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'Sticky' Policies—Three Country Cases on Long-Term Commitment and Rooting of RE Policy Goals

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Abstract: Denmark, Germany, and Finland are countries that have emerged as technology leaders in key renewable energy fields—wind energy, solar power, and bioenergy. In this article, we dig into the policy trajectories of these countries and concentrate particularly on a phenomenon that is common for them all—the long-term commitment to promoting particular renewable energy (RE) technologies. Analyzing commitment, its causes and its consequences, can be considered important, as earlier findings show that long-term, consistent policy signals are a key for policy success. In this article, we point out that this 'sticking' to a RE technology has emerged and manifested in multiple ways in the case countries. Examples include relying on existing cultural capacities when navigating energy policy direction, strategically promoting scaling of technology markets to root new energy practices in society and developing energy policies as an extension of existing socio-technical structures. In order to understand these dynamics in more depth, we utilize literature on policy robustness and resilience. While all the case countries, Denmark, Germany, and Finland, have generated robust RE policy goals, Finland has failed to foster resilience simultaneously. We conclude that analysing stickiness of policy elements can be fruitful when seeking to understand and design transformative policies. Further, it can be taken as a complementary analytical perspective in the policy mix studies.

Keywords: renewable energy; policy mix; adaptiveness; robustness; resilience; Denmark; Germany; Finland; wind energy; solar power; bioenergy

1. Introduction

Increasing the share of renewable energy (RE) in the energy palette is one of the key measures to combat climate change and to promote energy security, self-sufficiency, and environmental health, among other things. Europe has set the target to cut at least 40% of greenhouse gas emissions (from 1990 levels) and to reach the 27% share for renewable energy by 2030 [1]. However, it has become apparent that more radical and cross-cutting transformations are needed [2], and the EU has pledged to achieve carbon neutral economy by 2050 [3].

Though the EU is approaching the climate challenge as a unit, the member states differ greatly in their political cultures, available resources, and industrial histories, which has affected the RE support policies. RE sources, for example, wind energy, solar power, and bioenergy also differ greatly in their availability, means of production, innovation potential, and spillover effects to society. Despite the occasional calls for EU-level instruments to support RE adoption or even scrapping RE policies altogether to support more effective climate policy [4,5], the RE policies have remained an important element of national constituency.

In practice, the national RE policies take the shape of policy mixes that emerge through processes of policy change with shifting policy goals, as well as the addition and subtraction of elements

over time [6,7]. The policy mixes are not result of conscious design but emerge incrementally as different policy goals and sectoral demands are navigated. Recent studies have shown that the number of instruments in the RE policy mixes has been growing in the EU and around the world [8,9], which signifies the growing importance of the policy area. Multiple instruments are required for overcoming constraints of technical, institutional, political, and economic realities [10].

As the RE has become mainstreamed in the field of energy policy, Denmark, Germany and Finland have emerged as leading developers and implementers of key RE technologies, wind energy, solar power and bioenergy. Through historical developments and political commitments, the three countries qualify for fairly different types of technology leadership, as the three RE technologies differ significantly in their requirements. Germany's 9867 solar technology patents, between 1990 and 2016, equal about 25% of all RE technology innovations in Europe. At same time frame, Denmark has produced 2862 wind technology patents, which is significant for a country of Denmark's size and has resulted annual technology export revenues of about \$3.5 billion. Finland, meanwhile, has not been a successful technology innovator (526 RE patents between 1990 and 2016), but has relied more on the implementation of existing technologies in gaining RE prominence. See Table 1 for more details.

The countries were chosen to the study not only because of their relatively large RE production amounts, but also because they provide different insights into policy 'stickiness'. Earlier RE policy studies have shown that, long-term, consistent policy signals have been important drivers for policy success [11,12]. Denmark, Germany and Finland differ from each other in terms of policy making cultures, natural resources, and technological capacities. What is common for them, however, is their long-term commitment to particular RE technologies. They have all been able to maintain policy support schemes for specific RE technologies over decades despite challenges and changing political currents.

In this paper, we focus on these 'sticky' policy signals to analyze their causes and consequences. When describing the analysis, we discuss both the top-down commitment to particular RE policy goals and the bottom-up rooting of those goals. The idea of stickiness has been well-founded in the practice studies on energy consumption, as people get caught up in specific habits that are difficult to change [13]. However, in the sphere of RE policy making, stickiness of policy elements has not been explicitly discussed, even though path-dependency is a well-established notion and the concepts of policy robustness and resilience can offer fruitful tools for analyzing the phenomenon [14,15]. Policy robustness and resilience shed light on the deeper roots of policies within the existing socio-technical regimes, as well as their natural and cultural landscapes. We define sticky policy elements as policy elements that are robust and/or resilient enough to stick with the predominant policy mix for a long time, despite changing conditions.

This paper utilizes the stickiness lens in analyzing the long-term policy trajectories of European RE technology leaders. At the end of the article, we broaden the discussion on the potential of using policy stickiness as an interesting contrast to policy disruption [16] and the opportunities of using stickiness to analyze complex RE policy mixes in more depth. The key questions to be discussed include: How have Denmark, Germany, and Finland sustained long-term policy signals to promote certain RE technologies? What kinds of robustness and resilience characteristics are indicative of the policy stickiness in the RE context? Can the stickiness approach offer added value to policy mix analysis?

The rest of the paper is structured in four sections. In the following section, we provide a comprehensive overview on the development of energy policies in the case study countries since the 1970s. In section three, we provide the conceptual framework based on the literature on policy robustness and resilience. The subsequent section discusses key aspects of policy stickiness in the case countries. The final section draws conclusions for future research, particularly from the policy mix point of view.

2. Commitment and Rooting in Action: The Cases of Three European RE Leaders

In this section, we present the three RE policy cases from Denmark, Germany, and Finland. The cases deal with the ways how the specific renewable energy technologies have gained prominence

in the energy policy mix over long period of time. In the sphere of energy and climate policies, Denmark, Germany, and Finland share certain turning points, such as the oil crises of the 1970s, Chernobyl nuclear disaster, and those related to European and international climate policies. The three countries are open economies that have long been relying on global export and import markets in their innovation and industrial policies. The countries also differ in historical, societal, and environmental conditions, and distinct country-specific policy choices that have diversified their paths. For example, Germany is a federation by its government type and a leading industrial country with a large internal market to create demand and support industry on different sectors. Meanwhile, Denmark and Finland are smaller Nordic welfare states that are very dependent on exports to provide support for their industry.

The promotion of RE in the attempt to reduce the carbon emissions of society has been central in EU-level policy making. Since 2000, there have been distinct phases of RE targets. Initially, the Renewed EU Sustainable Development Strategy stated as its primary goal that 12% of the energy consumption and 21% of the electricity consumption should be met by RE sources by 2010 [17]. Subsequently, the ambition level was raised in the Europe 2020 Strategy and at the Directive 2009/28/EC to 20% share of energy from RE sources to be attained by 2020 [18,19]. Finally, a new and binding EU-level target of 32% of overall energy production from renewables was set for 2030 in the Directive 2018/2001 [20]. Nevertheless, the mobilization of these targets has remained at the constituency of the member states, resulting in varied interpretations rooted in uneven resource bases, national policy making cultures, and different societal structures.

Table 1. Sticky R&D efforts and results: The amount of RE technology patents (wind, solar, and biofuels) in the case study countries between 1990 and 2016 and the average state direct R&D expenditures [21,22]. As the bolded numbers show, the analyzed countries have concentrated particularly on certain technologies in their R&D efforts—and this has also paid dividends in most cases.

	Denmark	Germany	Finland
Average R&D expenditure on RE	41.6 M€ (41% on wind)	151.2 M€ (49% on solar)	20.8 M€ (76% on bio)
Total patents	3404	16,387	526
Wind patents	2862 (84%)	5389	138
Solar patents	191	9867 (60%)	166
Biofuel patents	350	1130	222 (42%)

The three countries in focus have been proactive in developing technology specific policies for renewable energy, increasing the share in the national energy mix, and creating economic benefits in terms of jobs, technology exports, and patents. However, all the countries have also faced adversities in ‘sticking’ to the technology of their choice. Table 1 provides a summary in terms of the research and development (R&D) expenditures for RE technologies in the case countries and the cumulative number of patents since 1990. The table illustrates that over the 26-year period, Denmark has generated 20% of the wind energy patents in the EU and that about half of the solar technology patents in the EU have been issued in Germany. However, Finland’s focus on biofuels has not translated in innovation success, though it has been a key in achieving several other policy goals.

2.1. Wind Energy Policy in Denmark

Over the last two decades, Denmark has become an important player in the growing wind energy technology markets, which reflects long-term developments in policy, the economy, and society more generally. Wind energy is broadly applied in Denmark, already surpassing 50 TJ production capacity in 2015, which equals 42% of the overall electricity production [23]. In roughly two decades, the energy system of Denmark has transitioned from a centralized electricity network based on large-scale fossil-fueled plants to more dispersed one featuring wind turbines and smaller combined heat and power (CHP) units [24]. However, the roots for this transition are much longer.

The political promotion of wind energy production started in Denmark in the aftermath of oil crises in the mid-1970s [25]. Moreover, the long-standing political debate on the role of nuclear power in Danish energy production catalyzed the emergence of non-governmental organizations (NGOs) advocating for wind power, that were central in gathering policy support for wind power [26]. Peculiar in the Danish approach is the early government commitment to fostering alternative sources of energy by combining both bottom-up and top-down approaches, which is also often named as the key to the initial success in Denmark [11,25,27,28].

From the bottom-up perspective, there are three important elements in the Danish wind energy policy. First, many of the Danish wind energy facilities are owned by local actors, such as municipalities and farmers. Farmers and rural households have been ensured a chance to join local cooperatives in the near-by municipalities, and exclusive local ownership has been a condition for the operating permits of wind power plants. In addition, the energy utilities can build large wind farms only in agreement with the government, when not violating the wishes of local farmers and residents. The grid access is guaranteed, and the cost of interconnection is paid by the consumers [24].

Second, local testing of the immature technologies has been actively promoted, which provides market references and has enabled the development of reliable small wind turbines [25]. The Danish regulators have worked with manufacturers and interested citizens since the 1970s to better understand the development of renewable technologies and markets [28,29]. Third, the Danish planning system has divided responsibilities between the national and local levels quite successfully [28]. The national planners have developed appropriate guidelines, whereas the local planners and cooperatives have focused on the wind power plans and supported locally relevant projects. These elements have aligned practical experience and incremental learning-by-doing to enable long-term developments.

The top-down policy support, meanwhile, has strongly relied on the sustained feed-in tariff (FIT) for wind that was established in the early 1990s, requiring utilities to buy all power produced by renewable energy technologies at a rate above the wholesale price of electricity in a given distribution area [24,25]. It should be noted that, recently, Denmark has turned from fixed feed-in tariffs to tenders in response to the state aid guidelines by the EU Commission. The first off-shore wind power auction was held in 2015 and the first technology neutral tender for on-shore wind turbines and solar PV installations in 2018. In general, however, FIT has been considered the stimulus needed for widespread market development that has allowed projects to move beyond wind enthusiasts and involve wider variety of actors [30].

In addition, the ongoing support mechanisms through various energy acts [11], such as the investment subsidy provided for individuals, municipalities, and farming communities between 1979 and 1989, have been instrumental in achieving the early expansion of the capacity and in familiarizing actors with the technology. On the national level, coordination of the energy system, the strong integration of the energy supply companies in developing the distributed production system, and the refunding of CO₂ and energy tax to wind turbine operators have been important [25]. Moreover, the active research policy has managed to balance R&D funding for innovation with procurement support to enable the diffusion of wind energy technologies.

The resources have been balanced between different kinds of actors in the energy field. For example, funds to empower independent lobbyists have been allocated by Parliament for technical pilot projects, energy offices, and independent research centers [30]. This has been stimulating diversity, as it allows development in a range of locations, technologies, and project sizes, spreading the benefits to diverse participants [11]. However, in 1998–2007, there was a period of pendulum in the policy support seeking to match the liberalized energy markets with policy objectives that favored larger scale wind turbines [11,24,31]. On the ground-level, the change resulted in the development of larger wind turbines with less local involvement, which reduced the societal support for wind energy policies. The policy change stagnated the development and domestic market of wind energy and was reverted after the turbulent period [11,24].

For the time being, wind power is reaching a dominant position in the Danish energy system, but the long-term policy development for wind power has not come without drawbacks. Problems of wind power intermittency and storages require market integration of electricity, heating, and fuel markets, as well as strengthened transmission lines to other electricity pricing areas. These are technical and economic issues that need active policy coordination. Currently, the combined heat and power (CHP) units suffer from low profitability due to low power prices in the Nord Pool area. Moreover, the local acceptability of wind power is not guaranteed, as the ownership in off-shore wind power projects and larger on-shore projects has shifted more to the bigger companies [26]. Finally, the large amount and diversity of actors has made the Danish policy making more complicated, which might also reduce the ability to cope with currently pressing system-level challenges [24].

2.2. Germany's Solar Power Policy

Germany is one of the leading countries for the development of renewable energy, especially in the European context [32]. The German photovoltaics (PV) installation capacity is the largest per capita in Europe and it has also been the leading country for solar energy innovations in terms of generated patents (see Table 1). Germany had 45.9 GW worth of installed solar PV capacity in 2018—covering almost 9% of Germany's net electricity consumption [33]. Moreover, German innovation activities have helped to create a global market for certain RE technologies over the last two decades.

The first steps in the German renewable energy policy were also taken after the oil crises in 1970. The key policy in the renewable energy sector, the RES-E legislation, was introduced in 1979 [34]. Thereafter, the German RE policies have been very technology-oriented, which has affected the R&D activities, market creation, and more general societal support for solar technologies.

The systematic installations of residential PV systems started under the 1000 roofs program in 1989. The government subsidized individuals to cover the costs of installing a PV rooftop system. The aims of the program were to gain experience with solar installations, make new housing compatible with renewable electricity generation needs, and stimulate consumer usage of solar power [11,35]. The program was also complemented by feed-in tariff for solar electricity introduced in 1991. Though the support for RE was not widespread, and the installations increased slowly until 1999 [11,36], this phase created foundation and societal demand for the later policies.

The political situation at the federal level allowed that the experiences gathered by numerous local initiatives in the 1990s were translated into a strong federal market support scheme [37]. A period of rapid growth in solar installations started under the program 100 000 roofs (1999–2003) that was designed to scale up the earlier activities to the national scale. Additionally, the FIT was updated in the 2000 introduction of Renewable Energy Sources Act (EEG) and it guarantees a higher-than-market price for electricity generated by solar PV [34,36]. The price rate was fixed for 20 years beyond the installation date, providing investment certainty for firms and individuals.

Despite the introduction of Germany's federal, cost-covering FIT scheme and the removal of the cap on policy-supported market growth, the increase in installation numbers was tempered by rising module prices in 2004–2008. The period between 2009 and 2011 represented the steepest growth in annual installed capacity and was characterized by a drastic decline in module prices. Growing employment in the industry further bolstered the sector's political clout, and the rapidly emerging solar industry played a central role in justifying the increase of the solar feed-in tariff in late 2013 [37]. The cumulative installed PV capacity increased 196-fold in 2000–2011 [35]. At the same time, Germany established itself as the main driver of global demand and enabled the growth of many German solar manufacturing start-ups, establishing a presence along the entire PV value chain.

The German solar power promotion has not only involved various domestic stakeholders in industry, society, and policy making, but it has enabled co-development of German and Chinese PV industries and markets. The exponential solar installation growth after 2008 was launched by the market introduction of the cheaper Chinese components. Thus, the German policy orientation in the solar PV deployment has not translated into the expected competitive advantages, but it has been

successful in rapidly scaling up the local technology experiments and shaping a global market for solar PV technologies [37].

The German 'Energiewende' (Energy transformation) has also boosted the promotion of RE technologies after the Fukushima nuclear disaster in 2011. The decision was to reduce the share of fossil fuels from 80% to 20% of the energy supply by 2050 and enhance the nuclear phase-out by 2022 [38]. Consequently, the new Renewable Energy Sources Act was introduced in 2012 to facilitate the development of sustainable energy [34,36]. Although the 'Energiewende' has become famous in Europe and globally, the share of renewable energy is still rather modest in Germany [35].

On the one hand, the German RE policies have been successful in utilizing large domestic markets and industrial structures in constituting global market development for the solar PV. This has provided lots of societal spillover effects in terms of employment, innovations, and dispersed electricity production. On the other hand, the technology-oriented policies have been criticized for being expensive. German households have been paying some of the highest electricity rates in the EU [34], and it has been questioned whether Germany will be able to meet its green industrial policy aims at reasonable cost [32]. The total amount of subsidies paid under the feed-in-tariff system in Germany increased from less than a billion Euro in 2000 to 26 billion Euro in 2016 [39].

Thus, there have been growing calls for technology neutral policies, which have been determined more cost-efficient in the short run [40]. Solar power can no longer be considered a niche technology in Germany and the share of the intermittent renewable electricity capacity is growing. This has raised discussion on the need for system and market integration [5]. In response to the rising costs, feed-in tariffs have been lowered continuously. The solar power cap has been set at 52 GW, after which the feed-in tariff will no longer be paid. Moreover, the EU Commission's state aid guidelines push EU member states towards renewable energy tenders. Germany started its own auctions of renewable energy in 2015, after which support levels for solar power have fallen even further [33]. Despite the shortcomings, 'Energiewende' has been a regime shift that has altered the German technological, political, and economic structure [39].

2.3. Finland's Bioenergy Policy

Finland is one of the countries in which RE has the highest share in the primary energy supply [41]. Over the past 30 years, the share of bioenergy has been growing. In 2016, it reached 51% of the primary energy production and enabled Finland to reach its renewable energy targets well in time [42,43]. It should be noted that bioenergy differs from solar and wind power in two key ways that have policy implications: It is combustion-based energy production and it relies on natural resource supply. These two features also condition the energy policies, since the industrial and societal networks are profoundly different. Therefore, the emergence of bioenergy in Finland is related as much to shifting power relations in natural resource governance as the development of energy technologies, policies, and business activities.

On the household-scale, wood heating has had a central position in Finland for centuries. However, the development of larger-scale bioenergy use in the combined heat and power (CHP) production did not take place before the 1970s. The oil-crises caused a market shock that led to rapid conversion of local oil-based CHP units for bioenergy, which was supported also by investments from state research and innovation programs. The development was, however, countered by industrial interest groups that started active lobbying for the primacy of industrial forest use against dispersed bioenergy developments. In addition, these interest groups demanded that the nuclear energy power capacity in energy supply should be increased [43,44]. These efforts by the industry actors proved highly successful and have led to a central role of the forest industry in the Finnish energy sector [43].

Nevertheless, the national-level shock in the 1970s led to the formulation of energy policy principles that emphasize energy self-sufficiency, security of supply, and access to inexpensive energy [45]. Bioenergy also had a role to play in fulfilling these ideals, but the use of biomass for energy became increasingly interpreted as part of the existing forestry infrastructure [46]. The policies

have therefore been shaped to support incumbent actors, as almost 90% of bioenergy has consisted of forest industry by-products [42].

The main bioenergy policy instruments include research and development and investment support, energy tax exemptions and rebates, and information provision that have remained in place over the decades with gradual modifications to target specific bioenergy sources. New instruments, such as the feed-in tariff scheme and biofuel distribution obligation in the transport sector, have been introduced and layered at the top of the existing policies. The layering has taken place when new policy goals, such as climate targets, have emerged [47].

However, there have been more fine-grained dynamics taking place behind the linear top-level development. Especially since the turn of 1990s, the number of small-scale heating plants, utilizing forest residues as their main resource, has increased quickly [48]. While the total amount of energy produced by these plants is small in the context of the whole bioenergy system, their existence has changed local forestry practices, created jobs, and improved energy self-sufficiency of communities [48]. Further, the emergence of smaller-scale bioenergy applications such as wood gasification, biogas, and house-specific heating solutions have created space for a more diverse set of actors, such as farms, micro-businesses, and service providers in the bioenergy sector. Moreover, the massive structural changes in the pulp and paper industry have become drivers for the bioenergy policy since the early 2000s. The reason is that energy use has been interpreted as the only existing alternative for the closing of paper factories. In practice, climate policy has been used as a political justification for bioenergy development and it has utilized the space opened by the stagnant forest industry and structural changes in agriculture [43,49].

The latent rupture between industrial and communal framing of bioenergy development surfaced in 2011, when the government decided on the subsidy scheme for energy wood as a key policy to achieve the renewable energy targets for 2020. In the discussion, small-scale energy producers and forest owners wanted to change 'the rules of the game', gain more access in decision making and diversify the definition of bioenergy. However, after several rounds of deliberation and intervention by the European Commission, the industrial status quo was maintained [50].

In the recent developments reflecting EU-level discussions on the role of the land use, land use change and forestry (LULUCF) sector, the leading position of bioenergy has become questioned also in the terms of the actual, verifiable carbon reductions. The reason is that bioenergy production is still largely based on combustion and the existing forest management practices disturb the soil carbon balance in certain ecological contexts. The public debate has been especially vivid around stump removal for energy production. Stump removal has the most suspect climate impact by reducing the biogenetic carbon storage and it is often linked to the municipal energy producers operating the space between the local and industrial definitions of bioenergy [51].

3. Robustness and Resilience as Features Constituting Policy Stickiness

As the cases of wind energy in Denmark, solar power in Germany, and bioenergy in Finland revealed, sticking to a RE technology has become a key part of the long-term energy policy trajectories of the countries. Simultaneously, the developments have affected the ways how energy is perceived by citizens and communities, what kinds of economic activities emerge, and what kinds of natural resource policies are favored. When seeking to understand the different types, manifestations, causes and consequences of this sticking, it is useful to draw from the theories of policy robustness and resilience.

Over the last three decades, there has been a rising interest in robustness and resilience in several policy fields, such as climate change, environmental policy and risk management, and among scholars of comparative politics who are interested in institutional design [52,53]. The concepts are utilized to understand policy change and stability because they refer to the ability of policy to cope with both external shocks and internal perturbations [15,54]. However, rather than focusing on e.g., the role of specific instruments in a policy mix, robustness and resilience attach attention on the underlying societal dynamics that lead to certain selection processes among other things.

Robustness has been described as the ‘ability of a system to withstand perturbations in structure without change in function’ [55] (p. 14). In more specific terms, robustness can be seen to reflect the capacity of a policy to adapt to anticipated conditions and self-adjust to linear changes in its environment. Robust but adaptive policies maintain the function of the policy, while robust and stable policies maintain their actual state. For example, the Danish wind power policies maintained their goal throughout the liberal policy reforms favoring large-scale wind-parks in the early 2000s, while adjusting—and later re-adjusting—to the changing political power relations [11,24].

In practice, policy robustness generally depends on the competence of governmental policy, as well as the configuration of socio-political interests [15,56]. The following principles are reflected by robust policies [15,57,58]:

- maintain the original definition of a problem and control wider societal agenda-setting
- design general principles of operation and allocate general roles and responsibilities

Due to their intrinsic ability to keep functioning, robust policies might also inhibit policy change [15,59]. The principle of maintaining primacy of the industrial forestry in the Finnish energy policy in general, and bioenergy policy more specifically, is a prime example of creating robust, non-adaptive policy frames. Such frames bind political interests of different actor groups to serve pre-defined policy goals.

Meanwhile, resilient policies can navigate toward successful outcomes in settings that cannot be anticipated in advance [60,61]. Resilience highlights the capacities of policies to adapt to unanticipated conditions and non-linear shifts in their contexts [54,61]. Resilience can be described as an ‘emergent’ rather than ‘static’ feature of systems or policies [54]. Resilience-oriented policy process facilitates more incremental adaptations to the existing policy mix [6]. It highlights learning by doing and multi-stakeholder engagement for policy design and implementation [54,61]. Policy review and multi-stakeholder deliberation support such actions. In general, however, resilient policies reflect the following principles:

- enable self-organization and social networking
- decentralize decision-making to the lowest and most effective jurisdictional level
- promote variation in policy responses

As an example of resilient policy strategy, the Fukushima nuclear accident was met in Germany’s policy context by mobilizing diverse social groups behind the ‘Energiewende’. The rupture was utilized to further scale-up the growing solar energy markets. This led to the commercializing of global solar technology markets on the one hand and the readjusting of expensive subsidy systems on the other hand.

To sum up the bearings of this section for policy analysis, it is worthwhile to differentiate between (1) stable robustness, (2) adaptive robustness, and (3) emergent resilience. In the next section, we will analyze the policy trajectories of our three cases in more detail by using these concepts and by deepening the analysis by concentrating particularly on the feed-in tariff schemes.

4. The Sticky Policy Trajectories of the Three RE Policy Leaders

The three country cases presented in section two can be read as relative success stories in balancing national energy policy interests and reaching the EU-level RE targets. In this section, we use the stickiness lens and the concepts of policy robustness and resilience to sum up the bearings of the cases, to compare them, and to deepen the analysis by paying special attention to the role of feed-in tariff schemes in the policy trajectories. In particular, we seek to answer the first and second research question that we posed in the beginning: How have Denmark, Germany, and Finland sustained long-term policy signals to promote certain RE technologies? What kinds of robustness and resilience characteristics are indicative of the policy stickiness in the RE context?

The Danish long-term wind-power policy has provided local actors, communities, and companies with the stability to take risks and experiment with new technology leading to emergence of new social structures. The policy has encouraged diversity of actors in many frontiers, including research and development, project implementation, lobbying, and planning on different levels [11,29]. At the same time, Denmark has built on the existing structures, respected history, and the local strengths and assets, such as cooperative tradition and long history of utilizing wind energy. Thus, policy has been committed and robust, strongly rooted, and consistent over long periods of time. Yet, it has also featured resilient elements, especially in terms of decentralized decision making and the self-organization of the social networks.

The German solar power policy mix, meanwhile, has oriented more directly around market creation by providing long-term price guarantees for the produced energy. The 1000 and 100,000 roofs programs were designed to generate experiences on solar installations, educate specialists of different sectors, and stimulate broad consumer usage [11,35]. The goal of promoting solar power was rooted to the large internal market and the needs of diverse industrial sectors involved in the innovation activities. While the policy has been criticized for expensive costs [32,34,38], it has still been robust enough to have a long-term influence and to promote e.g., dispersed citizen energy production. The dispersed production distributes also benefits to wider circles and brings stability to energy policy. Though not anticipated, the co-evolution of solar technology industries in Germany and China has benefited from Germany's long-term policy support. Germany has also been able to build on and maintain strong public support for alternative energy paths [7], a resilient policy feature that became central in the development of Energiewende after the Fukushima disaster.

Finally, Finland's bioenergy policy has been largely supported by the actions of the incumbent players, i.e., the forest industry [42,47], which has rooted the energy policy development in the national industrial policies. The prioritizing of energy security, inexpensive energy, and the industrial use of natural resources have been guiding features of the policy. These features have been coded into a policy mix that has favored robust, industrial interpretation of bioenergy policies. Especially the late adoption of the feed-in tariff can be interpreted as a continuation of path-dependency, where the vested policy interests have been transported to the national renewable energy policy. While the industrial framing was favorable in weathering the impacts of the forest-industrial restructuring since the beginning of 2000s, the Finnish bioenergy policy has not been able to take advantage of the alternative technologies and societal networks that have emerged around the dispersed energy production [48]. This successful, but single-eyed, technological orientation has been questioned in light of a wider technology transition that is required to achieve more significant carbon emission reductions [62].

The stickiness of the technology specific policy goals and their societal implications are best examined by focusing on the feed-in tariff schemes implemented in each of the case study countries in different points of time and with varied designs. FIT schemes are policies suited at creating conditions to make renewables more attractive for industries and markets [36], but their effects have had societal effects beyond market development. The design and success of FIT schemes have relied on the contextual features of industrial heritage, natural resources, and social histories, as well as a relatively stable period in the policy making. In a policy mix, FIT is often used to stabilize certain conditions of market demand to enable varied technological, social and economic developments to take place and to reach the next level of technological maturity.

In Denmark, the FIT scheme to support wind power installations and market development was introduced already in 1991 [25]. At the post oil-crises period, the policy guaranteed participation of different types of actors in the wind electricity production from renewable sources and was mobilized to enhance the wide societal rooting of RE technologies, especially wind at the early commercialization state. In Germany, the first FIT implementation for solar power took place in the 1990s with very technology-specific orientation to support market creation and commercialization of the PV technologies. Periodical amendments have been applied to ensure the effectiveness of the policy, which have also resulted in cross-scalar and cross-sectoral feedback effects on the rapidly

expanding global technology markets [37]. Guaranteeing feeding of the produced electricity back to the distribution grid has made solar installations very affordable for the customers and enhanced the conditions for citizen energy production. Finally, in Finland, the FIT was introduced only in 2011 to support bioenergy and biogas production [44]. While the emphasis of the other countries was on market creation for novel technologies, Finland stressed market creation for natural resources that were deemed underutilized in the era of industrial restructuring. However, like Germany and Denmark, FIT in Finland was also implemented to spread out the benefits of climate policy and to create wider societal acceptance for energy policies.

To summarize the broader RE policy trajectories, Denmark, Germany, and Finland have developed technology-specific and relatively robust policy trajectories at times of stable societal development. However, the policies have been rooted to different systems. The Danish RE policy mix has favored more the historical, cultural, and societal elements at supporting e.g., community practices. Meanwhile, the German RE policy mix has focused on market development and trans-scalar impacts on the global technology markets. The Finnish RE policy mix, in turn, has become an extension of industrial policy interests. The policies have functioned well under favorable economic conditions and the stability provided by the EU-level climate policies. However, resilience becomes central in times of political turmoil and societal adversity. From this perspective, Denmark's wind power policies, especially, seem to have featured both robustness and resilience in a relatively balanced manner. Meanwhile Finland's robust bioenergy orientation might have been too straight-forward.

The two elements of adaptive policy making, robustness and resilience, are not antonyms, but rather alternative axes in the same plane of policy development. For the wider policy mixes, the recognition of resilient and robust capabilities is crucial. This is true, especially since stronger policy interventions are needed to support societal decarbonization. The country cases on the evolution of long-term RE technology stickiness, presented in this article, provide important lessons on different means to create commitment and rooting for the transformation at hand.

5. Conclusions

In this concluding section, we address the third research question: Can stickiness approach offer added value to policy mix analysis? On the basis of the study presented in this article, stickiness offers analytical value in examining the broader context of policies and their abilities to maintain their role in the predominant policy mixes for longer times. Further, stickiness allows for the analysis of the mechanisms of policy robustness and resilience and their balance. It may reveal, for example, whether there are too many elements that encourage robustness but also stagnation or resilient but also non-directional floating.

In this paper, we have concentrated on the emergence of technology-specific policy mixes in three country contexts. The policies have been rooted to different elements in markets, society, and industry over the years. However, at the face of the current, rapid decarbonization challenge, there are new avenues to consider, as more disruptive instruments will enter the policy mix. In these developments, the asset of stickiness is that it focuses on the contextual elements that enable sharing benefits of, and participation in, the changing system. In this sense, it forms a fruitful contrast to disruptiveness as a feature of transformative policy mixes [16]: Roughly speaking, disruptiveness addresses the question of how much of the old regime should be abolished for allowing for a new system to take root. Meanwhile, stickiness asks how to enable some policy features to cope over time to allow for a deep societal effect to take place. How to utilize the existing regime and landscape as a breeding ground for change?

In future research, stickiness could be analyzed in the context of policy mixes in more detail. Here, we refer to Rogge and Reichardt [7] that have distinguished as the main building blocks of a wider policy mix: (1) policy elements such as strategies, instruments, and goals; (2) processes, e.g., the cyclic processes that facilitate policy learning; and (3) characteristics such as consistency, coherence, and credibility of policies. In this article, the focus has especially been on the stickiness of technology

specific policy goals in different country contexts. However, stickiness could potentially manifest itself within policy mixes in the following ways:

- The stickiness of elements is signified by goals and instruments maintaining their role in the policy over long periods of time. In an optimal situation, this is an important pre-condition for socio-technical transitions and wider societal transformations, but it may also lead to lock-ins on sub-optimal technologies.
- The stickiness of processes is the reproductive feature of policy making, where the selection of significant stakeholders and key interests is accomplished. Opening up and reworking the ‘sticky’ elements can start by maintaining enough open-endedness in the processes to enable turn-over of viewpoints and interest groups.
- The stickiness of characteristics is especially important in times of transitions and transformations, because lack of consistency or credibility can manifest in rapid withdrawal of new agendas. Therefore, e.g., the phase-out policies are central in identifying and sustaining well-functioning elements and resources from previous regimes to new systems.

In sum, we consider policy stickiness as an interesting viewpoint to climate and energy policy development. In the European Green Deal, EU targets to be the first climate neutral continent by 2050. Meanwhile, Finland has introduced its own target to be the first climate neutral country by 2035. These are ambitious goals that need both robust and resilient policy approaches, both commitment and rooting and both destructive and sticky policy elements as part of the wider policy mixes.

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