement refers specifically to the social controversy associated with these nearshore wind farms, and therefore prioritises offshore wind farms further from the coast (Danish Government, 2018).

In summary, from the first primitive wind turbines in the late 1800s, to the world wars and the energy crisis in the 70s, this historical account has shown how the emergence and the evolution of wind power technologies in Denmark was intimately intertwined with historical events, social and political change, and subject to varying levels of public and political support.

While the collective memories of energy scarcity and public anti-nuclear sentiments called for *alternatives* to oil and to nuclear power, the growing environmental awareness in the following decades translated this emphasis to the focus on *renewable energy resources* and to the notion of *sustainability*. The policy priorities were now energy independence and diversity in the mix of locally

available renewable energy resources, with wind energy and wind power technologies at the top of the priority list.

However, as the wind power plants gradually grew to industrial scale and height, resistance to local wind farm projects became more the norm than the exception.

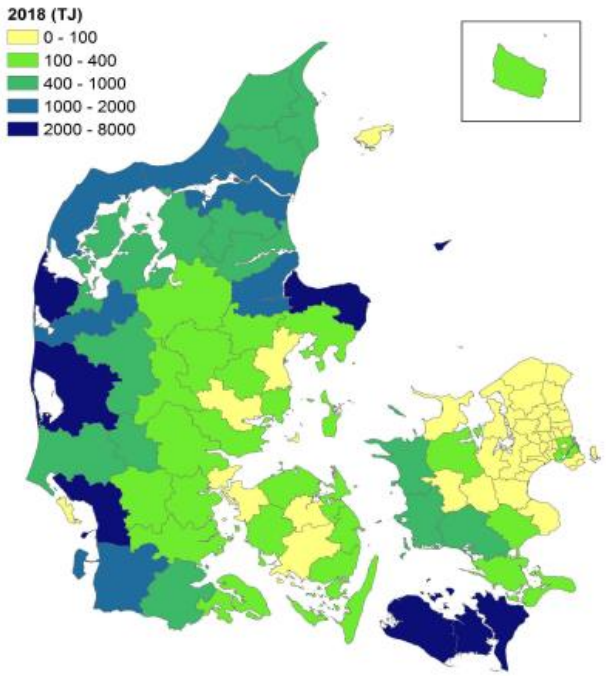


Figure 6: Onshore Wind Power in Denmark by Danish Municipalities**. Notes:** The total national wind power production was 50.0 PJ in 2018. Onshore wind farms produced 66.7% of this total while offshore wind farms produced 33.3%.The west coast of Denmark is relatively windy, and municipalities in this western part of the country (in western Jutland) host more wind farms than the rest of the country. 51.9% of the onshore wind power produced 2018 was from just 10 Danish municipalities (shown in blue). Source: DEA (2019).

Figure 7: Onshore and Nearshore wind farms in Denmark. Nearshore: Middelgrunden wind farm. Onshore: Lynetten wind farm.

4. Discussion

Drawing upon this historical account of the emergence and the evolution of wind power in Denmark, this section reflects on the importance and role of specific historical events, public sentiments, and it touches upon and discusses recurrent themes and grievances among wind farm stakeholders. The discussion also touches upon windfarm ownership models, and the inherent dilemmas of wind farm planning and deployment. Insights, lessons learnt and lingering questions may prove valuable and inspirational elsewhere.

4.1 What Wind Farm Stakeholders Care About

An informative body of research has mapped key recurrent themes and concerns that commonly preoccupy the local public and other stakeholder groups facing local wind farm projects (see Ellis & Ferraro, 2017). These include: concerns for local flora and fauna, visual wind farm impact, noise; wind farm ownership structures and commercial interests, wind farm impact on property value, and a wide array of issues associated with the notion of environmental justice (Aitken, 2010; Devine-Wright, 2009, Ellis & Ferraro, 2017; Johansen & Emborg, 2018; Upham & Johansen, 2020).

The topic of wind farm ownership structures is widely discussed, and some hold that local and cooperative ownership is the key to increased local acceptance of local wind farms. This may - in part - be true. However, the wind power ambitions set out by the Energy Agreements necessitate industrial scale wind power plants (see Figure 5). Taking this into account, rationales such as the above may sometimes fail to consider the technical and legal complexities, and the magnitude of

the necessary investments involved. The question lingers; has the industrial scale of modern renewable energy infrastructure projects perhaps outgrown the cooperative ownership model from the early days of wind power in Denmark?

Inspired by the rich history of cooperatives in Denmark, the Renewable Energy Act Wind Farm Co-ownership Scheme (WCS) was designed to enhance local acceptance of and engagement in new local wind farms; to nudge local bottom-up support for these local large-scale renewable energy infrastructures. The REA requires that minimum 20% of the local wind farms are offered for sale to the local publics as wind farm shares at cost price, and according to specific criteria set by the REA (see Table 1). Thus, the WCS comprises policy ambitions conceptually aligned with the notions of environmental justice and distributive justice (Walker, 2012).

However, recent research illustrates that the WCS does not sufficiently compensate for or target the wind farm related grievances experienced by the local wind farm stakeholders, as these grievances relate to values of a different ontological character, as it were, than the monetary goods targeted by the WCS (Johansen & Emborg, 2018). In other words, contradictory or irreconcilable sets of values and moral dilemmas among the wind farm "neighbours" and stakeholders act as barriers towards realizing the full remedial or compensatory potential of the WCS. These socio-psychological dynamics may mirror the inherent paradox of a top-down policy incentive scheme that aims for bottom-up engagement and support. Empirics from related research suggests (and perhaps not surprisingly) that similar socio-psychological dynamics inform perceptions of and reactions towards locally planned wind farms (or other RETs) among at least some RET stakeholders, regardless of the ownership model or type (Ellis & Ferraro, 2017; Johansen, K. 2018; Upham & Johansen, 2020).[5] Importantly, while compensation- and or incentive schemes may not completely compensate fully for any environmental injustice perceived by some wind farm stakeholders facing new local wind farms, they will help.

4.2 Proactive Opposition Groups and Representation Biases in Wind Farm Debates

The wind farm planning body of literature within the social sciences is mostly qualitative, and it focuses almost entirely on the *resistance* to wind farms.[6] Similarly, the media coverage is most attentive towards arguments and grievances from among the wind farm *opposition*, and opposition groups are often very proactive in the wind farm related debate via social media and various other available channels of communication. This was also the case in the controversial 2015-2016 DEA multisite nearshore wind farm tender (Johansen & Upham, 2019).

[5] For example, the bottom-up initiative and innovative joint ownership model for the three wind turbines on the harbor in the town of Hvide Sande (150 meters in total height) are widely celebrated among wind power professionals and researchers. For more information about this project, see e.g. shorturl.at/msCJ3. According to multiple criteria this is, indeed, a best case RET planning scenario. However, in the survey data referred to in section 4.3, some drawn from close to the coast in Hvide Sande, multiple respondents specifically described their opposition to and contempt for precisely this wind farm project.

[6] See the literature list in this review report (Ellis & Ferraro, 2017).

Surprisingly, however, survey data collected during this tender revealed what proved to be a silent majority of local permanent residents *supportive* of the planned local wind farms. In the wider near-shore wind farm tender debate, grievances and arguments from among the very active (minority) opposition groups frequently made the headlines, while the silent and positive local majority attracted all but no media attention (Johansen, K. 2019; Johansen & Upham, 2019). This suggests that resistance to plans for local RETs is not necessarily *only* local in nature, that RET related debates may be controlled by (perhaps minority) opposition groups, and that the media tendency to focus on and to favour the *opposition* further amplifies any biases of proactive participation in the RET related debates. This relative dominance of negative emotions associated with e.g. resistance and opposition over acceptance, and here in the RET related debates, is a socio-psychological phenomenon familiar within the social psychology domain of research (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Baumeister & Bushman, 2008).

Awareness of any such potential representation biases in RET related debates, and in the media, is fundamental for low-carbon transition processes, as these debates ultimately inform RET related planning and policy (Upham, Bögel, & Johansen, 2019). Moreover, this suggests that perhaps we should regard social and political controversy in wind farm and other RET planning as the norm rather than as the exception.

Figure 8. Wind Farm Visualizations from the EIA Material and by an Opposition Group. **Note:** Above. Visualization of a near-shore wind farm from the Environmental Impact Assessment (EIA) material for the 2015-2016 Danish Energy Agency nearshore wind farm tender. This EIA material is publicly available online(Energinet.dk. NIRAS. URLAND, 2015). Below: Visualization of the same wind farm project at approximately the same location as depicted by the STOPVesterhavSYD wind farm opposition group (Vesterhav Syd: name of the planned wind farm). As a part of their campaign against these nearshore wind farms, the STOPVesterhavSYD wind farm opposition group posted their version of the wind farm visualization as an advert in a nationwide newspaper.

5. Conclusion and Policy Implications

This paper explored the history of wind power and the integration of wind energy in the Danish energy system. It focussed first and foremost on the policies, socioeconomic and sociocultural changes, challenges and dynamics important on this technological journey. From the first primitive wind turbines in the late 1800s, to the world wars, through the energy crisis in the 70s, and into the decades of growing environmental awareness, this historical account traced the gradual technological advances of the Danish wind power technologies, and it described how top-down and bottom-up initiatives informed, supported and ultimately shaped the emergent wind energy sector. From the bottom up, the collective memories of the global energy crisis and antinuclear sentiments called for alternatives to oil and nuclear power, and throughout the country, local wind farm cooperatives jointly invested in wind turbines or smaller wind farms. From the top down, energy policies focussed on energy diversification, energy efficiency and energy independence. The growing environmental concern in the following decades led to increasing focus on *renewable energy resources* and the notion of *sustainability*. Policy priorities were now energy independence and diversity in the mix of locally available renewable energy resources, with wind energy and wind power technologies at the top of the priority list. Throughout history, wind power has been widely popular among the Danes. According to opinion polls, it still is.

However, as the wind turbines gradually grew to industrial scale heights, unchallenged support for local wind farms could no longer be taken for granted. Noting these changes in public sentiment, this paper touches upon the inherent dilemmas of wind farm planning and deployment, for example issues related to environmental justice, ownership structures, and the role of social psychology for low-carbon energy transition processes. Attention is also drawn to the representation biases that may result in the emphasis of wind farm opposition/ grievances in the wider wind farm related debates, where resistance to local wind farm projects might derive from minority opposition groups. Insights and lessons learnt from this Danish history of wind power may be valuable and inspirational for other countries engaging in low-carbon energy transitions.

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