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Innovation policy, regulation and the transition to net zero

by

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Abstract

This paper addresses the role of innovation policy, including regulation, in the transition to a society characterized by net zero emissions of climate gasses. A broad range of policy-actors, notably the European Union, have already publicly embraced this goal. Nevertheless, transforming the society to a state consistent with the net-zero objective is a very demanding task, and to succeed in this endeavour extensive change – including a lot of innovation - in the way energy is provided, distributed and used across all parts of society will be needed. A crucial question, therefore, is how policy – and particularly innovation policy – can contribute to mobilize innovation for this purpose. This paper critically examines the extant literature on the subject, and discusses examples of transformational change from policy practice, including onshore wind and solar in Denmark and Germany; offshore wind in the UK, Denmark and Norway; and the emerging quest for zero-emission ships.

Keywords: Net zero emissions, climate change mitigation, innovation policy, wind energy, solar energy, maritime sector

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1 Introduction

This paper addresses the role of innovation policy, including regulation, in the transition to a society and economy characterized by net zero emissions of climate gasses. Climate change, mainly caused by emission of climate gases from burning of fossil fuels, is probably the most important challenge facing humankind today (Stern, 2015), and to avoid the most negative environmental, social and economic consequences that climate change entails, net emission of climate gases has to be reduced to zero by mid-century (IPCC, 2018). This means for example that fossil fuels - which currently provide 80 % of global energy - will have to be phased out and substituted with renewable energy in energy-production as well as in energy-using sectors (Goodall, 2016). A broad range of policy-actors, notably the European Union[1], has already publicly embraced this goal. In fact, in the EU the net-zero by 2050 objective is in the process of being enshrined into law,[2] illustrating the central role played by regulation in this context.[3]

However, transforming the society and economy to a state that is consistent with the net-zero objective is a very demanding task, and to succeed in this endeavour extensive change – including a lot of innovation - in the way energy is provided, distributed and used across all parts of society will be needed (IEA, 2021). Arguably, this will require simultaneous (and relatively quick) changes in a whole range of technologies, sectors, and ways of life. Moreover, these changes will have to happen much faster than earlier energy transitions, which typically lasted for about a century (Fouquet, 2016; Smil, 2016; Wilson, 2012).[4] A crucial question, therefore, is how policy – and particularly innovation policy - can contribute to mobilize innovation for this purpose (Fagerberg, Laestadius, & Martin, 2016; Mowery, Nelson, & Martin, 2010).

Until recently many doubted that renewable energy would ever be sufficient to cater for humanity's needs, mostly because of their (then) high costs. However, continuing innovation

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[1] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[2]https://www.consilium.europa.eu/en/press/press-releases/2021/05/05/european-climate-law-council-and-parliament-reach-provisional-agreement/

[3] Regulation can be defined as management of a complex system with the help of rule-setting. Such rules can exist at many levels. The European Climate Law, for example, is an example of a very broad regulation, which encompasses many other, more specific regulations in various fields, and gives rise to use of different policy instruments affecting e.g., supply, demand and the system level.

[4] For example, as Smil (2017, p. 85) explains, it took about a century for coal to replace biomass as the most common energy source, and the same holds for oil and gas in relation to coal.

in renewable energy technologies, particularly wind and solar, aided by dedicated policy-interventions in a limited number of countries, have largely changed these perceptions. In fact, for both wind and solar the costs of producing electricity have diminished year by year (i.e. productivity has increased) as output has expanded. As a result cost-levels for renewables have become substantially lower than those of e.g., nuclear energy plants (Seba, 2014), and - in many if not most locations world-wide - on pair with or below plants producing electricity by burning fossil fuels. This pattern, i.e., rapidly falling costs, potentially almost unlimited availability and very broad applicability, is as several observers (Fagerberg, 2018; Mathews, 2013; Mathews, 2014; Stern, 2015) have pointed out, reminiscent of previous technological (industrial) revolutions.[5] If continuing on the same path it may have very far-reaching implications (Pearson & Foxon, 2012) and open up new opportunities for both policymakers and other stakeholders all over the world.

Innovation policy is a relatively new field of politics. In fact, the term only started to gain prominence in policy discourses around the turn of the century (Fagerberg, 2017).[6] The increasing interest in innovation policy at the time was related to the spread of a new, systemic understanding of innovation and its social, institutional and economic underpinnings, that is, the innovation system approach (Freeman, 1987; Lundvall, 1992; Nelson, 1993). Building on Schumpeterian (evolutionary) theorizing[7] the new approach acknowledged the central role of innovation in economic development, and, in particular, the wide range of factors – and actors – influencing it, as well as their mutual interaction (Bergek, Jacobsson, Carlsson et al., 2008; Edquist, 2005; Fagerberg, 2017). This also led to a quest for innovation policymaking to be based on a holistic analysis of the innovation dynamics in the specific context in which policies were going to be implemented, and for these analyses to be underpinned by adequate analytical capabilities (Smits and Kuhlmann 2004). Furthermore, the emphasis on the many of factors/actors taking part eventually led to a focus on the need for well-functioning coordination and alignment of public policies influencing innovation

[5] Technological revolutions (or – alternatively – "changes in techno-economic paradigm") are "changes in technology systems (that) are so far reaching in their effects that they have a major influence on the behaviour of the entire economy" (Freeman & Perez, 1988, pp. 46-47). See section 2 for an extended discussion

[6] This does not mean there were no polices affecting innovation, if that is what we understand with innovation policy as e.g. Edquist (2005) suggests, prior to that time. It was just called something else. For example, Roy Rothwell from the Science Policy Research Unit (SPRU) at the University of Sussex in the UK, one of the first academic proponents of the term, described innovation policy as "a fusion of science and technology policy (…) and industrial policy" (Rothwell, 1982, p. 3).

[7] See e.g., Fagerberg (2003).

across different parts (and levels) of government (Braun, 2008; Fagerberg & Hutschenreiter, 2020).

When innovation policy started to become popular among policymakers around the turn of the century, it was primarily the potential economic effects that attracted their interest. Nevertheless, since innovation is about solving problems, it can also be mobilized to tackle challenges that are more specific. In fact, there is a long tradition for doing so, particularly in the US (Mazzucato, 2013; Mowery, 2011). Recently, such so-called mission-oriented innovation policies have received renewed attention (Mazzucato, 2018b) as ways to tackle important challenges facing humankind (and hence also policymakers), including e.g., the climate challenge (Larrue, 2021; Mazzucato, 2021). Nevertheless, there is a long way from engineering specific innovation-projects, even very daring ones such as bringing a man to the moon, to transforming the global economy to a state consistent with net-zero emissions. What arguably will be required is, as pointed out above, simultaneous (and relatively rapid) change in a whole range of technologies, sectors, and ways of life, that is, so-called “system innovation” (OECD, 2015), for which new, bold “system innovation policies” (OECD, 2015) or “transformative innovation policies” (Schot & Steinmueller, 2018; Steward, 2012) may be needed (Geels, 2014b). Moreover, what seems evident is that such new, bolder policies will make the need for effective coordination (extending to important non-governmental actors) of innovation policy even more pressing (Edler & Fagerberg, 2017; Fagerberg & Hutschenreiter, 2020; Weber & Rohracher, 2012).

The next section delves deeper into the role of innovation and policies influencing it in the transition to net zero, while section 3 discusses selected examples of transformational change from policy practice, with a particular focus on the role of policy in these transition(s). The examples include onshore wind and solar in Denmark and Germany; offshore wind in the UK, Denmark and Norway; and the emerging quest for zero-emission ships. Finally, theory and evidence are brought together in a concluding section.

2 Policy challenges - A system perspective

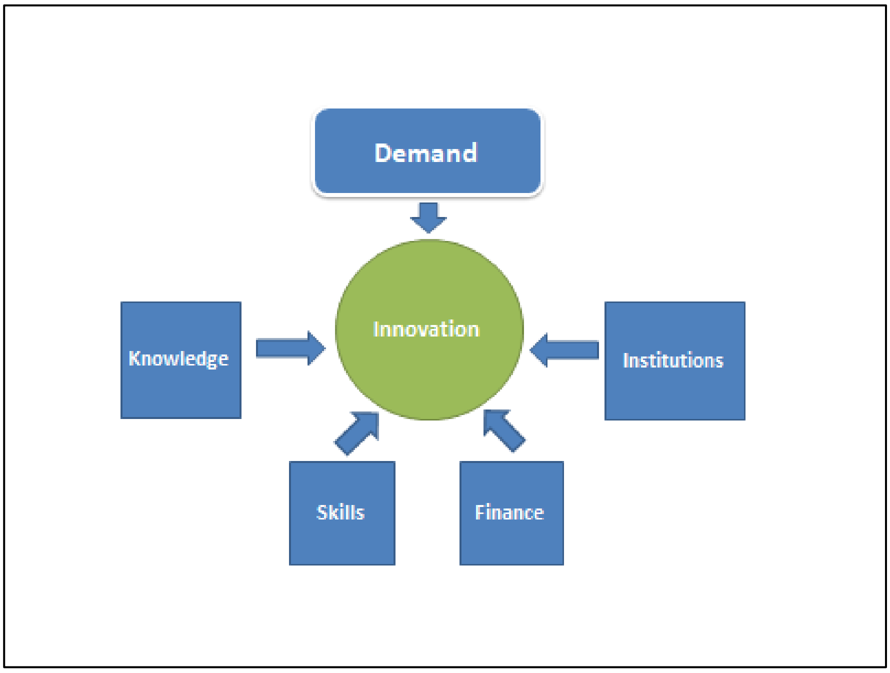
This section sets out a system perspective on the roles of innovation - and policies influencing it - in long run social and economic change, which will guide our discussion of transformative change in what follows.

2.1 Innovation, innovation-systems and policy

While it is common in e.g., the media to associate innovation with spectacular scientific breakthroughs and/or high-tech environments, modern innovation research places innovation in a much broader context (Fagerberg, 2005). Innovations come in many different shapes, e.g., not only technological but also organizational, and different sizes, ranging from very radical innovations to minor changes in existing products and processes, and they all matter. Hence, innovation matters in all kind of economic activities, i.e., in services as well as industry.

Schumpeter used the metaphor "new combinations" to characterize innovation. In this combinatory dynamics, innovative firms draw on various resources such as knowledge, skills and finance (Figure 1) . Innovative firms also depend on whether there is a market for their innovations: Innovations that are not sufficiently appreciated by potential customers, that is, are selected against, are doomed to failure. The institutional framework – laws, regulations, practices - into which they are embedded also matters (Lundvall, 1992; Nelson, 1993).

Figure 1 Innovation



Moreover, these various factors are often complementary rather than substitutes. For example, it is of little help to have access to some potentially interesting knowledge, if you lack the skills to exploit it, the required financial backing for doing so or if demand is lacking. There are important lessons from this, not only for firms (that tend to learn this the hard way), but also for policymakers that wish to encourage innovation. That is, to succeed with innovation it is not sufficient to focus one particular resource, say knowledge, because there may be other constraints that are equally or more relevant (Bergek, Jacobsson, Carlsson, et al., 2008).

The innovation system approach, under influence of Schumpeterian and evolutionary thinking, look at innovation from a wider lens than what was common previously, e.g., the so-called "the linear model of innovation" (Kline & Rosenberg, 1986), which mainly focused on invention and forgot about the subsequent phases.[8] In contrast, the new approach extended the analysis far beyond invention to include e.g., implementation and diffusion, and the interaction between the various phases. Moreover, it was argued that successful innovation does not only (or mainly) depend on factors internal to the firm but also hinges on interaction with external actors, from customers and suppliers to public research organizations, that hence need to be taken into account in design and implementation of policy. It was also pointed out that the capacity to benefit from such interactive innovation cannot be taken for granted but needs to be nurtured.

However, research showed the interaction that takes place between firms and their environments - the central focus of the approach - evolves along distinct paths in different national systems, influenced by variations in industrial specialization patterns, history and other factors (Fagerberg, 2016; Fagerberg, Mowery, & Verspagen, 2009). Such contextual factors complicate the task of policy learning, for example, policies that work in one context may not do so in another (Edler, Cunningham, Gök et al., 2016). Nevertheless, at a deeper level there may still be similarities in what goes on, that may be exploited to inform analyses of innovation policy. A common approach in the literature has been to focus on the various processes[9] that matter for innovation and the way these interact (Bergek, Jacobsson, Carlsson, et al., 2008; Edquist, 2005; Liu & White, 2001). As an illustration, Figure 2 identifies five basic processes in a national innovation system[10] influencing (and being influenced by) the system's "technological dynamics" (or innovation):

- Knowledge provision
- Supply of skills
- Demand for innovation

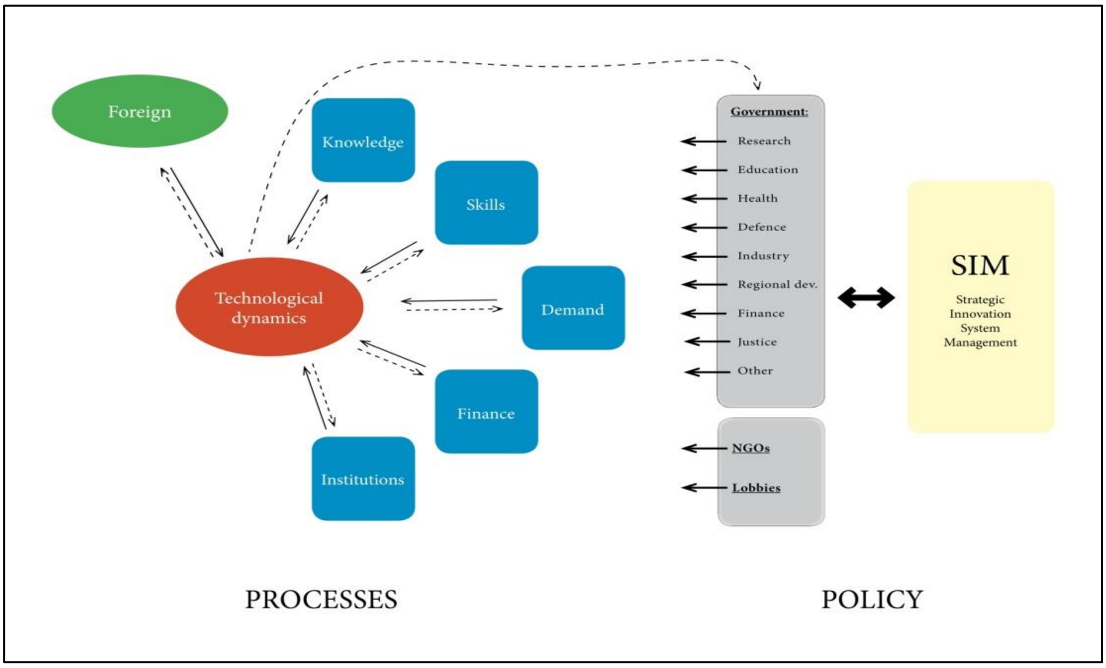
[8] See e.g., Boekholt (2010), Steinmueller (2010) and Fagerberg (2017) for overviews and discussion.

[9] These have also been labelled functions (Bergek et al. 2008) or activities (Edquist 2004).

[10] Some contributions have longer lists of processes/functions/activities but these five will usually be included in one way or another.

- Finance of innovation
- Shaping of institutions (e.g. laws and regulations)

Figure 2 The National Innovation System: Dynamics, processes and policy



Source: Fagerberg (2017)

As pointed out above, such processes often are complements (rather than substitutes) and under these circumstances, problems related to one process may be sufficient to block the entire system (Bergek, Jacobsson, Carlsson, et al., 2008). Identifying and rectifying such problems requires an analysis of the working of the system as a whole, which in turn depends on access to relevant analytical capabilities (Smits & Kuhlmann, 2004).

An important aspect of innovation system dynamics highlighted in the figure concerns the role of policy actors (different ministries for instance), which influence the main processes in the system in various ways.[11] For example, several ministries may influence knowledge provision, and the same goes for other processes (demand for instance). Sometimes influencing a process with the purpose of supporting innovation is the main purpose of the intervention. However, interventions may also (or mainly) have other aims, such as improving health, energy security or defence. This points to a major challenge for innovation policy governance, because there is no guarantee that interventions by different policy actors

[11] The processes may also be influenced by non-governmental bodies (directly or via policymakers).

pursuing different goals are consistent with each other. Hence, to get the most out of innovation policy also requires effective coordination among the various actors (Braun, 2008; Fagerberg, 2017; OECD, 2010a, 2010b). Such coordination may also give policymakers an opportunity to make connections between innovation policy and wider strategic goals for society more broadly, e.g. coping with societal challenges.

2.2 Policy strategies for a transition to net zero

What is it that is particular for policies for net zero? Due to the societal, technological and economic changes necessary for a transition, policies for a transition have certain characteristics. (1) They need to address societal, economic and technological change; (2) cover many domains (e.g. climate, transport, and energy); (3) and be persistent over time. This means that a transition to net zero depends on a comprehensive mix of policies that is evolving over time. Yet, there is considerable variation in the political scope for the various measures that could make up such a policy mix (Jewell & Cherp, 2020). For instance, studies of energy transitions demonstrate it is easier to introduce policies that support new technology if they do not challenge the positions of established industries and actors (Kern, Smith, Shaw et al., 2014; Normann, 2017), while introducing policies that threaten established interests tends to be more difficult (Meckling, Sterner, & Wagner, 2017; Smith, Voß, & Grin, 2010, pp. 445-446). An emerging body of research has therefore investigated how legitimacy for policies that appear to lack political feasibility can be created (Edmondson, Kern, & Rogge, 2019; Jewell & Cherp, 2020; Normann & Tellmann, 2021). We discuss some aspects of this below.

The extent to which a given policy mix contributes to a transition to net zero depends among other things on the overall vision or policy strategy, the composition and interaction between instruments, and the consistency of the overall policy mix (Rogge & Reichardt, 2016). The recent turn in innovation studies towards societal grand challenges has led to an increased interest for identification of long-term-goals and policy objectives (Grillitsch, Hansen, Coenen et al., 2019). Expectations about the future trajectories of individual technologies, solutions, or the energy system are important for guiding public and private investments (Scrase & Smith, 2009). Such expectations are influenced by specific policies and regulations, as well as the broader goals – or vision – underlying these policies.

A policy strategy can be understood as a set of policy objectives, including long-term targets and quantified ambition levels, and a plan for achieving these objectives (Rogge & Reichardt, 2016). Having such a strategy is important for the ability to set direction and stimulate action, and it strengthens commitment and legitimacy for the strategy. A transition to net zero relies on a range of different instruments and regulations that act in concert towards ambitious goals. A clear vision and actionable objectives that guides the direction of instruments and regulations is therefore important.

A policy objective may be limited to influencing specific activities and actors, such as to encourage increased R&D activity, it may be broadened to the creation of markets for a wider set of zero-emission technologies (Christensen, Drejer, Andersen et al., 2016; Mazzucato, 2016), or it can include long-term targets for industrial restructuring including the phase-out of certain industries (Rosenbloom & Rinscheid, 2020). This represents a potential dilemma for policymakers. On the one hand, considering the urgent nature of the climate challenge, policy objectives need to be concrete, measurable and actionable (Mazzucato, 2018a), to ensure that the objectives translate into actual change. The advantage of narrow policy objectives – for example accelerating the development of a technology such as carbon capture and storage – is that they are sufficiently concrete to be relatively easily followed up by relevant instruments that stimulate R&D and regulations that incentivise the uptake of zero-emission technologies. Moreover, such policy objectives are less often resisted by industry interests. On the other hand, considering the comprehensive changes needed, policy objectives also need to be ambitious and broad (Larrue, 2021). Without bold targets that target the harder to decarbonise sectors or even broader system change, we risk ending up with a set of narrow goals that are politically feasible but insufficient to solve grand challenges such as the climate crisis.

In the recent work on mission-oriented innovation policies, we can identify two ways in which policymakers can attempt to deal with this challenge. Firstly, it is important that even the broad policy objectives are formulated as concretely as possible. The recent climate law in Denmark, established in 2019, provide an example of a broad and ambitious target for emissions reductions by 2030 and 2050, which in turn has been followed up by four green partnerships mobilising public funding and industry (Wohlert, Lind, Norn et al., 2021). Secondly, broad policy objectives need to be broken down into more manageable objectives. For example, the Dutch government have set a goal of *a carbon-free built environment by 2050*. This goal has been broken down into subgoals, including *disconnecting 200 000 houses from the gas infrastructure every year until 2030* and that *20% of local energy consumption within the built environment should be based on sustainable energy production* (Janssen, 2020). In this way, it may be possible to maintain broad and ambitious objectives that give direction to more concrete and actionable goals.

2.3 Policy instruments, mixes and coordination

A policy strategy is of limited use unless it is followed up by policies and regulations. It is not uncommon for governments to announce ambitious climate targets, without following up with the necessary policies and regulations[12]. Broadly defined, we can distinguish between policies that aim to stimulate either the supply or demand of a technology. In addition, policies may also be aimed at the system level (Edler & Fagerberg, 2017).

With supply-oriented policies, we refer to policies that stimulate the creation of technological knowledge. The main rationale for such policies is to correct market failure associated with insufficient market incentives for firms to invest in knowledge production. The three most common types of policies for correcting this failure are investing in public R&D (e.g. universities and institutes), subsidising R&D in private firms, and strengthening the intellectual property rights regime (Edler & Fagerberg, 2017). Many of today's core technologies were initiated and matured with substantial involvement of publicly funded universities, labs, and large-scale technology programs (Smith, 2009).

In addition to stimulating technology supply, there is also a need to stimulate the demand for zero-emission solutions. A measure often advocated by economists is to incentivize innovation in clean energy technologies through policies that put a price on emissions, in the form of taxes or traded emission allowances (Smith, 2009). CO2-taxes have been in place for several decades, and there are many examples of how such an instrument has led to emission reductions.[13] However, such instruments primarily stimulate investments in the most mature, cheapest technologies, and provide insufficient incentives for investments in the less mature (more costly) technologies, that may also be needed in the transition (Smith, 2009).

An important insight from innovation studies is that because technology develops through stages, the importance of different processes – and therefore different policies and regulations - will vary depending on the maturity of a given technology (Bergek, Jacobsson, & Sanden, 2008). Decades of empirical studies have shown that it is after technologies are deployed in

[12] For instance, the UNEP reports that around half of the G20 countries will not meet their 2030 commitments from 2010 in Cancun under current policies (Olhoff & Christensen, 2018).

[13] E.g. the high CO2 tax in Norway contributed to the implementation of carbon capture and storage (CCS) technology on the Sleipner natural gas production facility, leading to a reduction in CO2-emissions (Sanden and Azar 2005).

markets that they may become competitive with existing technologies (Hanson, 2013; Rosenberg, 1972). New technologies are often expensive and inefficient when compared with more established solutions and are therefore not preferred by potential users (Kemp, Schot, & Hoogma, 1998). They therefore need to be protected from selection mechanisms in the market so that the learning can occur (Kemp et al., 1998; Smith & Raven, 2012), and to allow for scaling-up production at the unit and industry level, which is necessary to reduce costs (Grubler, 2012). Demand-oriented policies and regulations play an important part in providing such protection.

Putting a price on emissions therefore need to be complemented by technology-fostering instruments and regulations which aim to bring new technologies to the shelf. Such instruments include government procurement, green labelling, and specific subsidies (direct investment support, tax redemption, low interest loan, feed-in tariffs) (Sanden & Azar, 2005). These instruments can contribute to the creation of a 'protected space' for less mature technologies, which allows for a number of important processes to develop: articulating needs, institutional alignment, various kinds of learning, and the build-up of coalitions (Smith & Raven, 2012). A well-known example is the electrical vehicle, which was in development for many decades, but only recently became competitive with the internal combustion engine in some markets, helped by demand-oriented policies there (Fagerberg, 2021).

In addition to supply- and demand-oriented policies and regulations, innovation is also shaped by system level policies. For example, new technologies often require changes in existing, or the investment in new, infrastructure (Kemp et al., 1998). The expansion of the market for hydrogen-based vehicles, for instance, depends on the roll-out of a charging network, which in turn is necessary for manufacturers to further invest in hydrogen technology.

Other examples of systemic instruments include tax system, supporting education and training, facilitating public debates and engagement, and the formation of clusters (Rogge & Reichardt, 2016). However, system level policies are often applied in support of existing industries (Fagerberg et al., 2009), while a transition to net zero also requires system change as an objective for policy (Kemp et al., 1998). This entails changes in institutions and infrastructure, but also changes in policies that maintain the hegemony of existing technologies, industries and practices (Rosenbloom & Rinscheid, 2020). The transition to net zero therefore not only depend on the progress of individual technologies but that certain technologies or industries need to be phased out (Kivimaa & Kern, 2016), and current consumption patterns need to change (Petschow, Lange, Hofmann et al., 2018). However, policies stimulating such system changes can threaten employment and economic growth (Normann & Tellmann, 2021). To achieve their aims, politicians therefore need to balance climate concerns with other objectives such as competitiveness and job creation (Fagerberg et al., 2016).

From the discussion above, we can identify two types of coordination failures that needs to be resolved (Weber & Rohracher, 2012). Firstly, a policy goal such as the acceleration of a particular technology depends on a mix of supply-, demand-, and system-oriented policies. Failure to align and coordinate these different policies towards a common goal can hamper the development of necessary solutions. It is therefore important that agencies supporting basic and applied research coordinate their instruments with agencies supporting experimentation and commercialisation. Improving coordination between types of instruments and regulations (e.g. simultaneously supporting basic research and demand articulation) can be achieved through specific programs and are sometimes delegated to certain agencies or ministries (Arnold, Åström, Andréasson et al., 2019).

Secondly, policy instruments often target a specific goal (e.g. increased energy efficiency in the building sector), and may be tied to particular visions or interests (Flanagan, Uyarra, & Laranja, 2011). As different actors can have different goals and interests, the goals of multiple instruments working simultaneously may be more or less aligned. Coordination is therefore often hampered by conflicting societal interests or diverging policy goals. Policymakers (and in particular politicians) constantly pursue multiple goals, whose priority vary over time (Kingdon, 1984). Many of these goals will conflict. For instance, a goal of increased new renewable energy, which often requires encroachment on nature, may not be aligned with nature preservation goals. Thus, even when there exist coherent policy strategies and goals for a specific policy area (such as energy), this strategy will often be in conflict with other goals (such as the environment). This issue of political coordination in relation to a transition to net zero is therefore particularly challenging, but also critical to resolve. Lessons from the Dutch mission-oriented innovation policy strategy shows that political coordination can be addressed through establishing cross-ministerial panels and by anchoring policy objectives at the political leadership. However, the evidence so far shows that these coordination efforts can come with high transaction costs due to the complexity and size of the coordination structures that have been put in place. Moreover, it has in some instances been difficult to elevate ownership of the goals to a sufficiently high political level, thus leaving many of the political conflicts unresolved (Janssen, 2020).

Even if we were to overcome the problem of conflicting interests, an additional challenge is that even though policy mixes in theory can be designed, policies are most commonly introduced on top of the existing policy mix (Flanagan & Uyarra, 2016). Moreover, policies are in general much easier to introduce than they are to remove (Bauer, Jordan, Green-Pedersen et al., 2012). Thus, if a new policy comes into conflict with the existing policy mix, this conflict is not easily resolved. This, of course, is an argument for a more comprehensive, holistic approach to how policy should contribute towards solving grand challenges.

2.4 A broader deal

Perhaps the greatest obstacle to the implementation of more ambitious policies, and one in which policymakers have to consider, is that many of the policies needed for a transition to net zero will create losers (e.g. increased taxes on consumer goods, increased road tolls, or the phase-out of industries). Policy and regulatory proposals therefore run into considerable resistance from a variety of stakeholders, including industry, trade unions and citizen groups. This resistance can translate into protests and social unrest e.g. in response to taxes that are distributed unfairly, and weakened legitimacy of democratic institutions. For example, the unequal impact of increased petrol prices on rural and urban populations can fuel social and political polarisation and calls for a heightened sensitivity to the spatial and justice dimensions of a transition (Martiskainen, Jenkins, Bouzarovski et al., 2021).

It is not easy to see how more radical, but necessary policies, can be introduced unless these are coupled with policies that compensate losers. In the context of industry phase-out, such policies can aim to lessen hardship for those affected whilst also promoting opportunities in new industries (Heyen, 2017) and may include retraining, infrastructure investments, financial compensation and stimulation of new industry (Leipprand & Flachsland, 2018; Normann, 2019; Rosenbloom, 2018). Similarly, the effects from increased taxes on CO2-intensive activities can be compensated through reduced income taxes for less affluent or through direct pay-outs. This policy approach builds on the notion of a “just transition”, increasingly promoted by trade unions (Healy & Barry, 2017). Policies for net zero, therefore, cannot be treated individually, but has to be seen as part of an overall plan, which is evident in the EUs embracement of ‘missions’ as a concept to address climate change and the European Green Deal.

However, there are unresolved issues related to how such overarching plans can be implemented. There is now a growing body of literature suggesting it is possible to harness path dependent processes to make low-carbon policy more durable and to ramp up stringency over time (Meckling et al., 2017; Rosenbloom, Meadowcroft, & Cashore, 2019). Even though more radical policies targeting a transition to net zero lack political feasibility, more subtle policy and technology changes can instigate feedback cycles that subsequently give room for more radical change (Edmondson et al., 2019). As an example, we can consider proposals to limit or ban fossil fuel production, which in many cases are considered politically unfeasible (Jewell & Cherp, 2020). Rather than first attempting to introduce such regulatory changes, policies could initially aim to diversify fossil fuel industries as an intermediate step (Geels, 2014a). Reorientation policies can thus be developed in a way that sequence policy costs and benefits in ways that shift the balance between coalitions so more radical reforms can be enacted (Mildenberger, 2020). Deliberate decline may therefore also involve incentivising firms to diversify and ultimately reorient (Normann & Hanson, 2018). Overcoming political constraints to ambitious climate mitigation can therefore by achieved by sequencing policies in such a way as to engineer feedback effects that expand the politically acceptable set of climate policies over time (Green & Denniss, 2018).

The European Green Deal was launched by the European Commission in 2019 and consists of three overarching goals. The EU is to become climate neutral by 2050, it will decouple economic growth and resource depletion, and it will ensure that all people and places will be part of the green transition. The plan therefore reflects high ambitions in terms of emission cuts, a green growth agenda, and a commitment to a just transition.

The European Green Deal includes a long list of actions and targets for 2050. Some of these targets are specific such as a reduction of greenhouse gas emissions by at least 55% by 2030 (compared with 1990 levels). However, many of the actions lack a deadline for when they need to occur. Moreover, the plan is a mix of soft targets (ambitions, evaluations, strategies) and hard targets.

The European Green Deal also consists of several more specific plans and strategies, such as the European ‘Climate law’ (2020), the EU Industrial Strategy, and circular economy action plan. There are also sector specific plans and ambitions, covering sectors such as transport and construction.

The European Green Deal does represent a policy strategy, and it includes several more specific goals. However, it is unclear whether the main goals will be sufficiently followed up by a coherent and ambitious mix of policies and regulations.

The need to overcome political contestation and to align conflicting interest means that governance of transitions becomes important. There are different perspectives as to how such governance should be done. Crucially, there is a need to balance the need to set top-down goals that are ambitious and concrete (Mazzucato, 2018b) with the need to mobilise a broad set of actors across sectors and policy domains (Kuhlmann & Rip, 2018). The recent work on transformative innovation policy (Schot & Steinmueller, 2018) emphasizes the need to involve multiple stakeholders, including those that are traditionally not given a voice, in the development of long-term policy goals and strategies, and the ways in which such goals should be reached. Yet, evidence shows that such broad involvement is not easy to implement in the practicalities of regular policy formulation (Wohlert et al., 2021). One way, however, in which such broad involvement can be achieved is through policy experimentation and pilots that are later scaled up (Kivimaa & Rogge, 2022).

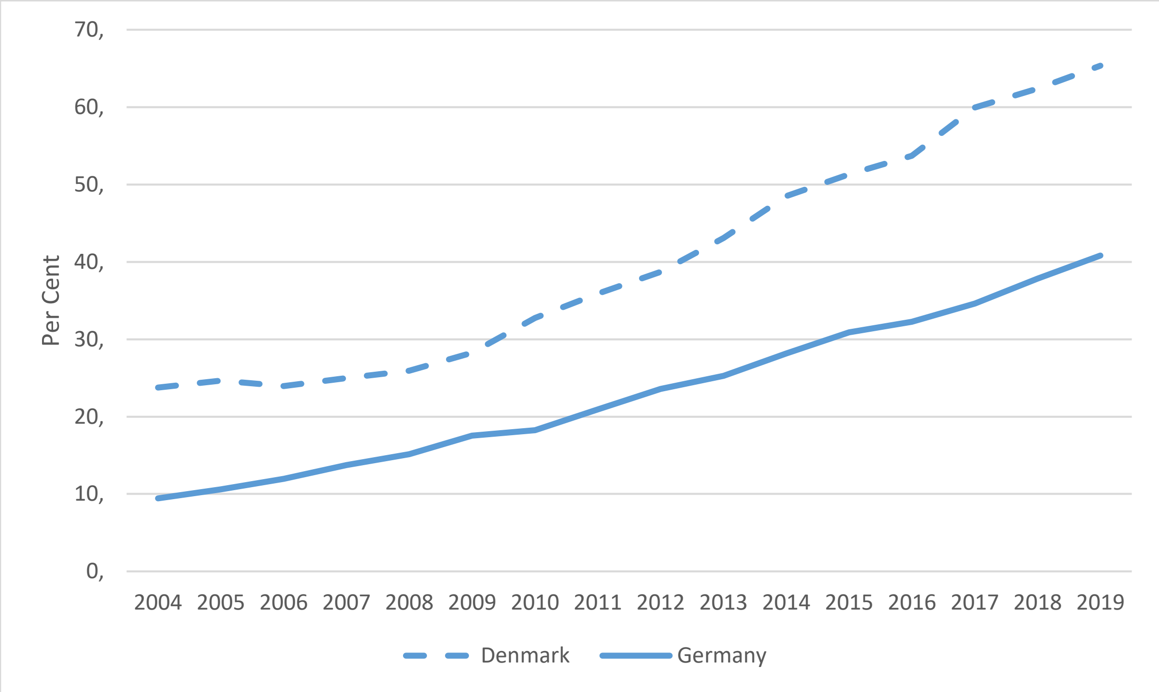
3 Transformational change: Lessons from policy practice

The purpose of this section is to present and discuss examples of innovation-driven transformational change in which policy has played an important role, drawing on the theoretical perspective outlined above. The lion's share of current emissions come from burning fossil fuels for various purposes, such as electricity production; transport services; industrial processes; heating/cooling etc. The electricity sector will have to play a key role in the transition since it, first, is a major emitter of climate gasses and needs to decarbonize by switching from fossil fuels to renewable sources, and, second, needs to massively ramp up production in the years to come so that other sectors and industries can decarbonize by substituting fossil fuels with (green) electricity (IEA, 2021). Hence, two of the three examples considered here are from the electricity sector. However, some sectors or industries are harder to decarbonize through electrification than others. Therefore, the third example discussed below concerns an energy-using sector that is commonly regarded as being among the ones that are particularly hard to decarbonize, i.e., the maritime sector.

3.1 Transforming the electricity sector to sustainability: Policy-driven driven change in Denmark and Germany

During the last few decades a dramatic transformation of the European electricity sector has taken place, driven by innovation and diffusion of renewable energy – primarily wind and solar - and policies supporting this in a number of European countries. Here we will focus on two countries, Denmark and Germany, which both have experienced very rapid growth of renewably produced electricity (Figure 3) and, as we will show, been home to important policy innovations influencing these developments.[14]

Figure 3 Shares of renewable energy in electricity



Source: Own calculations based on data from Eurostat, https://ec.europa.eu/eurostat/web/energy/data/main-tables, consulted on 27.8.2021

Wind power is an old technology and was used to produce electricity on a small scale already a century ago in e.g., Denmark and Germany. However, for most of the twentieth century cheap fossil fuels combined with continuing technological progress in (fossil fuel-based) power production appeared as a more promising technological trajectory for governments and the electricity industry. To the extent that there was a challenge to the fossil hegemony in the sector it came not from renewables but from nuclear. Nevertheless, the supply-problems and oil-price shocks in the 1970s somewhat changed these perceptions. Motivated by energy security concerns several governments started to devote more resources to alternative sources of energy. Although most of this went to nuclear, research and experimentation with "new renewables", particularly wind, also got a boost.

[14] This section draws on Fagerberg (2021).

The problems facing the emerging wind industry at the time were familiar; high costs, low performance, quality/reliability challenges, a poorly developed value chain, sluggish and highly variable demand etc. In dealing with these challenges policymakers at the time first built on the classical mission-oriented policies pioneered in the US in the decades following the 2nd World War, that is, combining excellence in science and engineering with the goal of producing a technological breakthrough, i.e., much larger and more efficient wind turbines than what had been available previously. However, the results of these attempts, in the US, Germany and other countries, were generally disappointing, as the large, technologically complex wind turbines that these projects aimed for proved to be unable to withstand extreme and variable wind, and policymakers' interest eventually faded.

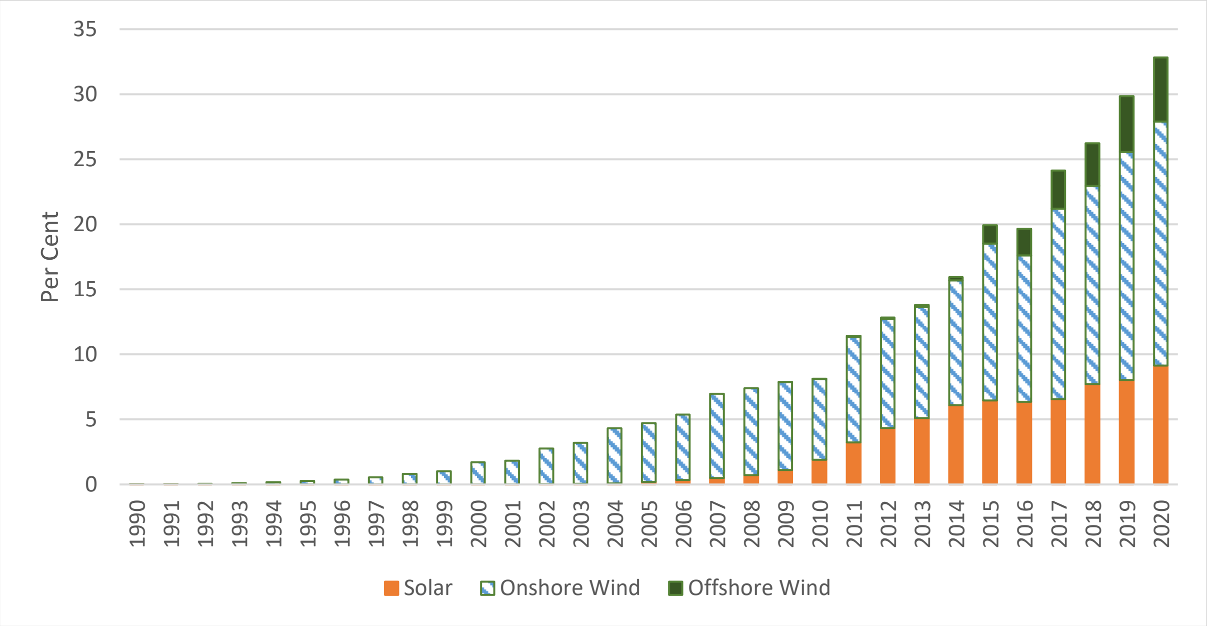
Nevertheless, in the shadow of these high-tech failures, a lot of experimentation was going on among wind technology enthusiasts in several countries, who saw wind technology as a promising alternative to the polluting, inflexible, large-scale energy systems - particularly nuclear - dominating at the time. For example, during the 1970s several initiatives were taken in Denmark, mostly by individuals, to build wind turbines and gradually a social organization of believers with regular "wind meetings", a journal and an association evolved (Karnøe, 1991). These initiatives were able to build on designs from previous projects, e.g., a Danish engineer had already in the 1950s constructed a small-scale wind turbine that worked flawlessly for at least a decade. The 1970s were troubled times economically, and several smaller firms with a background from other sectors of the economy (e.g., suppliers of agricultural machinery, such as Vestas) became interested in exploiting the emerging market for wind-turbines in Denmark as a way to diversify their business. The Danish government was lobbied for support and funding was secured for a test centre at Risø, which soon became a hub for know-how, support and interaction between users and producers in the field. Building on previous experience, the test-centre placed particular emphasis on solid, robust and durable designs suitable for withstanding extreme weather conditions, which became a hallmark of the Danish wind-power industry in the years that followed. The centre's role in the emerging technological innovation system was further strengthened by the Danish government's decision to make subsidies to deployment of wind turbines contingent on the centre's approval of their design (Karnøe & Garud, 2012).

Quality, performance and costs were of course important challenges for the emerging industry, as emphasized earlier. This also meant that, despite the enthusiasm of the believers, it was challenging to expand the customer-base beyond the technology's most ardent supporters. In fact, these problems were interlinked, because small and sluggish demand could not support the development of a thriving industry with continuous quality and cost improvements and a well-developed value chain. To address the demand constraint policymakers in some countries opted for subsidies to deployment of the new technology. However, while subsidies are easy to introduce, they may also be removed on short notice, possibly giving rise to a pattern characterized by very hectic activity followed by collapse (when the subsidies are removed). In fact, this is exactly what happened with wind energy in California in the 1980s.

Moreover, another – and perhaps more fundamental – problem hampering demand for wind turbines at the time was that potential customers were unable to sell the excess electricity they produced to the grid at a reasonable price, drastically reducing the profitability of the investment. Responding to this challenge Danish policymakers eventually replaced the investment subsidy with a regulation, a so-called "feed-in-tariff" (FIT), that secured access to the grid and a fixed, guaranteed price for the power supplied, with the goal of providing a fair (albeit not excessive) return on the investment. This regulation, introduced for the first time in 1984, became the most important mechanism behind the rapid growth in renewables in Denmark in the years that followed. It also spread to other countries, notably Germany, where a similar scheme was put into law in 1990.

In Germany the feed-in tariff was originally stipulated to 90 % of the electricity price. However, while giving a boost to onshore wind-energy, the incentives entailed by this regulatory scheme were hardly sufficient for more immature renewable technologies, such as solar energy. As in the case of wind, there had from the late 1970s onwards been some public R&D funding for solar, followed by some demonstration programs (Jacobsson & Lauber, 2006). Still, by the turn of the century, solar energy accounted for an almost negligible amount of Germany's electricity production. The new "red-green" government that came to power in 1998 proposed a radical overhaul of the scheme with a technology-specific fixed feed-in tariff (independent on the electricity price) for twenty years, the cost of which was baked into the electricity price through a surcharge. While fixed for a specific installation (at a certain point in time) future installations of the same type would receive a lower support due to anticipated future technological progress/cost-reductions (so-called automatically declining tariffs). This regulation, introduced in 2000, and subsequently revised several times based on experience, led in the years that followed to a surge in investment in renewable energy, much more than foreseen by most experts, for onshore wind as well as solar, for which the level of support was raised to a much higher level than in the previous decade (Hoppmann, Huenteler, & Girod, 2014). Accompanying this rapid increase in deployment (Figure 4), and in the derived demand for capital goods that it led to, a German industry catering for these needs emerged (Lauber & Jacobsson, 2015).

Figure 4 Germany: Shares of solar and wind in electricity



Source : Own calculations based on data from Federal Ministry for Economic Affairs and Energy, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html , consulted on 1.9.2021

Viewed as a means to support the transition to clean energy, not only in Germany but worldwide, these demand-oriented policies accomplished much more than anyone would have anticipated beforehand. For example, as late as 1994, the then Minister for the Environment, Angela Merkel, said that “solar, hydro-power and wind-power will not be able to make up more than four percent of power supply even in the long term” (Morris & Jungjohann, 2016, p. 127). German policies in this area can also be credited with creating a global mass-market for solar panels and related equipment, leading to rapid learning, innovation and reduced costs, helping to spread the technology across the globe and contributing to less green-house gas emissions worldwide. Moreover, the rapidly expanding German market for photovoltaics attracted the interest of Chinese firms, initially mainly for exports but increasingly also for domestic use, helping the much-needed transition to sustainability in China itself and in other parts of the developing world (Mathews, 2014; Schmitz & Lema, 2015). However, increasing competition from China also took its toll on the part of German industry producing solar power equipment, leading to drastic reductions in employment there.

In Germany the support to renewable energy became quite controversial, more so in fact than in Denmark. First, parts of the political establishment, particularly the FDP (the liberal party), were against the policy because they saw it as excessive interventionism in the working of markets. Similar views were also expressed among political right parties in Demark. Second, another faction opposing the policy consists of the large incumbents in the electricity sector (based on coal and nuclear) and their allies in the coal industry (and affected regions) who saw their economic interests threatened by the growth of renewables. This was not the case to the same extent in Denmark which did not possess coal and where nuclear energy initiatives had been laid to rest already in the 1980s. Third, the scheme was criticized for being too expensive, leading to excessively high costs for consumers and undermining the cost-competitiveness of industry. Responding to these concerns, German governments in successive rounds exempted a large part of the country's industrial sector from having to pay most of the surcharge financing the scheme, further adding to the costs for ordinary consumers and the remaining part industry, and leading to a controversy with the European Commission about the legality of the entire regulatory framework. After a lengthy procedure the European General Court decided in 2016 that while supporting renewables was justified, the wide-ranging exemptions to industry were in breach with European Law. However, at that time the German government had already decided to undertake a more radical change of policy, the aim of which was to reduce costs by curbing future growth in renewables, particularly photovoltaics, and substitute politically decided feed-in tariffs with remunerations set by auctions. A similar change of policy stance has also happened in Denmark. In both cases this reflects a desire to involve larger, professional actors in the transition, particularly in the emerging offshore wind segment, which is much more capital-intensive (see below). Nevertheless, the policy change also implies that it may be more demanding for smaller actors, such as individuals or community-based groups, to take active part in the transition, which may be matter of concern, since much of the success hitherto has rested on the ability to mobilize large parts of the population for this purpose.

3.2 Upscaling offshore wind in Europe: Demand-oriented policies and regulatory changes

Offshore wind has since the first turbines were installed off the coast of Denmark in 1991 matured in terms of scale and efficiency. Through continuous improvements in technology and offshore competences, offshore wind has gone from a small niche activity to become a large, international industry. After a period of increased costs in the early 2000s, the cost of energy from offshore wind fell considerably from 2014 to 2019 (Wiser, Rand, Seel et al., 2021), and it can now provide electricity at a cost that is competitive with many of the alternatives in the energy sector.

The offshore wind industry has developed primarily in Europe, around the North Sea, even though the industry has expanded to other parts of the world in recent years. In 2019, approx. 3 600 MW of new capacity was added in Europe (502 turbines across 10 wind farms), which is between 5-6 times the installed capacity 10 years earlier (WindEurope, 2020).

An important driver for the recent cost reductions in offshore wind is the growth in installed capacity – a result of increased number of annual turbines installed and increased turbine sizes. This installation growth has been driven by private-public investments in the deployment of large-scale projects. Offshore wind installation has for a long time been heavily subsidized by different governments in Europe, also in periods with increased costs and uncertain prospects for future cost reductions (Kern et al., 2014). Despite initial investments in the 1990s and early 2000s, with early niche markets in Denmark and the UK, it was not until around 2007 and onwards that the market started to grow. From 2013 and onwards, large quantities were also installed in Germany, and in 2019 the UK and Germany represented by far the two largest markets for offshore wind in Europe. Other countries that have contributed to the European market formation include Denmark, Belgium, and the Netherlands. In addition, inputs for the offshore wind industry have come from other countries in Europe, including Norway, Italy, and France.

To illustrate the role of policy and regulation, we focus on the UK – contrasting with developments in the Netherlands and Norway where the developments of offshore wind have followed rather different paths. All three countries represent a potential for an offshore wind market and an offshore wind supply industry, and there have in all countries been articulated ambitions to realize such potentials. Nevertheless, a domestic market for offshore wind did not emerge in Norway. The deployment numbers in the UK and the Netherlands, however, followed similar paths until around 2010 when deployment rates levelled off in the Netherlands at a time when they increased in the UK. In the following, we discuss how policy strategies, instruments and regulations have played a critical role in stimulating the growth of offshore wind in Europe.

The motivation for government support for offshore wind in Europe has been partly driven by climate change targets and partly the opportunity represented by offshore wind to generate economic value and jobs. In the early 2000s, the policy rationale was that renewable energy expansion should follow a least-cost principle meaning that demand-oriented policies supported more mature technologies such as onshore wind, and that cost reductions in offshore wind could we realized through R&D (Kern, Verhees, Raven et al., 2015; Normann, 2015). Most of these policies and government initiatives were directed towards R&D. However, in spite of these initiatives, the roll-out of offshore wind in Europe remained slow, largely due to the costs of constructing and installing wind turbines at sea (Kaldellis & Kapsali, 2013).

In Norway, offshore wind was particularly high on the political agenda following the financial crisis in 2008 and subsequent reduced demand for oil and gas (Normann, 2015). The Norwegian government's strategy to develop an offshore wind industry was to support R&D, with the rationale that through improvements in technology, Norwegian firms could compete in the emerging international offshore wind market. However, in Norway, the energy and climate concerns were less articulated due to the high share of renewable energy from hydropower (Wicken, 2011). Perhaps most importantly, the jobs argument was only relevant in periods of low demand for oil and gas. When demand for oil and gas was high, such as between 2011 and 2014, offshore wind almost disappeared from the political agenda (Mäkitie, Normann, Thune et al., 2019). Thus, offshore wind has only periodically been seen as an important solution for climate change mitigation or job creation. As a consequence, there has not been sufficient incentives for the government to introduce market deployment policies. Whilst some firms have succeeded in participating in the European market, the lack of a domestic market for offshore wind has inhibited the development of a national offshore wind industry (Normann & Hanson, 2018; Tsouri, Hanson, & Normann, 2021).

In the Netherlands, long-term targets for offshore wind where introduced already in 2002 with a goal of installing 6000 MW by 2020 – a goal that was reiterated several times (Van der Loos, Normann, Hanson et al., 2020). To follow up this goal, regulatory changes were introduced a year later with the Ministry of Economic Affair's 2003 renewable energy production subsidy. This scheme was intended to compensate for the high costs of less mature technologies, giving higher subsidies for e.g. offshore wind. However, because of an unexpected high number of planned offshore wind parks, and the potential impact this could have on government finances, the licensing procedure and production subsidy scheme was cancelled shortly after its introduction. In 2007, a new scheme was introduced, yet, this scheme was again altered in 2010, benefitting cheaper alternatives at the expense of offshore wind (Kern et al., 2015). In short, offshore wind support in the Netherlands has repeatably been contested in parliament and policy signals have been inconsistent, hampering the development of the Dutch offshore wind industry (Verhees, Raven, Kern et al., 2015).

Whereas there was a complete lack of demand-oriented policies in Norway and a wavering support for offshore wind deployment in the Netherlands, the development in the UK was different. In contrast to the situation in Norway, offshore wind has in the UK been presented as a solution to energy security concerns and for the creation of new manufacturing jobs (Kern et al 2014). An important actor in this respect has been the Crown Estate[15], which although it has no specific sustainability agenda, has been active in offshore wind since 2000. The 2004 Energy Act gave the Crown Estate the right to license renewable energy production on the continental shelf (Kern et al., 2015), and it has later been instrumental in forging collaboration between government and industry actors (Kern et al., 2014). This collaboration has later resulted in the Offshore Wind Sector Deal, which is a partnership between the government and the offshore wind industry, with the joined goal of creating jobs and renewable energy (Offshore Wind Industry Council, 2021).

As climate change rose to the top of the political agenda, the UK made stronger commitments to the EU to increase its share of renewable energy in the domestic energy mix. The 2009 EU Renewable Directive established a target of 15% of all energy in the UK to come from renewables. Offshore wind was seen as a necessary component to realize this goal (Kern et al., 2015). To bring down the cost of offshore wind, the Department of Energy and Climate Change (DECC) argued that large-scale industrial development was essential (Kern et al., 2014). Several support schemes were then set up to realize this large-scale development. First, a change was made to the Renewables Obligation (RO). This scheme provided power producers Renewable Obligation Certificates (ROC) for every MWh of electricity produced. Until 2009, this scheme was technology neutral, giving renewable energy producers the same number of certificates regardless of the technology. After the change in 2009, offshore wind producers received 1.5 certificates rather than 1 certificate per MWh. This was increased to 2 certificates in 2010, thus offering greater support to more expensive technologies (Kern et al.,

[15] The Crown Estate was set up as an independent company to create revenue for the Treasury in 1961. It owns the sea bed out to the 12 mile zone and the rights to use the resources of the UK continental shelf (but not including oil and gas) (Kern et al., 2015).

2014). Second, the licensing process was revised in the Round 3 of the Crown Estates' licensing where 9 zones with a potential for 25 GW was offered. In this third round, the Crown Estate became more involved as it began to co-invest alongside developers and implemented a new planning process designed to reduce risk and accelerate offshore wind project development (Kern et al., 2014). Third, with the Electricity Market Reform in 2013, the electricity market rules went through an overhaul with the introduction of long-term feed-in tariffs (MacKinnon, Dawley, Steen et al., 2019). Here, the main change for offshore wind was the move away from Renewable Obligation Certificates to a Contracts for Difference (CoD) system. Under CfD, a competitive auction process is used to award contracts to potential bidders. The main mechanism in this system is that it requires electricity producers to pay money back to the state when electricity prices are higher than the strike price,[16] but more importantly for offshore wind developers, it provides financial support when the electricity prices are lower. The CoD, thus, reduced the economic uncertainty for offshore wind developers.

Following the changes in the UK renewable energy strategy, offshore wind deployment accelerated in the UK making it the market leader. However, most of the value of the offshore wind installations had been sourced from outside the UK. To sustain the legitimacy for continued investment in market deployment policies and to reach the goals of industry development, the regulatory changes in the electricity market were complemented by a series of industrial policy measures. In 2013, the Offshore Wind Industrial Strategy was launched, with the aspiration of generating 50% of value from domestic suppliers (MacKinnon et al., 2019). This strategy included the promotion of foreign direct investments; grants, assistance and advice for UK firms; and financial support for the formation of an Offshore Renewable Energy Catapult Centre focusing on RD&D, testing and cost reductions. Finally, in 2017, local content requirements were introduced to all project developers who wanted to secure the UK Government financial support under the Contracts for Difference system. These requirements boosted the participation of UK firms in offshore wind projects, and helped develop a UK supply chain for offshore wind (Kochegura, 2017).

The different development paths especially in Norway and the UK illustrate the importance of demand-oriented policies, coordination between policy areas, and long-term policy strategies

[16] The strike price is a guaranteed price to electricity producers, for the duration of the contract, determined through auction. See https://www.emrsettlement.co.uk/about-emr/contracts-for-difference/

that are followed up by concrete goals. However, the case of offshore wind in Europe also includes evidence of resistance to change. The development of a Norwegian offshore wind industry has been vulnerable to periods of booms and busts in the oil and gas industry, suggesting that a more ambitious policy strategy for supporting offshore wind in Norway may have to include efforts to reorient or even phase-out activities in oil and gas (Mäkitie, Andersen, Hanson et al., 2018). Such efforts, however, are met with significant resistance by not only the oil and gas industry, but also trade unions (Normann & Tellmann, 2021), which in turn spill over onto the political sphere.

The evidence from the Netherlands shows how political opposition and contestations had a negative impact on the long-term support schemes for offshore wind in the Netherlands (Kern et al., 2015). Demand-oriented policies that challenge the institutionalized cost-efficiency principles in the funding system was met with considerable resistance. This resistance was only periodically subdued, due to alternating political leaderships. This illustrates how long-term strategic plans that go beyond changing governments can be important (Larrue, 2021).

The initial approach in all three countries was to support R&D with no recognized need for major changes to either the support system for deployment (breaking with a cost efficiency principle) or the way in which infrastructure was funded. However, this changed in the UK, which resulted in large investments in market deployment that in turn accelerated overall cost reductions in the European offshore wind industry[17]. This underlines the importance of demand-oriented policies.

There are also notable differences in how successful national industries have been. Even though the Netherlands have not had a major domestic market, Dutch suppliers have successfully taken part in industry activities. There are numerous explanations for this, but the presence of small, niche markets, long-term targets and numerous test and demonstration facilities in Netherlands, when compared with Norway, must be seen as part of this explanation (Van der Loos et al., 2020). In addition, the prominence of a large oil and gas industry that politicians have been unwilling to undermine has further hampered the development in Norway.

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[17] Demand-oriented policies through regulatory changes were also implemented in Germany (Reichardt, Negro, Rogge et al., 2016), which was also important for stimulating the overall growth in the European market, and consequently cost reductions.

3.3 Greening the maritime transport sector in Norway

Norway is one of the world’s leading maritime nations, both measured in number of ships and tonnage. The maritime industry is a historically significant industry in Norway and remains important with around 85 000 people employed (Helseth, Baustad, Basso et al., 2019). It is also the second largest export industry after oil and gas. As mentioned in the example of offshore wind, the Norwegian power sector has been mostly electrified. Low-hanging fruits for achieving emissions cuts are therefore not in the power sector, but in other sectors such as transport (Ryghaug & Skjølsvold, 2019). In fact, transport represents the sector with the second highest CO2 emissions in Norway, after petroleum production. Within transport, substantial measures have been taken to reduce emissions, most notably through the diffusion of electric vehicles, stimulated through demand-oriented subsidies (Fagerberg, 2021). The other major contributor to emissions from transport is found within coastal shipping.

There are several environmental regulations that affect the Norwegian maritime sector. Vessels operating in Norway, such as ferries and fishing boats, fall under the national legislation and are therefore affected by the Norwegian government’s aim to cut carbon emissions by 50-55% by 2030 in comparison to the 1990s level. Coastal shipping is also part of the national transport infrastructure, which means that public administrations are responsible for public procurement of many of the 500 coastal passenger vessels (Bach, Bergek, Bjørgum et al., 2020). The sector is also influenced by the international agreements made in the International Maritime Organization (IMO) (Mäkitie, Steen, Thune et al., 2020). Thus, because of the economic significance of this industry, the existence of competences and capabilities (Steen, 2018), and the potential for emissions reductions, efforts have been made to reduce domestic emissions from maritime transport. Following the launch of the world’s first battery electric ferry in 2015 with the Norwegian *MF Ampere*, the Norwegian portfolio has expanded and by September 2021 there were 40 battery electric ferries running with an additional 18 planned for commission by the end of 2021 (Energi og Klima, 2021).

Reductions in emissions from maritime transport can be achieved through energy efficiency measures. However, to meet long-term targets of net zero it is necessary to develop zero emission solutions such as battery electric and hydrogen-based solutions. Addressing deep-sea/long-haul shipping with these solutions has been difficult due to complicated regulatory regimes and technological obstacles related to e.g. energy storage. Within coastal shipping there has, however, been a surge in the uptake of battery electric storage on ships and several demonstration projects for hydrogen fuel cells (Steen, Bach, Bjørgum et al., 2019). In the following, we describe the various regulatory changes that have accelerated a green transformation of the Norwegian maritime sector.

In 2008, a cross-partisan agreement on climate policy, which identified climate policy goals and proposed measures to be taken, was signed in parliament. The agreement included several statements of intent with regards to green maritime transport (Stortinget, 2008). One of the proposals in the agreement was to establish a test project, Transnova, for investments in infrastructure for alternative fuels. Transnova was established in 2009, under the control of the Norwegian Public Roads Administration (NPRA), and became an important policy instrument for the development of several low emission projects in maritime transport (Furset, 2013).

Another important policy development in 2008 was the establishment of the so-called NOx-fund. The authorities had in 2007 introduced a tax on NOx emissions. However, due to the added costs on firms from this tax, the authorities and key industry actors negotiated a NOx-agreement whereby income from the NOx tax would be channeled back to fund industry initiatives that would reduce NOx emissions. An important motivation upon making the agreement was to develop new and improved environmental technologies within shipping and fishery. Electrification of maritime activity is an example a technology that was later realised with support from the NOx-fund (NHO, 2019).

There had at this point been a lot of experimentation with different tendering contracts and there were discussions on how best to transition ferries towards climate-friendly solutions. There was, for instance, great uncertainty as to the relative pros and cons of different technologies, as well as uncertainty with regards to how the actual tendering processes should be executed. In 2010, the NPRA was in the process of announcing a tender for a development contract for a new ferry to cover a route in the county of Sogn og Fjordane. The goal for the tender was to find a solution that was environmentally friendly at the lowest possible cost (Sæther & Moe, 2021). To manage the technological uncertainty, the NPRA engaged potential bidders in a dialogue about possible solutions prior to the specification of the tender. An important element of this process was that the NPRA held one-to-one dialogues with several bidders (Furset, 2013). Moreover, the process involved funding for project development for multiple bidders. This gave the bidders the opportunity to work with the entire supply-chain and it reduced the uncertainty for the NPRA when making a final decision (Sæther & Moe, 2021). This procurement process was a departure from technology neutral tenders, as environmental technology became prioritized at the expense of costs, in dialogue with the potential bidders. In 2012, the company *Norled* was then awarded the contract to construct a battery electric ferry together with *Fjellstrand*, which led to the commissioning of the *Ampere* ferry in 2015.

The successful introduction of the first electric ferry was followed up by several developments that further accelerated green coastal shipping in Norway. For instance, the public procurement model, orchestrated by the NPRA, was later imitated by other regional councils (Andersen, Bugge, Capasso et al., 2019). Moreover, in 2015 parliament asked the government to implement measures that ensured that all county and municipal ferries and speedboats use low or zero emission technology in new tenders (Stortinget, 2015). This policy change would probably not have happened as fast without the *Ampere* project (Sjøtun, 2019). Following the *Ampere* project, there were several battery ferry initiatives on the west coast of Norway, and a change in the perception of low emission maritime transport among local politicians (Andersen, 2016).

Green maritime transport was in 2015 period lifted as a prioritized area for climate policy (Meld. St. 13, 2014-2015), and the revised state budget for 2016 included a proposal for 65 million NOK towards electric ferries and other environmentally friendly maritime transport solutions. However, weak coordination between the different policy instruments targeting activities from basic research to commercialization represented a bottleneck in the innovation system, hampering the acceleration of green maritime solutions. To solve this, a new support scheme called Pilot-E was introduced in 2016, intended to integrate innovation policy instruments ranging from basic research to commercialization. The Pilot-E programme, thus, aimed to facilitate a 'fast-track' support system for consortiums covering the entire innovation 'journey' (Græslie & Steen, 2021). The first call was for 70 million NOK for actors that wanted to develop zero emission solutions for maritime transport. The support towards maritime transport was also strengthened with the new agreement between The Ministry of Petroleum and Energy and Enova, a state agency previously established to fund environmental solutions, for the period 2017 to 2020, where environmentally friendly maritime transport was singled out as a prioritized area for the first time. This expansion of Enova's mandate facilitated several major maritime allocations, including charging projects which facilitated country municipalities green ferry tenders (Meld. St. 41, 2016-2017). The government also introduced a grant scheme that supported municipalities in their implementation of climate-oriented tendering processes. Access to funding from e.g. the

NOx-fund and Enova has both enabled knowledge development and entrepreneurial experimentation and, later, resulted in construction of infrastructure (Bach et al., 2020).

Coastal shipping is easier to decarbonize than other segments of maritime transport such as deep-sea shipping and cruise because battery electric technologies are only viable in short distance shipping (Grimsby, Winje, Lie et al., 2021). Hydrogen-based fuels, such as ammonium, represent a potential solution for longer distances. However, whereas support for battery electric has overall been rather good in Norway, it has been more challenging to accelerate hydrogen as a solution. These challenges are connected to infrastructure, high costs, and greater uncertainty. However, several of the instruments that have successfully accelerated battery electric ferries have been introduced for hydrogen, such as pilot projects and the NPRAs call for a hydrogen ferry (Bach et al 2020). As a result, the world's first hydrogen ferry, *MF Hydra*, was put into service in 2021. In this way, the development within coastal maritime transport battery electric ferries has provided opportunities for policy learning and the opportunity to develop competences, legitimacy, enrolment of actors, and infrastructure that will be important for the decarbonization of other segments. Nonetheless, hydrogen solutions necessary for long distance shipping will, due to more complex value chains, greater level of uncertainty, and higher costs, require a greater level of coordination between supply-oriented, demand-oriented and system level policies, strong directionality, concrete objectives and credible means by the state to reach them (Mäkitie, Danebergs, Hanson et al., 2021).

In addition to continued advancements in technology, changes in international regulations may provide this directionality. In April 2018, an important milestone was reached when the IMO adopted a strategy focusing on energy efficiency measures, which aims to reduce GHG emissions from shipping as soon as possible, and to phase out emissions completely by the end of this century (IMO, 2018). The Norwegian maritime industry has been pushing for these changes, which include a goal of reducing emissions by 50 per cent by 2050, compared with 2008.

The European Green Deal and Fit for 55 package provides another important set of objectives and regulations that will shape the greening of international maritime transport. The proposals that are particularly relevant is the extension of the EU ETS to also include maritime transport, the Alternative Fuels Infrastructure, and the FuelEU Maritime initiative. Together, these directives, regulations and initiatives define targets for ports to provide power, set requirements on greenhouse gas intensity, requirements for zero-emission whilst in port, and provides economic incentives for switching to non-fossil fuels.

The Norwegian maritime industry has been a test bed for the implementation of zero-emission technologies, being the first in the world to introduce both battery electric and hydrogen-based ferries. The market for maritime batteries and electrical installations has expanded rapidly, both in Norway and globally, and in 2020 approximately 40% of the global maritime battery installations were onboard Norwegian ships (Bach et al., 2020).

In the following, we sum up important policy and regulatory issues that have been important. First, long-term political visions and targets, through e.g. the climate settlement in 2008, the commitments in parliament on electrification, and more recently the direction set by ILO and EU, have all been important in steering investments in research and implementation of battery electric and hydrogen technologies.

The most important regulatory change has been through demand-oriented policies such as the public procurement policies and development contracts initiated by the NPRA (Sjøtun, 2019). Changing the criteria in favour of zero-emission technologies and stimulating the demand for battery electric and hydrogen-based solutions has been critical. In addition, policy learning has contributed to the successful upscaling of the initial projects. Yet, we should also acknowledge that without the recent improvements in battery technology, which in itself is a result of interaction between policy induced supply and demand (Stephan, Schmidt, Bening et al., 2017), the acceleration of green coastal transport would not have been possible. Thus, due to the complexity of the maritime transport value chains, and the differences across segments (e.g. deep-sea vs. coastal shipping), experimentation with different types of technologies, through RD&D, pilots and demonstration projects has been, and will remain, important.

Moving towards net zero in the maritime transport sector has therefore relied on clear goals and long-term targets, supported by a mix of instruments that support experimentation and stimulate demand for a portfolio of technological solutions. To scale up further, both in terms of volume and into harder to decarbonize segments, other demand-oriented policies such as removing subsidies for fossil fuels will be necessary (Bach et al., 2020). This is more contested, and underlines how also in this case, there is a need to overcome resistance and challenge established interests.

3.4 Summary of lessons from policy practice

Looking across the three cases, we can identify some general lessons that we see as particularly important for a transition to net zero. First, a policy-mix to support the growth of new industries based around new technologies need to include demand-oriented policies to help mature and scale up those industries. Stimulating demand through public policies and regulations can be done in a number of ways, and in our examples both subsidies and adapting criteria in public procurement programs have been effective. Yet, with both of these types of regulatory changes, it has been necessary to stimulate innovation at the expense of short-term principles of cost efficiency, for instance through the changes in the feed-in tariff and the Renewables Obligation systems. To ensure the legitimacy of such policies, it is important to couple these with public initiatives that stimulate job creation, as well as ensure close interaction with research and development, which underlines the importance of policy coordination. Second, and on a related note, a transition to net zero has the potential to put increased costs on certain groups, as with the examples of increased electricity prices or increased ferry costs. To avoid a potential backlash, those affected by increased costs may need to be compensated in some way. Moreover, to further ease the resistance from incumbent firms and industries, it may be necessary, and even beneficial, to invite these industries as partners in the ongoing transition, for instance by setting up public-private partnerships as in the example of offshore wind in the UK, or through consultation processes as in the example of maritime transport in Norway.

4 Concluding remarks

As pointed out in the introduction to this paper, the transition to net zero will require massive change in a whole range of areas and, hence, extensive innovation. Policies influencing innovation are therefore of central importance to the transition. Successful innovation depends on the presence of many (complementary) factors, e.g., knowledge, skills, finance, demand on so on, factors that policymakers in various settings (levels) may (and do) influence, without always paying much attention to it because they may also have other (and for them more pressing) goals on their minds. Thus, there is a veritable coordination problem in innovation policymaking which needs to be addressed if innovation is to play the central role it arguably must in the transition ahead of us. The facts that the required changes need to take place in many sectors in parallel and within a very compressed time span also raise the bar for policymakers.

As argued in this paper, what is needed is a comprehensive, goal-oriented policy (policy strategy), with clear, measurable objectives, focusing on all phases of the innovation process, not only on knowledge (invention) but also on the (later) diffusion phase. In fact, in general it is first during the diffusion phase it becomes clear whether or not a novel technology will deliver on its promise. Hence, having a broad focus on innovation, from ideas to implementation, is of utmost importance, as the transition to net zero is not so much about promising ideas, as it is about carrying such ideas into practice.

Thus, a sole focus on a single policy instrument, say, R&D support, or the phase of innovation is not likely to do the trick. In general, several different instruments will have to be combined, and the nature of the mix of instruments will vary across the various phases of the innovation cycle and the contexts into which these instrument mixes are implemented. This requires detailed knowledge about the technology, phase and context in question, that is, capabilities in policymaking.

The potency of regulation when it comes to stimulating green innovation has much to do with the systemic nature of innovation. Existing patterns of production and consumption and supporting regulations are deeply embedded in the fossil fuel paradigm. Transforming the economy to sustainability therefore depends on regulatory change. In fact, as shown above, without regulatory change, first in Denmark and then in Germany and elsewhere, renewable energy, particularly wind and solar, would probably not have developed into the potent force for change globally that it has since become. Similarly, offshore wind technology was given a boost by regulatory change, particularly in the UK, supporting its deployment. Regulatory change may also be a potent force for change in the maritime sector, as the Norwegian experiences with zero-emission ferries indicate. These processes also illustrate the crucial importance of capabilities in policymaking, including learning from experience, and the ability to revise regulations in light of that.

Despite the urgency of the climate crisis, innovation, and particularly systemic change, take time. Regulatory changes favouring innovation and the transition to net zero will need to be aligned with existing institutional practices, which may present barriers to change and delay a transition. The cases considered in this paper illustrate this in multiple ways. For example, the institutionalized practice of relying on R&D funding and cost-efficiency principles to promote innovation hampered the deployment and cost-reductions of offshore wind in the UK and elsewhere. Without a break with these practices, and the introduction of a (initially very costly) new regulatory scheme, we would probably not have witnessed the development of a large-scale market for offshore wind at the size and speed that we have seen over the last decade. However, as the contrasting developments in the UK, Netherlands and Norway illustrate, successfully changing regulations in this way require long-term political commitment based on a vision for change that is resistant to the electoral cycle. Particularly in Norway, policymakers' continuing support for the country's dominant oil and gas sector, and institutional practices and regulations associated with that, appears to have made it difficult to embrace offshore wind in the same way as e.g., the UK. However, a similar problem does not appear to have existed in the case of the country's maritime sector, for which regulatory changes, e.g., new criteria in procurement contracts, intended to support a green maritime transition in Norway, have been introduced.

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