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Institutional constellations and policy instruments for offshore wind power around the North sea

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ABSTRACT

This paper analyses how institutional constellations and their associated mode of risk allocation are reflected in the choice of policy instruments for the promotion of offshore wind power. Using the Varieties of Capitalism framework we expect that governments in Liberal Market Economies (LME) tend to use policy instruments that privatise investments and risk-taking, while those in Coordinated Market Economies (CME) use policy instruments that facilitate investments and shared risk-taking in the earlier, more riskful phase of technological development. We test our expectations through a longitudinal comparative analysis of the use of policy instruments and the deployment of offshore wind power in Denmark, the United Kingdom, Germany and the Netherlands between 1990 and 2020.

Our results confirm the market oriented nature of policy instruments employed by the LME case of the United Kingdom throughout, while we witness initially lower levels of market orientation among the CME cases of Germany, Denmark and the Netherlands. Though the market orientation of Germany's policy instruments declined half way to build up domestic momentum, we generally see an increased use of market oriented policy instruments over time by the CME. Putting the trajectories together we witness an overall convergence in the use of policy instruments which we attribute to the liberalisation of the energy sector in the EU as well as to policy-learning effects. The results have generic relevance and can also be used to inform future national strategies and policies for deploying new low-carbon technologies, such as electrolysis for green hydrogen, which face similar risks and challenges.

1. Introduction

To meet climate targets as agreed under the Paris Agreement ([UNFCCC(2015)]) governments promote deployment of new low-carbon energy technology. Particularly in the early stages of the technology life cycle such technology may incur a higher financial cost than incumbent technologies, if only for lack of scale and experience. Therefore governments seek policy instruments to stimulate low-carbon energy investment and to start virtuous cycles of experience, learnings, scale and cost saving. This warrants a growing body of empirical studies concerning these policy instruments. Research suggests that investment risk is of key importance in such policy instruments ([Polzin et al. (2019)], [Egli(2020)], [Dukan&Kitzing(2021)]). Risk allocation is particularly relevant for offshore wind power (OWP) because risks are higher than for other renewables, due to technological challenges, the large scale of projects and the high pre-construction investments ([Markard & Petersen(2009)], [Fitch-Roy(2016)]).

From 2017 onwards the policy instrument of choice for all governments around the North Sea consists of auctions that seek to minimize the subsidies that apply during operation ([Dukan&Kitzing(2021)]). However, historically nations around the North Sea have used quite different sets of policy instruments for OWP over the past decades. For instance, they started using these auctions as a policy instrument at quite different moments in time ([Araũjo(2017)], [Higgins & Foley(2014)], [Reichardt et al. (2016)], [Van der Loos et al. (2021)]). How can we account for these differences? In this paper we employ the analytical framework of Varieties of Capitalism (VoC) to explore how government risk-taking ([Mazzucato(2014)]) shapes the introduction of OWP. We argue that governments in so-called Coordinated Market Economies (CME) are comparatively more inclined to intervene in markets (cf. [Hall&Soskice(2001)]), whilst those in Liberal Market Economies (LME) generally strive to leave investments and technology choices, risks and

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price setting with the private sector where possible.

While there are a couple of explorative studies on institutional differences and OWP ([Markard & Petersen (2009)], [Ćetković & Buzogány (2016)], [MacKinnon et al. (2019)]), [Van der Loos et al. (2021)]), we explicitly investigate the relation between institutional constellations and policy instruments. In order to do so we make an inventory of policy instruments in terms of their compatibility with the CME and LME model and score them accordingly. Additionally, we analyse the timelines and the nature of different policy instruments over time as OWP went through several phases of the technology life cycle ([Klepper(1997)]). We investigate the patterns through a qualitative comparative analysis of OWP pathways between 1990 and 2020 in four equally developed nations around the North Sea, one typical LME (UK) and three CMEs (Germany, Denmark, the Netherlands).

Understanding these differences can inform policy advisors and strategists for future introductions of technology. For instance, similar questions surround the introduction and deployment of electrolysers for green hydrogen, which could replace fossil hydrogen (produced from fossil gas through steam methane reforming).

The results of our research suggest that at least for OWP, a sector where projects demand much capital and involve large risk and investments, the characteristics of institutional constellations did in fact show through in the nature of policy instruments in the industry's first 30 years. This offers insight into which policy instruments will fit which nation and which phase in future developments.

Currently a limited number of nations with a history in OWP exists, with relatively few data points (actual offshore wind farms). Nations which can be identified as CME or LME might consider and discuss their current position and likely role (first mover, smart follower, other) in the development of new low carbon technologies against the backdrop of our framework and findings. On the theoretical side, this study contributes by combining the literature on policy instruments with the comparative study of political economies.

In section 2 we explicate our theoretical framework and in section 3 the methodological set-up. In section 4 we describe the history of policy instruments governing the deployment of OWP in Denmark, the United Kingdom, Germany and the Netherlands. We evaluate the match between our expectations and the actual national histories of offshore wind power policies and patterns in section 5. We draw conclusions and discuss policy implications in section 6.

2. Theoretical framework

Fig. 1 depicts the explanatory model that we use in order to connect institutional constellations to the timing and choice of policy instruments by a country wanting to stimulate OWP.

2.1. Institutional constellations and risk allocation

Due to technological challenges, the large scale of projects and the high pre-construction investments, OWP are confronted with higher investment risks than other renewables ([Markard & Petersen(2009)], [Fitch-Roy(2016)]).

We expect that if a nation has institutions that emphasise market forces and limit government interference it will tend to leave the risk-taking comparatively more with firms. A comparative analysis of the impact from institutional constellations requires a systematic categorisation of institutional constellations. In the field of political economy, a useful categorisation of the institutional character of nations is the paradigm called Varieties of Capitalism ("VoC") ([Hall&Soskice (2001)]). Coherent with the paradigm is the broadly shared observation that market-oriented "Liberal Market Economies" ("LME"), archetypically the UK and the US, strive to minimalise government interference in markets, risks and prices for products, capital and labour more than EU nations do.

Fig. 1. Hypothesized causal relations between institutional constellations, risk allocation and policy instruments for offshore wind power (Diagram by authors).

VoC contends that different institutional constellations provide indigenous firms with different comparative advantages in types of economic activities. VoC discerns LME where 'coordination' ("aiming for nationally desirable outcomes") takes place primarily via market mechanisms ([Hall & Soskice(2001)]). Socio-economic outcomes in LME are determined mainly through competitive markets for products, capital and labour, and firms are comparatively more privatised (see Appendix, Figure A1). We expect that this focus on market mechanisms and competition also has implications for the orchestrated introduction of a new technology which has yet to become competitive with incumbent technologies. We would expect a comparatively limited support base in a LME for the government's intervention, risk-taking and financial support.

At its introduction VoC distinguished one other category[1] of institutional constellations, "Coordinated Market Economies" or "CME". National socio-economic outcomes in CME are comparatively more often the result of non-market interaction between government, firms and citizens [Hall & Soskice(2001)]). In these nations, where institutions tend to support the government interfering in markets for products, capital or labour, we expect that the government will comparatively deploy more policy instruments which involve the government funding or sharing investment risks in new technology. To achieve socio-economically desirable outcomes, CME governments will have comparatively less focus on short term returns, on market competition and on leaving risks with project developers than LME governments.

2.2. Policy instruments relevant to offshore wind power

Typically in the early stages of the technology life cycle ([Klepper (1997)]), new low-carbon technology may incur a higher economic cost than incumbent technologies, if only for lack of scale and experience. This implies that governments aiming for climate targets may need policy instruments to promote such technology. The importance of understanding the relevant policy instruments warrants a growing body of empirical studies investigating these policy instruments. Research suggests that how policies deal with investment risk is of key importance ([Polzin et al. (2019)], [Egli(2020)], [Dukan&Kitzing(2021)]).

A review of 96 such empirical studies finds that policy instruments are more effective in crowding in private investments in renewable energy if the policies address both the risks as well as the returns for the investors. Independent of policy details, instruments that reduce risk turn out to be highly effective. Examples are the government providing co-investments, guaranteeing a certain level of revenue or guaranteeing grid connections. Newer, less mature technologies require technology specific support to develop. Additionally, the effectiveness of policy instruments also requires that the government delivers credibility (no retro-active changes) ([Polzin et al. (2019)]).

New technologies starting in any market with incumbent technologies tend to face more technological challenges and risks and often temporary higher costs, which makes them dependent on government policy. This introduces "policy" as a second determinant of the

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[1] Later research has motivated several other categories, which have been subsequently challenged by other work. However, to answer our research question it will suffice to distinguish between more and less market-focus. The least contested categorisation is the distinction between LME and "others" ([Schneider&Paunescu(2012)]).

development of OWP next to technological risks. As costs go down through learning curves and growing scale while support is still necessary, operational risks[2] become more important than technological risks ([Egli(2020)]). At this stage the role governments can play in helping firms manage these operational risks becomes a more significant factor in determining a firms choice to develop OWP. Research informs us that auction-based support payments introduce more risk to renewable investments than less competitive policies, like guaranteed prices; but auctions also drive down costs ([Dukan&Kitzing(2021)]).

Table 1 provides an elaborate overview of the different policy instruments that governments can employ. We will first provide an overview of these and subsequently categorize these instruments in terms of their position on the spectrum of CME-LME institutional constellations.

Policy instruments to support renewables include additional payment for volumes, grants and tax measures, quota obligations, building obligations and auction schemes ([Kitzing et al.(2012)], [Fitch-Roy (2016)]). Furthermore we expect that policy regarding grid connections is relevant, as well as the willingness to issue project specific policies. Investments in grid connection are large and if a firm has to finance and take on the grid connection as well, this makes the investment considerably more challenging. Project specific policies may be decisive to enable project developers to invest in particularly uncertain circumstances and to take specific technological hurdles.

The above leads us to the categorisation of policy instruments which will structure our analysis as listed in Table 1. Our sets 2 to 4 are in line with ([Polzin et al. (2019)]), leaving out those options that are not appropriate for OWP.

Through the options in Set S1 "Initiation Mechanism" in Table 1 we categorize who takes the initiative for a particular offshore wind farm (OWF); either government or the firms[3] that develop OWP projects. The Building Obligation Scheme is highly non-market and at odds with liberalisation as governments simply require some (public) firms to build projects. The Open Door Policy is also non-competitive, but leaves it to firms to take the initiative. The most competitive policy instrument is auctions, where firms bid voluntarily and are in competition for competitively established amounts of money, and run more risks. Project developing firms run the risk of losing considerable upfront costs if they lose, or they may enter a bid for less subsidy than is actually necessary, which may prohibit actual investment decisions later on ([Dukan&Kitzing(2021)].

Furthermore, in order to further structure our analysis, we distinguish the initial investment (CAPEX, Set S2) from the exploitation of the deployed technology (OPEX, Set S3).[4] Set S2 looks into the use of government-supported national banks to invest or loan as well as governments' tax incentives for investment in OWP. Obviously, this amounts to government interference in the markets for capital.

Table 1

Inventory of policy instruments relevant to offshore wind power developments, based on literature study (see section 2.2) and analysis by authors.

Marker	Description of policy instruments
Set S1	**Initiation Mechanism**
BOS	Building Obligation Scheme; government requires firms to realise projects with certain technologies ("command and control"). No competitive market mechanism.
ODP	Open Door Policy; government allows firms to take initiatives for projects. The government sets a generic guaranteed price for OWP (FIP, FIT or FITT in Set S2 below). No competitive market mechanism, firms enter voluntarily.
AUC	Auctions (auction schemes); government invites firms to compete for projects through bidding for seabed licenses or bidding for the lowest requirement for financial support. Competitive market mechanism, firms enter voluntarily.
Set S2	**Investment support**
INV	Investment grants; nations implement organisations that support investments by firms in electricity production with certain technologies through co-investment.
TAX	Government implements tax incentives w.r.t. a certain set of technologies.
Set S3	**Support during operation**
FIT	Feed-in tariffs; government guarantees or pays out a price to firms producing electricity with a set of certain technologies. Firms share price risk with government. With ODP all project developing firms receive the same amount of subsidy, so no competitive element in this instrument. With AUC there is competition for the lowest need for financial support.
FITT	Same as FIT, but a technology specific policy (generally, a higher support payment for OWP was necessary than for other renewables, like onshore wind power or solar).
CfD	Contracts for Difference; government pays support when the market price goes below the agreed tariff, government receives returns if the market price goes above the agreed tariff (price risk, both costs and profits, shared between government and firms).
FIP	Government pays a fixed premium on top of the market price to firms producing electricity with a set of certain technologies (dampened price risk with project developing firms).
QOS	Quota Obligation Schemes; Government requires firms (Electricity Suppliers) to purchase a volume of electricity from a set of certain technologies (price risk with firms that produce said electricity). Government sets volume for Suppliers, the market sets prices as OWP producers negotiate for price of volumes with Suppliers.
QOST	Same as QOS, but technology specific policy (government systematically attributes a higher value to volumes of OWP than to volumes from other renewables).
Set S4	**Grid support**
GRM	Risks for realisation of offshore grid connection with market (project developers)
GRS	Risks for realisation of offshore grid connection socialised (public infrastructure)
Set S5	**Scope (characteristic of Set 1–4)**
SPC	The policy instruments are related to specific projects
GEN	The policy instruments are generic and related to the entire market

Set S3 looks into the often discussed subsidies for produced electricity from renewable technologies, and specifically into the allocation of risk. Set 3 also acknowledges the relevance of "technology specificity": policy instruments that take into account that newer technology is comparatively more riskful and expensive and for a time requires extra support that is specific to this technology. Technology specificity generally allocates budget to newer low-carbon energy technologies that are at that point in time less competitive than low-carbon energy technologies that have already been deployed for a longer period and have experienced a longer learning curve. This generally adds cost to a nation's overall renewable support policy. On the other hand, it promotes technology diversity, innovation and learning curves which can lead to a higher overall value add at system level ([Polzin et al. (2019)]). OWP

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[2] For renewables such operational risks are typically price risk and curtailment risk. Price risk is the risk that over time electricity prices go down below what was expected, which may cause losses to the owner of the renewable energy assets or the firm that is responsible for trading the volumes. Curtailment risk is the risk that the grid can't transport all produced electricity to the demand side, forcing the grid operator to shut down ("curtail") parts of the renewable energy production, also causing a loss in revenues.

[3] It is this "project developer" who shoulders the initial project risk and must invest in engineering, succesfully secure permits, personnel, financing, foundations, robust and productive turbines, vessels for installation and maintenance, and an offshore grid connection. Specifically in the earliest phase of the technology life cycle, this confronts the project developer with many unknowns of the technology, the installation and maintenance process, the required vessels and materials, the performance and future perspectives of the technology.

[4] This is not as self-evident as it may seem. During the California onshore wind 'boom' of the early eighties, the US government mainly rewarded the investment with tax credits, leaving the actual electricity production with lower incentives. A policy which promoted markedly different policy outcomes (lower production, more turbine malfunctions) than Danish policies of the day which incentivised the produced volumes more ([van Est(1999)]).

was developed decades after solar energy and onshore wind power, and OWP requires structures built out at sea, more expensive maintenance and more robust turbine technology. Therefore we expect that, to derisk OWP investments in the uncompetitive phase enough to attract the desired numbers of investments and project developers, OWP will need policy instruments with higher support in comparison to other renewables.

If the feed-in tariffs (FIT) are the same for all developers of renewables they are a government intervention in the electricity market, since non-renewables do not receive the same price guarantees.[5] Actually a generic "FIT" is more market-oriented than technology specific (higher) guaranteed prices, where for instance OWP receives a higher guaranteed price than other renewables. We analyse Contracts for Difference (CfD) as halfway non-market and market-oriented policies, since the government not only guarantees an auctioned price level, but the government also receives revenue if the prices are actually higher than the agreed price level ([UK Government(2020)]).

A feed-in premium (FIP) is more market-oriented than that because although it adds a subsidy to the revenues of the firm, it doesn't adjust the subsidy if the prices go too far below the revenue that the firms require. The Quota Obligation Schema (QOS) does not set or guarantee prices for the produced electricity at all. It sets a requirement for volumes of renewable energy that Suppliers deliver to customers, and Suppliers have to acquire that from producers. Though the government sets the volumes, market principles set the price and leave the risks with firms, as producers and Suppliers negotiate prices and terms of contracts ([Mitchell & Connor(2004)], p1939). A technology-specific variant of QOS setting a higher value in certificates for OWP is more non-market.

In Set S4, we categorize the policies for covering the investment and risks associated with the grid connection for OWF. We expect CME to be more willing to socialise the costs for grid connection and we expect LME to leave more costs and risks with firms. Finally, with Set S5, we hypothesize that during the technology life cycle, to cross technological hurdles, firms might need specific support from governments for specific projects. Since the support is project-specific, there is a 'cap' on the amount of exposure for the government. This might be key in the more riskful early phase of the technology life cycle. So in Set S5 we distinguish between policies which are project specific and policies which are generic. This is not a policy instrument in itself but a characteristic of a set of policy instruments. We expect CME to be more willing to negotiate such non-generic and non-market agreements.

2.3. Relating policy instruments to institutional constellations

We expect the differences in institutional constellations to be reflected in the distribution of types of policy instruments, where in CME we expect policy instruments with less focus on competition, more room for government risk-taking and more room for government involvement with prices. In LME we expect the opposite, as illustrated in Fig. 2.

Based on the considerations in the previous sections, we can then sort the policy instruments from the previous section 2.2 as more typical for CME versus more typical for LME (see Fig. 3).

The focus on market mechanisms implies that the LME governments will deploy policy instruments which emphasise competition between firms and which strive to leave it to firms to shoulder investment risks. For the policy instruments listed in Table 1, we would (see Fig. 3) expect the LME governments to favour auction schemes (Set S1, AUC), to supply little or no investment support (Set S2) and to refrain from price setting for electricity production as much as possible (Set S3, QOS). Also we expect an LME to privatise the investment in grid connection (Set S4, GRM) and promote generic, market wide policies (Set S5, GEN).

The earliest phase is the more riskful phase of the technology life cycle ([Mazzucato(2014)], Chapter 6). We expect that, comparatively, particularly in this earliest phase, CME governments would be more willing to share risk with OWP project developers than LME governments. For the policy instruments listed in Table 1, we would expect (see Fig. 3) the CME governments to be more open to alternatives for auction schemes, and perhaps execute command-and-control policies through Building Obligation Schemes (BOS). Also, if competition for projects isn't necessarily the major strategic focus, then the guaranteed price for OWP can be identical for all projects through a Feed-in tariff (FIT). Without auctioning for project-subsidies there can be an open door policy where firms apply for permits (ODP). We would expect comparatively more investment support from CME governments (Set S2). We would expect the CME to be more willing to socialise the costs of grid connection (GRS) and to accept project specific sets of policy instruments to promote development of the technology (SPC).

Except for a cross-sectional difference between nations due to different institutional constellations, we also expect a longitudinal effect, where we see more of the liberal, market-oriented policy instruments and patterns over time. Firstly, when a technology matures and becomes more competitive with incumbent technologies, governments can leave its promotion more to the market. Secondly, the EU has seen a move to more liberalized markets ([Schneider&Paunescu(2012)]) and this is true for energy markets as well.[6]

3. Method and design

We investigate the relevant patterns through a comparative analysis of OWP pathways between 1990 and 2020 in four equally developed nations around the North Sea; two large nations and two smaller economies, including both one large and one small economy with a tendency towards more privatisation. Viewing the VoC classification more as a continuum (see Appendix, Figure A1) the UK ranks as the clear LME case fairly closely followed by the Netherlands, whereas Germany and Denmark are considered to be CME's. ([Schneider&Paunescu(2012)]). By ensuring this variety of institutional constellations we can assess whether this has indeed resulted in the use of different policy instruments.

We have systematically mapped the use of policy instruments for OWP by these four countries between 1990 and 2020. Data concerning financing and the impact of e.g. auctions on financial conditions are typically private and confidential information ([Dukan&Kitzing(2021)], p152). But the national choice of policy instruments for support payment during operation (Set S2, section 2.2) is public information. The quantitative data concerning other policy instruments is harder to retrieve and analyse. However, in order to present a more complete and balanced picture, we have collected this data qualitatively as well and organised it for analysis in section 4.

With regard to scope, we have selected those changes in policy that actually meant a change in the choice of policy instruments related to risk-taking for project developers in OWP (see Table 1) and reviewed them through the study of secondary literature (e.g. [Araujo(2017)], [Higgins & Foley(2014)], [Reichardt et al. (2016)], [Van der Loos et al. (2021)])), trade magazines and policy papers (see section 9, References). Other policies, like environmental policies related to OWP, or site locations, were off scope, just as mere opinions in the media and so on.

In section 4 we provide a country by country historic process tracing of the main policy instruments for OWP in these four countries, whilst in

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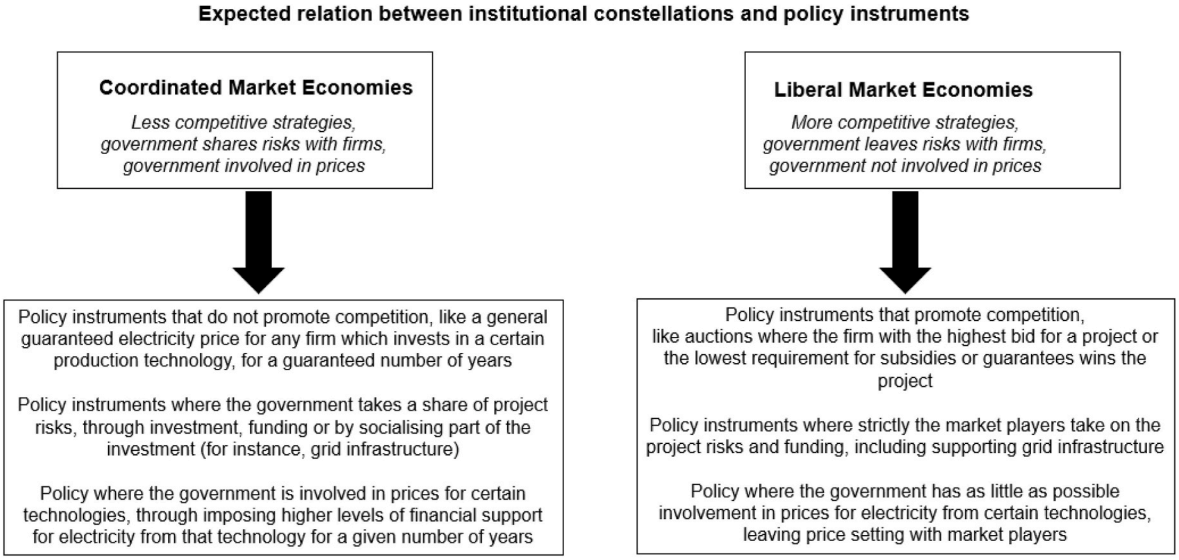
[5] Both FIT in Set S3 as well as INV in Set S2 amount to "patient capital", with governments supporting long-term growth for low-carbon energy technologies and taking on risks, through providing patient and committed finance where the market isn't providing it (cf. [Mazzucato(2014)], pp. 149).

[6] The EU Energy market Liberalisation through the 1998 first Energy Package, strengthened by the second and third Energy Package and the EU State Aid Guidelines ([European Commission(2014)]), are clear examples of EU policies pushing Member States towards more market orientation in energy policies.



Expected relation between institutional constellations and policy instruments

Coordinated Market Economies

Less competitive strategies, government shares risks with firms, government involved in prices

Policy instruments that do not promote competition, like a general guaranteed electricity price for any firm which invests in a certain production technology, for a guaranteed number of years

Policy instruments where the government takes a share of project risks, through investment, funding or by socialising part of the investment (for instance, grid infrastructure)

Policy where the government is involved in prices for certain technologies, through imposing higher levels of financial support for electricity from that technology for a given number of years

Liberal Market Economies

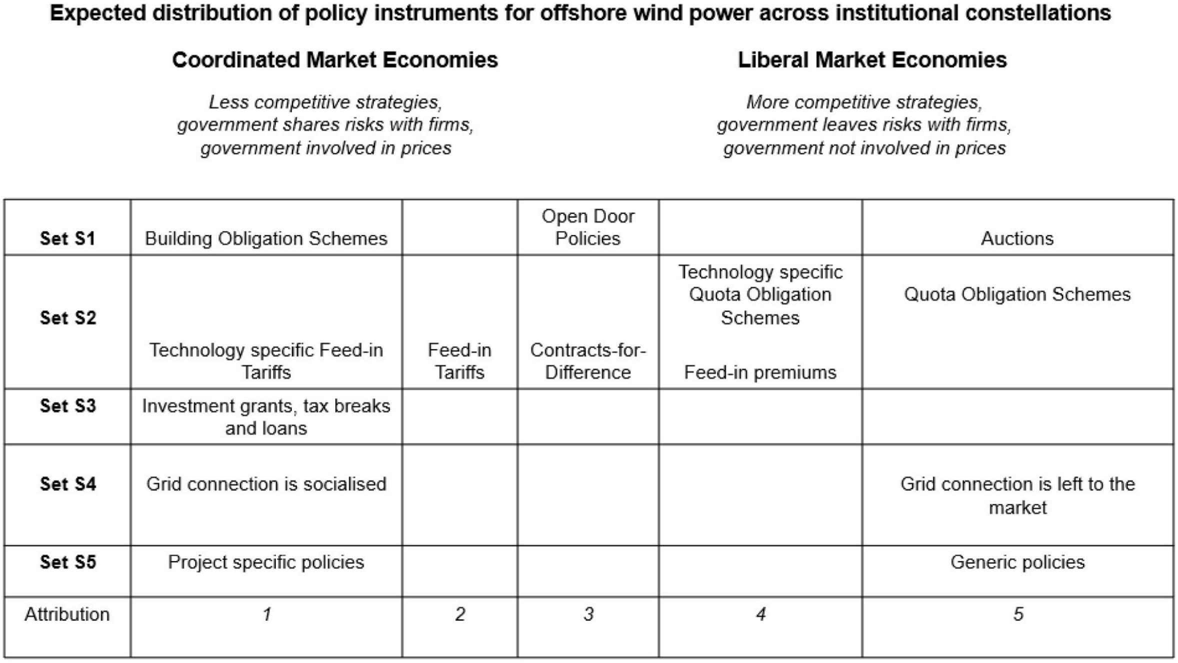
More competitive strategies, government leaves risks with firms, government not involved in prices

Policy instruments that promote competition, like auctions where the firm with the highest bid for a project or the lowest requirement for subsidies or guarantees wins the project

Policy instruments where strictly the market players take on the project risks and funding, including supporting grid infrastructure

Policy where the government has as little as possible involvement in prices for electricity from certain technologies, leaving price setting with market players

Fig. 2. Expected relation between institutional constellations and the nature of policy instruments.



Expected distribution of policy instruments for offshore wind power across institutional constellations

Coordinated Market Economies

Less competitive strategies, government shares risks with firms, government involved in prices

Liberal Market Economies

More competitive strategies, government leaves risks with firms, government not involved in prices

Set S1	Building Obligation Schemes		Open Door Policies		Auctions
Set S2	Technology specific Feed-in Tariffs	Feed-in Tariffs	Contracts-for-Difference	Technology specific Quota Obligation Schemes Feed-in premiums	Quota Obligation Schemes
Set S3	Investment grants, tax breaks and loans				
Set S4	Grid connection is socialised				Grid connection is left to the market
Set S5	Project specific policies				Generic policies
Attribution	*1*	*2*	*3*	*4*	*5*

Fig. 3. Expected distribution of policy instruments for offshore wind power across different institutional constellations. Attributed numerical score in last row based on discussion of market-orientation and policy instruments in section 2.2. Higher score indicates more market orientation and less government risk-taking. The numerical score enables us to illustrate patterns in our comparative analysis more clearly (Authors).

section 5 we present a comparative assessment of these findings.

4. Policy instruments and offshore wind power

In this section we describe when and how the nations in scope have used policy instruments, listed in section 2 Table 1, to promote investment in OWP between 1990 and 2020.[7]

4.1. Offshore wind power in Denmark

Typical for Denmark's timeline is a policy shift from directly negotiated or even imposed government-utility deals to competitive auctions ([Araujo(2017)] p174). This is reflected in Fig. 4 where we see offshore wind farms (OWF) delivered without competitive bidding (AUC) between 1991 and 2004.

The government obligated municipal utilities Elkraft and Elsam to install OWP without subsidies through the so-called "100 MW Agreement", December 20th, 1985 ([Araujo(2017)], p157). The government

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[7] For illustrative purposes we have depicted the policy instruments on a timeline with the deployed capacity volumes of OWP. We do not claim that the policy instruments directly imply deployment or lack thereof; for instance, situations in technology and the financial market or the geophysical situation are relevant as well.

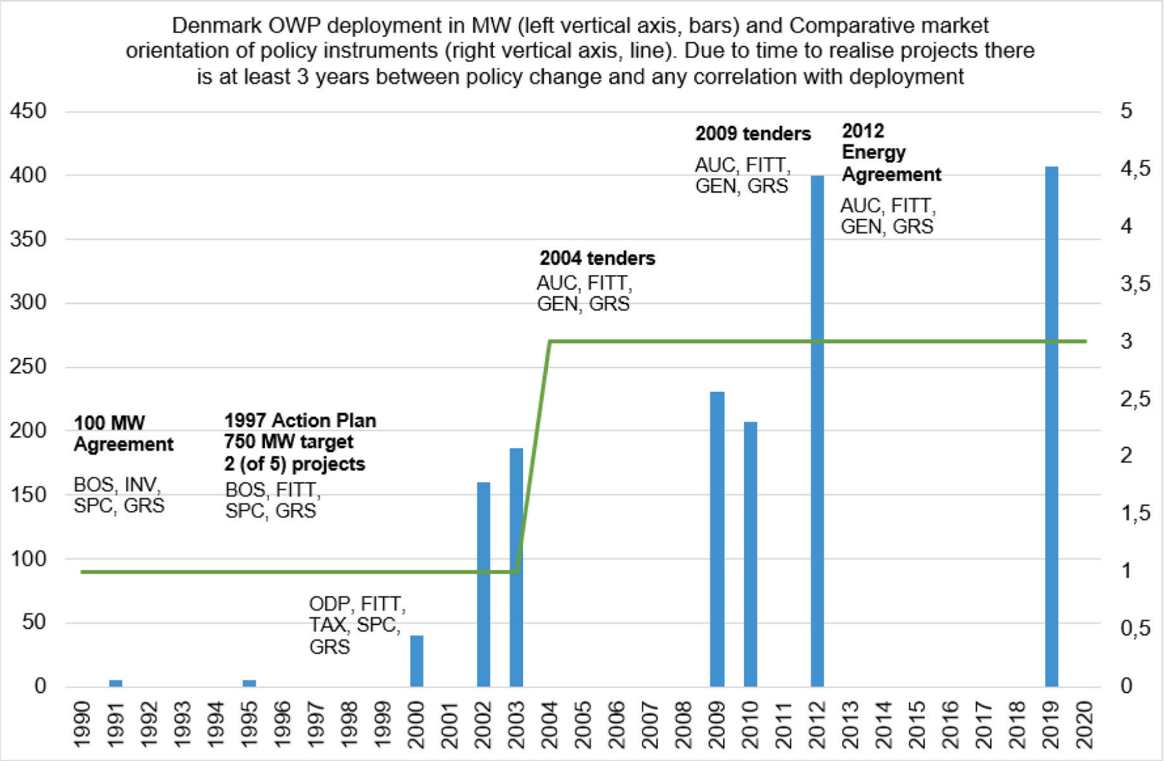

Fig. 4. The time line for the main policy instruments and the deployment of offshore wind farms in Denmark 1990–2020. Source: Data collection by authors.

made these leading public utilities commit to deploy 100 MW of OWP (Elsam 55 MW, Elkraft 45 MW) between 1986 and 1990 (BOS, INV, SPC, GRS) in exchange for a less permissive policy towards private investors in wind energy.[8] Subsequently, Elkraft then built OWF "Vindeby" (4.5 MW, 1991), the world's first multi-turbine OWF, and Elsam built OWF "Tuno Knob" (5 MW, 1995) ([Araujo(2017)], p162) (see Fig. 4). A further step to scale-up was citizen-funded 40 MW OWF "Middelgrunden" near Copenhagen in 2000 ([Larsen et al. (2005)]).

The 1997 "750 MW obligation" was a requirement placed on power companies to install an additional 750 MW of OWP before 2008 ([Araujo (2017)], p162) (BOS). The utilities were to build five OWF under a political agreement with the government ([OECD(2000)], p27).[9] There was strengthened commitment of Danish power companies and an eagerness to develop the first 750 MW of OWP. Applications for planning permission were launched even before the actual Government order was issued ([Krohn(2000)]). The results were the first commercial-scale 160 MW OWF "Horns Rev 1" in 2002 ([Power Technology(2008)]) and "Rødsand Nysted" 160 MW in 2003 by Elsam under "an order or particular agreement" (BOS, SPC) at a technology-specific guaranteed market price (FITT, GRS).[10]

However, the other three OWF under the 750 MW Obligation weren't realised as agreed. This was due to the changing institutional constellation, where the small, open Scandinavian and Dutch economies liberalized due to influence from the UK via EU regulations ([Schneider&Paunescu(2012)]). The EU agreed the Liberalisation of Electricity Markets in 1996 and this was implemented in Denmark in 1999 through the "Electricity Supply Act".[11] The related EU State Aid regulation implied reduced subsidies for wind power and thus limited public investment in renewables.

The Danish elections led to a break in the OWP strategy when in December 2001 the liberal-conservative Venstre government came to power, leading to policy uncertainty ([Araujo(2017)], p164) and the consideration of more competitive policies ([Meyer(2004)], [Smit et al. (2007)] section 4.2). The idea was to have three international auctions for 160 MW OWF each but no decision was reached ([WPM(2002)]). By March 2004 the government reached an agreement with the opposition ([Meyer(2004)]) for two 200 MW international auctions with technology-specific subsidies and socialised grid connection (AUC, FITT, GRS, GEN; see Fig. 4). The shift in policy instruments for Danish OWP, from directly negotiated government-utility deals to competitive auctions, took several years of political discussions.

April 2009 auctions for the construction of OWF "Anholt" were held by the Danish Ministry of Climate and Energy (AUC, FITT) and the project was online January 2012. And by 2012 political harmony was restored, as the "Energy Agreement" of March 22nd, 2012 met with 95% approval and introduced a target of 50% of electricity from wind power in 2020 ([Araujo(2017)]) p166, [DEA(2012)]). April 2012 Parliament set out auctions for "Horns Rev 3" (400 MW) and "Kriegers Flak" (600 MW) (AUC, FITT) which came online in 2019 and 2021 respectively (see Fig. 4).

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[8] Both Elkraft and Elsam owned grids and cited problems in dealing with concentrations of private investors' wind farms in North-Jutland and elsewhere ([van Est(1999)], pp. 89).

[9] In Denmark the institutional constellation supported government obligations to firms through "agreements" in the 1970s, 80s and 90s. For example, the transition in the 1970s from oil to coal (after the 1974 Oil Crises) and the introduction in 1995 of a 100 gas-fired CHP plants, were also "agreements" ([Krohn(2000)]).

[10] The government paid a technology specific feed in tariff for OWP that, with the market price, amounted to a price of €60/MWh for 42.000 full load hours (technology specific, "FITT") ([DEA(2006)], p25). The government allowed utilities to pass on costs to customers.

[11] The first liberalisation directives (First Energy Package) were adopted in 1996 (electricity) and 1998 (gas), to be transposed into Member States' legal systems by 1998 (electricity) and 2000 (gas).

4.2. Offshore wind power in the United Kingdom

Typical for the UK's timeline is that liberalisation of the electricity supply industry was comparatively thorough and early. From the Electricity Act of 1989 on privatisation, a series of mergers and the entry of large foreign multinational utilities (German RWE and others) led to the emergence of 10 generation companies, owning 85.8% of UK generation assets by 2012 ([Hall et al. (2016)]). The 1989 Electricity Act also contained the Non-Fossil Fuel Obligation (NFFO) which consisted of a quota obligation scheme (QOS, see Table 1) to electricity suppliers as well as rounds of auctions for support for non-fossil electricity production (AUC).

Firstly, legislation obligated the privatised electricity suppliers to buy all NFFO electricity (nuclear or renewable) offered to them from producers. Secondly, the government awarded contracts to firms that offered to develop non-fossil fuel electricity production requiring the lowest amount of subsidy within a technology band.[12] The average prices lowered through 5 rounds as competition was intense ([Mitchell (2000)]), an early demonstration of how auctions drive down costs.

The Utilities Act of 2000 introduced Renewable Obligation certificates (ROC), the UK government obligating suppliers to cover a certain volume of their sold electricity with tradeable certificates for renewable electricity generation (QOS). The renewable quota increased annually from 3% in 2002–2003 to 10.4% in 2010–2011. Originally this would increase from 2002 until 2027 but it stabilized after 2012 ([Woodman& Mitchell(2011)], p3915). The ROC were traded to make it a 'market' policy even though it is a government obligation: the government setting volumes, the market setting prices. Market principles set the price for ROC and left the risks with firms, as OWP producers and Suppliers negotiated dynamically for prices and terms of contracts. The ROC policy was more market-oriented than the NFFO and project developers carried the risk ([Mitchell & Connor(2004)], p1939).

The 2001 "Offshore Wind Capital Grants Scheme" introduced €147 mio grant funding to ten OWF as government agency DECC advanced another 90 mio pound (€ 113,4 mio) and agency ETI advanced 16 mio pound ([Higgins & Foley(2014)] p606). Except for investment subsidies the consented first OWF also received capital grants and were exempt from the climate change levy (INV, TAX) ([Markard & Petersen(2009)]).

The UK roll out of OWP was not guided by deals between government and firms on specific projects but was generic (GEN). From the start it was mediated through auctions for wind farm sites issued by the Crown Estate, which manages the UK sea beds, in a series of 'Rounds' (AUC), whereas remuneration was dealt with indirectly through competitive policies that left risks with firms as much as possible (QOS) ([MacKinnon et al. (2019)]).

Without a license for a site there is no future offshore wind farm (OWF) project and therefore no future access to remuneration for OWP through ROC. Vice versa, without the additional remuneration through ROC, OWP project developers have no subsidy to counter the additional costs and risks that OWP brings about in comparison to incumbent technologies. Therefore we analyse the bidding for the site for an OWF as indirect competitive bidding for subsidies for renewables (our category "AUC" in Table 1, Set S1). With this analysis of the UK policy instruments early 2000 as competitive bidding for subsidy we defer from previous analyses of UK OWP policy, e.g. [Fitch-Roy(2016)], who views the 2015 Contracts for Difference policy instrument as the first competitive bidding for subsidy.

Firms had to realise the grid connection as well (GRM).[13] Round 1 was realised 2003–2013: eventually 1200 MW, seeing 12 projects realised of originally 17 projects, which illustrates the risk for project developers. Development and commissioning of all rounds except Round 1 are still in progress.

After the first 5 rounds of auctions, the UK government multiplied the value of green certificates under Renewable Obligation Certificates ("ROC") for OWP by 1.5, and even higher than 1.5 between 2010 and 2014 (QOST).[14] This was a reversal of the UK's liberal 'not picking winners' approach ([Woodman Mitchell(2011)], p3919). The policy instrument is more technology-specific so more non-market and reflects more government intervention in prices (€ 97,51/MWh). At a later point the value of ROC for OWP was even awarded double the value of other ROC ([IRENA and GWEC(2013)]).

In the aftermath of the 2008 financial crisis, investment in OWP fell off and in 2012 the government introduced the Green Investment Bank, which was government-owned until in 2017 it went to the private firm Macquarie. As project developers developed bigger OWF, at greater distance and water depth, utilities were no longer able to finance projects from balance sheets ([PWC(2010)]). The UK government turned to co-investment (INV) to facilitate project developers and to crowd in pre-construction funding from banks ([Higgins & Foley(2014)], p610). These policies coincide with a higher volume of OWP in 2013 and further on (Fig. 5).

The Energy Act of 2013 introduced Contracts for Difference ("CfD") that were applied for the first time in an auction in February 2015 ([UK Government(2020)]). If the electricity market price is lower than production cost, the government reimburses a part of the difference to a measure set during competitive auctioning. If the market price is higher, the government receives part of the difference from the producers. First bids range around € 120/MWh ([Jansen et al. (2020)]). The government expects the CfD to limit the exposure to electricity price volatility for producers of renewable energy, reduce financial risk for projects and therefore encourage investment in the production of renewable energy ([Higgins & Foley(2014)]).

This policy instrument shares price risk between firms and governments more evenly and still seems to drive down the costs for OWP. The bid price halved between 2015 and 2017 which suggests that the policy of reducing risks for developers and producers is highly effective, for instance making access to capital cheaper ([Jansen et al. (2020)]). But developments in technology are also relevant (larger turbines, more efficient installation at sea), and the eagerness from developers to offer competitive bids is increasing, so several independent factors are at play driving down bid prices (see Appendix Figure A2).

4.3. Offshore wind power in Germany

In Germany, three types of utilities are operating at national (about 8; RWE, Vattenfall, E.On), regional or local (municipal) level, under a mixture of public and private ownership. Also, vertical integration in the electricity sector (production, networks, trade, supply) is common in Germany ([Rentier et al. (2019)]). While in 1990 in Denmark the first

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[12] The subsidy was funded through a Fossil Fuel Levy ("FFL") to customers, which from 1990 to 1995 on almost exclusively funded uncompetitive nuclear power generation ([Mitchell (2000)],Table 4).

[13] Each project developer can agree on specific feed-in conditions with the local network operator (a third party offshore transmission operator ("OFTO"), a private firm). Alternatively, they can build the grid connection themselves before transferring the assets to the OFTO ([IEA(2019)] p38). Project developers generally build it themselves. Subsequently the UK regulator organises an auction and an OFTO buys the grid connection. Once the site is in operation, the owner pays UK National Grid who pays the OFTO a regulated fee ([IEA (2019)] p39).

[14] Actually the government rewarded one MWh of OWP with more than 1 ROC, so first 1.5 ROC and eventually 2 ROC ([IRENA and GWEC(2013)], p132), as actual prices of ROC were determined dynamically by market actions between producers of OWP and Suppliers. But this effectively multiplied the revenue for OWP volumes.

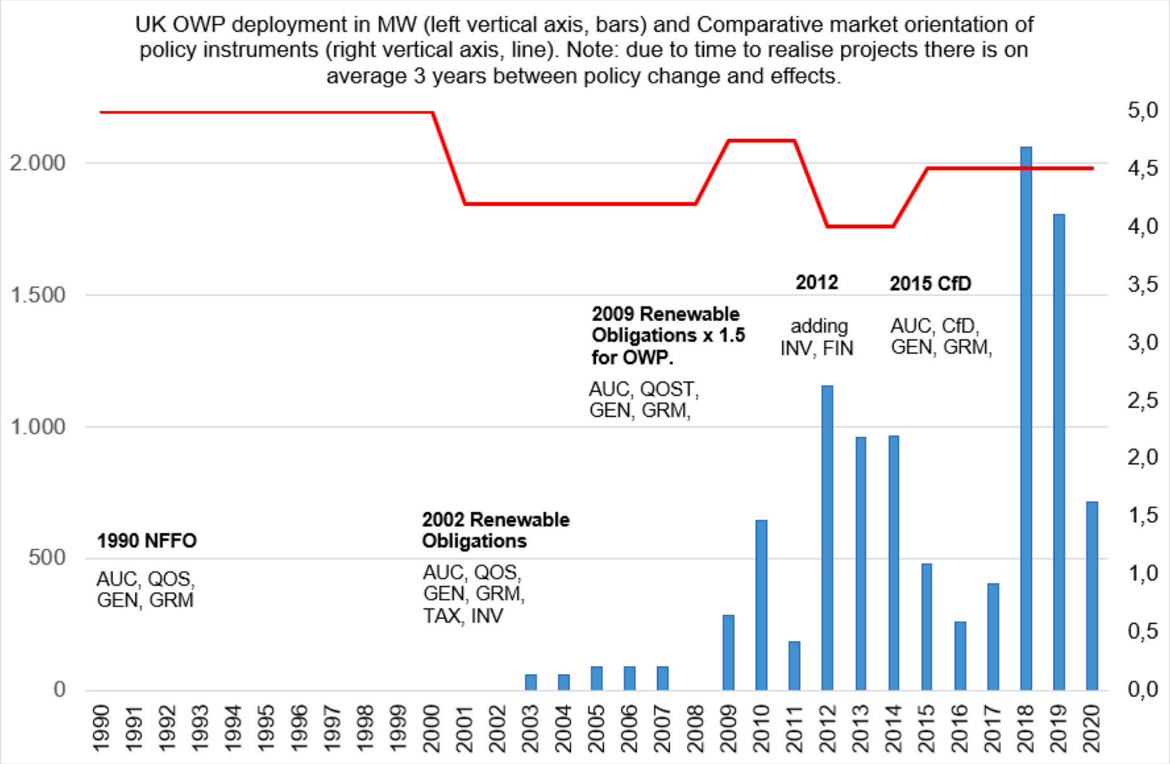

Fig. 5. The timeline for the main policy instruments and the deployment of offshore wind farms in the United Kingdom 1990–2020. Source: Data collection by authors.

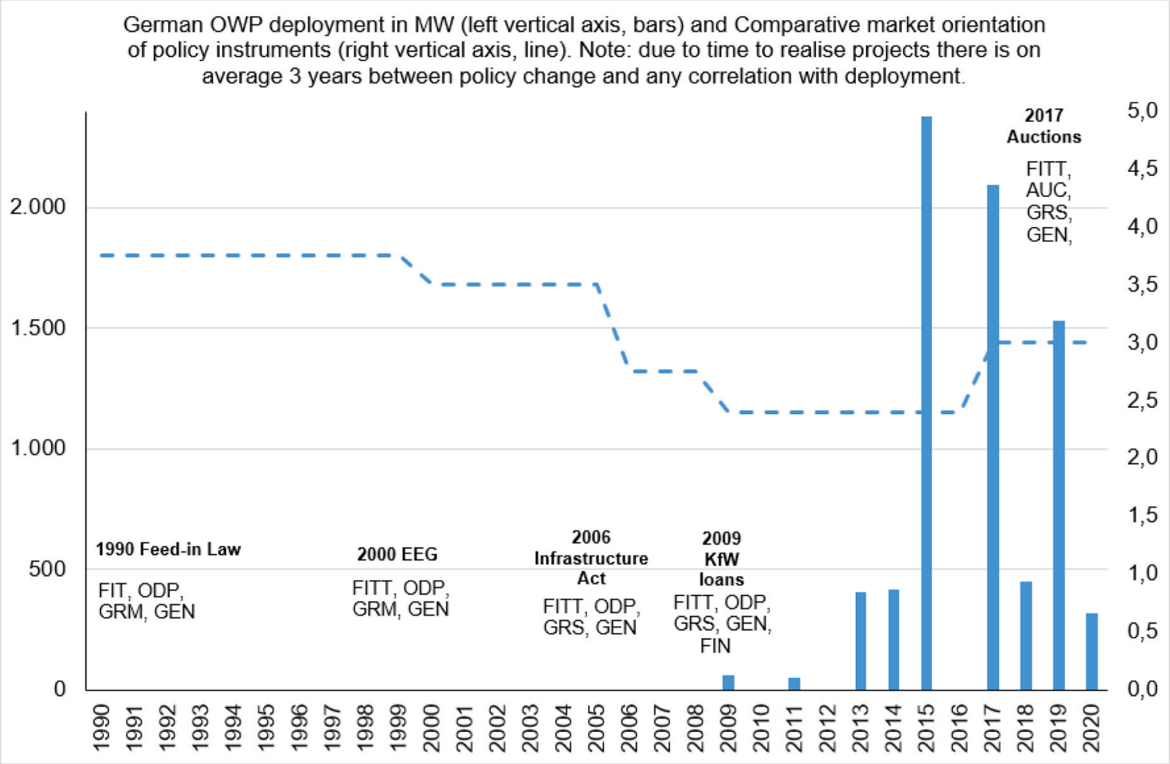

Fig. 6. The timeline for the main policy instruments and the deployment of offshore wind farms in Germany 1990–2020. Source: Data collection by authors.

OWP was built and the UK introduced the NFFO, Germany introduced the 1991 Feed-in law (“Stromeinspeisungsgesetz”) (FIT), leading to a large development of solar and onshore wind energy.

The first remarkable fact about German OWP is its relatively late start, with the first OWF in 2009 (see Fig. 6). This was due to its lack of shallow waters that weren’t protected by environmental policies and the fact that it took the OWP industry until around 2007 to develop technology for the deeper waters.[15] So the fact that policies didn't invite OWP has a reason not related to institutional constellations. More related to institutional constellations and policy instruments is the remarkable fact that until 2017 there were no auctions for OWP (AUC) in Germany.

The 2000 Renewable Energy Sources Act (the "EEG") introduced technology specific and size specific support payments for renewables but did not introduce a specific technology band for OWP ([Nkomo (2018)], p19). The level of subsidy was generically established into law (FIT, ODP) so auctions were unnecessary. The project developers take the initiative and list their interest (ODP) and subsequently the government can grant permits and license grid connections ([Reichardt & Rogge (2015)], [Leiner & Reimer (2018)]).

The 2004 EEG contained the federal goal of achieving 30% electricity generation from renewables by 2020 but did specifically address OWP by stipulating that 15% of that 30% would have to be OWP and the OWP share in the overall mix should be 25% in 2025 ([Portman et al. (2009)], p3597). Following this, in 2005 wind turbine manufacturers through the Foundation for Offshore Wind Energy convinced three (partly) government-owned utilities (EWE, E.On, Vattenfall (33% each)) to develop test field Alpha Ventus with 2 manufacturers supplying 12 wind turbines ([Reichardt et al. (2016)]) (ODP, SPC). Additionally, new law in 2006 imposed costs for grid connection on transmission system operators and thus on all electricity customers ([Markard et al. (2009)], p3553) (GRS). High costs and perceived risks for OWP meant still no capacity had been installed by 2008 ([Markard et al. (2009)]). In 2009 the new EEG introduced a higher FIT for OWP in 2009 to compensate the great water depths and distance from shore ([MacKinnon et al. (2019)], p11) (FITT), an increase from € 91 to € 150 per MWh until 2015 ([Nkomo(2018)], p23).

The result of all these efforts from firms and government was "Alpha Ventus", the first German OWF in 2009, with water depth 35 m and distance from shore 45 km, taking on the technological risk of doubling the state of the art in both dimensions. It demonstrated the feasibility of such large-scale deep-water projects with high uncertainties and inspired other investors ([Reichardt et al. (2016)]).

The years 2009–2010 saw the climax of the financial crisis, and with the high risks involved with investments in OWP there was not enough financing from private banks. The government solved this through arrangements with the KfW public bank. This Kreditanstalt fur Wiederaufbau (KfW, public bank) unleashed a € 5 billion federal loan program for OWP in 2011 (INV). The 2011 Fukushima incident with nuclear power boosted the German exit from nuclear and the 2012 EEG Amendments for OWP, guaranteeing €150/MWh until 2018 instead of until 2015, but with a decrease from 2018 of 7% a year ([Reichardt et al. (2016)]).

Later on, a German political majority wanted competitive auctions (AUC) to replace the open door policies (ODP) in order to control the volume of deployment. The introduction of auctions was speeded up by EU State aid guidelines requiring member states to align their renewable support schemes to competitive bidding processes ([Leiren & Reimer (2018)]). The German 2017 EEG introduced competitive bidding for OWP in Germany. First half of 2017 the very first auction for OWP in Germany immediately produced the first three zero-subsidy bids (winning three out of four offshore wind farms).

The zero-subsidy bids were enabled by German policies firstly socialising the costs of grid connection, and secondly by auctions with long lead times for project developers. This made it possible for project developers to base their bids on electricity production at even more competitive prices, by calculating with the yet to be produced bigger 13MW–15MW capacity offshore wind turbines for these OWP projects ([WPM (2017)]). Subsequent policies introduced a clear pipeline of projects, auctioning 500 MW a year in 2021 and 2022, 700 MW 2023–2025, 840 MW per year from 2026 onwards, offering project developers a stable future and benefits from learnings. It also centralised project coordination as in Denmark ([Nkomo (2018)], p25).

4.4. *Offshore wind power in the Netherlands*

During the 1990s the Netherlands became, after Sweden, the CME with the most institutional support for privatisation ([Schneider&Paunescu(2012)], see Appendix Figure A1). In the 1990s around 50 Dutch municipal and regional utilities went into a series of mergers, resulting in 6 public owned utilities and 4 foreign utilities by 2000. By 2009, after liberalisation in 2004, foreign multi-nationals (Vattenfall (alias Nuon), RWE (alias Essent), GdF Suez, E.On) dominated the Dutch energy market. After ownership unbundling in 2016 the third and last significant public utility (>25% market share), Eneco, was bought by Mitsubishi in March 2020. The resulting energy market is similar to the UK's LME situation.

Initially, the Netherlands started late 1990s with small scale OWP from municipal utilities just like Denmark (see Fig. 7). In 1994 2 MW windfarm Lely by regional public energy company PEN ("Provinciaal Energiebedrijf Noord-Holland") was in fact the second grid-connected OWF (near-shore 800 m off the coast, water depth −5 to −10 m) ever after Vindeby, before 1995 Danish Tuno Knob. In 1996 Dutch 16 MW near-shore windfarm Irene Vorrink followed by then regional public energy company Nuon (ODP, SPC, GRS).

After this early start, the 1998 Electricity Law implementing EU liberalisation preceded 13 years of unstable OWP policies. Between 2001 and 2014 there were more false starts (3) than OWF (2) as "*Dutch OWP policy [was] sporadic, tumultuous and inconsistent*" ([Van der Loos et al. (2020)], p6). Without a coordinated roll-out or a stable pipeline the Netherlands were unattractive to investors in OWP.

In 13 years from 2001 the Netherlands switched to "Go" four times and three times back to "Stop". In 2001 privatised project developer Econnection developed "Q7" (to become Amalia Park), the project developer taking on the cost and responsibility for grid connection ([TWOZ(2010)], p16) (ODP, FIP, GRM, SPC). Also in 2001 the first "Go" government initiative, Egmond aan Zee, involved 27 million euro subsidy through an auction and a feed-in premium, leaving more risk with the project developer than with a FIT (AUC, FIP, GRS, SPC). However, subsequent other ODP-initiatives from other developers faced a moratorium because there was no actual legislation ([Verhees et al. (2015)], p821).

In 2004 the second "Go" was the introduction of the MEP subsidy, a guaranteed premium for 10 years, on a "First come first served" basis and a FIP of EUR 100/MWh. This led to 54 applications involving 20.000 MW (ODP, FIP, GRM) ([Energeia(2005)]). The government closed the MEP policy when in 2006 it concluded this was too expensive and awarded no projects ([Verhees et al. (2015)], p.821)).

Learning from this experience, in 2007 the government introduced (third "Go") competitive bidding for Feed-in tariffs with the capped technology-specific SDE policy (AUC, FITT, GRM). In 2009 the actual 950 MW auction led German Bard winning 2 × 300 MW north of Schiermonnikoog (to become "Gemini"). Three Dutch utilities lost, leaving 1 billion which was awarded to 129 MW "Luchterduinen" ([Verhees et al. (2015)], p824). In 2010 government erased technology bands in the SDE policy, leaving OWP unable to compete ([Energeia (2011)], [Verhees et al. (2015)], p825).

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[15] This seems at odds with Germany's reputedly early and strong push for more renewable energy. The protected Wattenmeer National Park meant that suitable shallow areas (mud flats) near the coast were off limits for OWP. Options for OWP started at 40-m water depth beyond 22 km ([Ćetković & Buzogány(2016)], p14), and Germany had to wait until around 2007 before the industry was able to deliver the required technology. The OWP industry built at depths of less than 20-m water depth until 2007. Only in 2007 UK Beatrice Demonstration was built at -45m water depth, 25 km from shore, as a pilot ([Ćetković & Buzogány(2016)]).

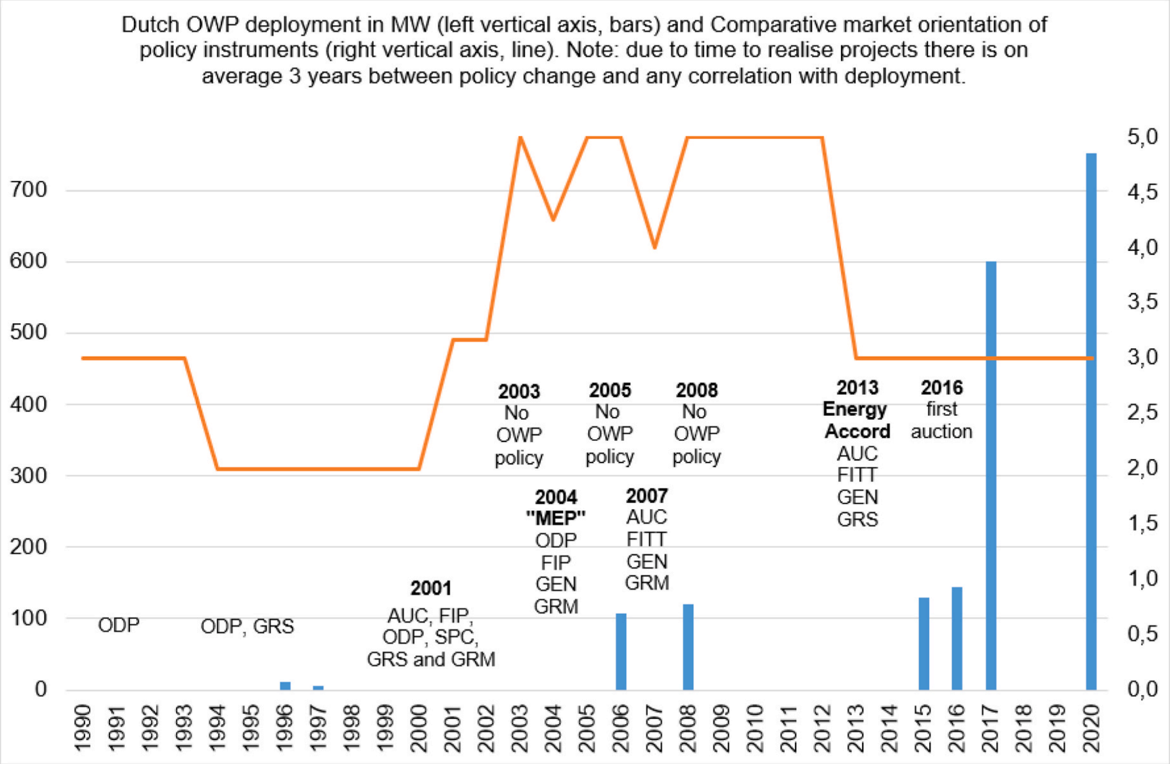

Fig. 7. The time line for the main policy instruments and the deployment of offshore wind farms in The Netherlands 1991–2020. Source: Data collection by authors.

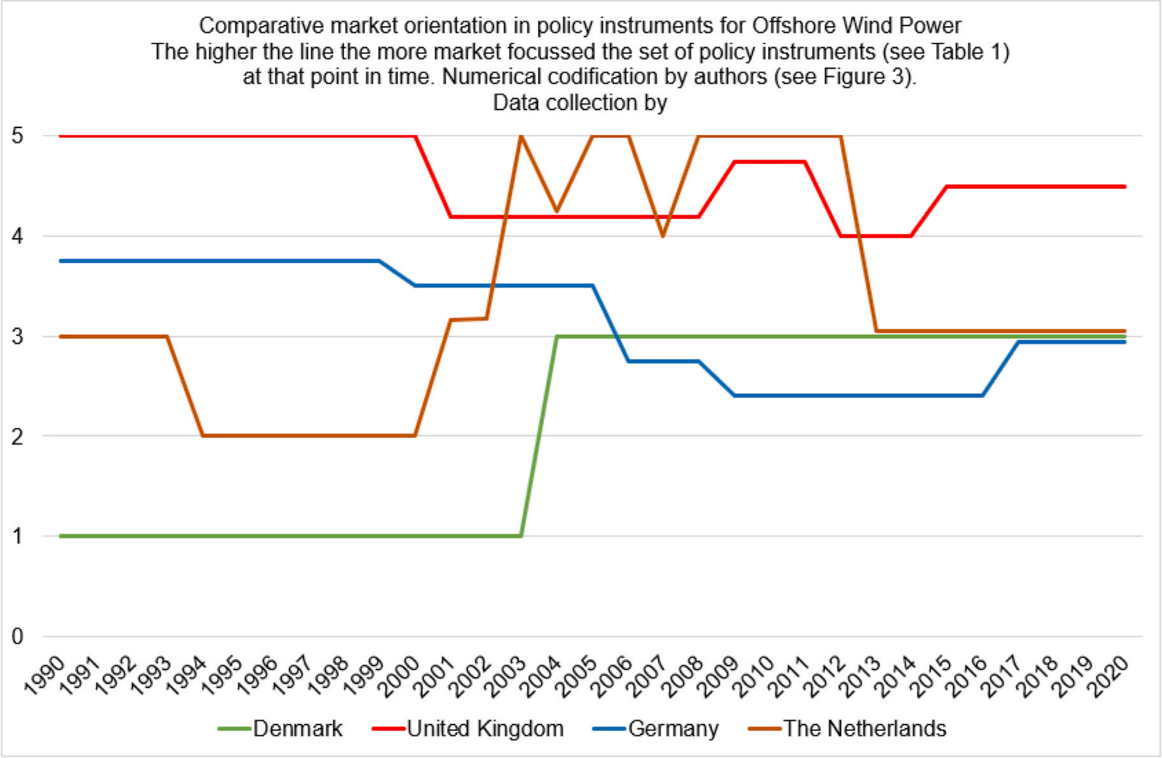

Fig. 8. The policy instruments (cf. Table 1) as applied to offshore wind power in Denmark, UK, Germany and the Netherlands between 1991 and 2020, quantified for market focus by numerical coding (cf. Fig. 3). The values for the policy instruments are averaged at each point of policy change. Source: data collection (section 4) and coding (in Fig. 3) by authors.

Halfway 2013 the fourth “Go” earmarked part of SDE + for OWP in a technology band for OWP ([Verhees et al. (2015)] p425). A major Energy Agreement (“Energieakkoord” by government, firms, NGO’s) set a 4450 MW target per 2023 for OWP through auctions and socialised the costs of grid connection, like Denmark did in March 2004 (AUC, FITT, GEN, GRS) ([RVO(2015)], [Van der Loos et al. (2021)], p7). This fourth set of policy instruments brought a stable pipeline and cost reductions beyond expectation, as in July 2016 the first auction “Borssele I + II” was awarded at a guaranteed tariff of 72,20 instead of the €91,50/MWh FITT that was forecast in 2013. The second auction “Borssele III + IV” was awarded at 54,50 in December 2016, and July 2019 the third auction, “Hollandse Kust Zuid” at a zero-subsidy bid.

5. Discussion

We have described the relevant details of the policy instruments in the previous subsections. To illustrate the general trends comparatively, we have also quantified the policy instruments (from Table 1) through the coding that was introduced in Fig. 3 and we have arranged them in a timeline. The results are in Fig. 8 below, where a higher line indicates more market orientation in the nation’s policy instruments[16]

When analysing the patterns in section 4 and Fig. 8 we can discern two trends. First, we see that after the EU liberalisation of the electricity market, in 2004 Denmark was the first to start employing policy instruments including auctions, socialised grid connection and technology-specific FIT. Germany joined that in 2017, after a less market-oriented phase kick-started German OWP between 2005 and 2017. In the Netherlands EU liberalisation preceded unstable periods of high market-orientation until 2013 when it also implemented the Danish March 2004-approach. The UK consistently featured the highest market-orientation, apart from the Dutch decade of ‘outbursts’ of market-orientation.

The data in section 4 illustrates the nature of policy instruments in the OWP industry’s first 30 years. The UK’s market orientation as an LME has been apparent from the start in 2003 with its use of auctions[17] and with leaving risks and the setting of prices to the market. The UK has left building grid connections to market dynamics as much as possible, whereas the CME have socialised this.

Because of the initial unavailability of OWP technology to deal with Germany’s greater water depths, German policy wasn’t particularly geared towards OWP until 2006–2009. But when the necessary technology became available by 2006, CME Germany’s policy instruments for OWP were much more government risk-taking and least market-oriented, with a one-size-fits-all guaranteed feed-in tariff determined by the government, not the market. Only in 2017 German legislation for competitive bidding was introduced, 14 years after LME the UK’s first competitive bidding for OWP.

However, with respect to intervention in the market for capital, the LME and CME acted similarly. The 2001 UK “Offshore Wind Capital Grants Scheme” kick-started the first round of OWP deployment. And the 2012 introduction of the UK’s Green Investment Bank, which was government-owned until 2017, is very similar to the role in OWP of the government-owned German KfW in 2011. Both LME and CME chose public investment in OWP to deal with the larger demand for capital as OWF became bigger, while the financial world was still dealing with the negative effects of the financial crisis.

Both the Netherlands and Denmark qualify as CME, have large opportunities in OWP and started out early in the 1990s with small near-shore OWF financed by municipal utilities. But after the EU agreed to liberalise all electricity markets by 1998, the Netherlands set out a stronger strategy for privatisation than Denmark, Denmark keeping a number of key utilities government-owned. Until March 2004 Denmark’s policy instruments were clearly non-market, when OWP was in its vulnerable phase of research, design and demonstration. In contrast, Dutch OWP policies in the 2000s experimented with high degrees of market-orientation, which failed to reduce risks effectively for the project developers and, through frequent retro-active changes, failed to deliver credibility between 2000 and 2013. Only by 2013 Dutch legislation became available which copied effective policies from Denmark and which led to a first steady pipeline of auctions for OWP from January 2016 on.

A pattern across all four nations is that, in order to start or boost deployment of OWP, they all applied technology-specific variations on their policy instruments. Denmark used OWP-specific subsidies from 2000 on, mitigating that OWP was then a more expensive low-carbon technology than onshore wind or solar. The UK multiplied the value of Renewable Obligation Certificates by one and a half for OWP in 2009, Germany multiplied the value of its Feed-in Tariff by one and a half for OWP in 2009, and the Netherlands allowed a specific technology band for OWP in its SDE + policy from 2013 onwards.

6. Conclusions and policy implications

From the data in section 4 it is clear that Denmark kick-started the development of OWP through a crucial period of 14 years of obviously non-market policies (Fig. 4, section 4.1). In the other three nations we see that the really significant deployment of large volumes of OWP was always preceded by a policy change towards less market-oriented policy instruments (Figs. 5–7, sections 4.2, 4.3, 4.4). So across the board, promotion of this new low carbon technology correlated with a degree of government intervention in markets, leading to a new technology which was eventually competitive with incumbent technologies (Appendix, Figure A2). The research question in this paper goes beyond that, and asks if the difference between more market oriented institutional constellations (LME) versus less market oriented institutional constellations (CME) is reflected in the policy instruments for OWP.

From sections 4 and 5 we actually conclude that the characteristics of institutional constellations have indeed shown through in the nature of policy instruments in the first 30 years of OWP deployment. However, both LME and CME applied investment aid and technology-specific support, making them more similar then we would expect. But the UK’s other policy instruments were typically LME from 2003 on,[19] auctions leaving more risks with project developers. Those firms run the risk of losing upfront costs or may enter a bid for less subsidy than is eventually necessary. After a comparatively late start due to geophysical and technological circumstances, Germany’s policy instruments included general government guaranteed prices and socialised costs for grid connection, more typical for CME, with less risk for project developers. Germany didn’t introduce competitive bidding for OWP until 2017, leading to the first German auctions for OWP comparatively late, but immediately allowing for three zero-subsidy bids out of four offshore wind farms ([WPM(2017)]).

Between 1990 and 2020 the overall trend across these four nations is that policy instruments became more market-oriented. First, the institutional constellations of all smaller EU nations underwent a period of liberalisation around 2000 ([Schneider&Paunescu(2012)]. We see this with both Denmark and the Netherlands, though for OWP the impacts were different. Denmark had by then already taken important steps and had agreed on a couple of important first commercial scale offshore wind farms, just before liberalisation confused Danish OWP policies. The

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[16] Where the Netherlands stopped support for OWP in the 2000s we have coded this as “maximum market focus”. Similarly for the period in the 1990s where the UK did not support OWP specifically in the NFFO. Coding as discussed in section 2, policy instruments as discussed in sections 4.1 to 4.4.

[17] In this research we analyse the developer’s bidding to the Crown Estate for the site for an OWF as indirect competitive bidding for subsidies for renewables (our category “AUC” in Table 1, Set S1). This is because without a site there is no OWF and therefore no future subsidy through ROC, and vice versa; there is no business case for the OWF so no business case for bidding for a site without the ROC. See sections 2.2 and 4.2.

Netherlands had not yet agreed on significant offshore wind farms as it went into unstable OWP policies from 2001 until 2014.

Secondly, through policy learning and EU State Aid regulation all national policies started to converge by 2017, while still showing a difference between LME and CME. After Denmark showed that commercial scale offshore wind farms were possible (160 MW, 2002; section 4.1), the EU liberalisation of energy markets forced members to introduce more competition in policies. March 2004 Denmark invented the model where project risk is still reduced by socialising the costs for the grid connection, while incentivising cost reduction by awarding projects through auctions to developers with the lowest requirement for subsidy. The Netherlands, after periods of high market orientation, also implemented the Danish March 2004-approach in 2013. Germany, after a decade of low market orientation to facilitate the start of deployment, copied the Danish March 2004-approach in 2017. Thus the policy instruments in the three CME, including the highly privatised institutional constellation of the Netherlands, converged through EU membership and policy learning. The UK, as a pure LME, showed high market orientation throughout, using auctions from the very beginning and never socialising grid connections.

From the Danish case we can gather that in the early phase of research, development and demonstration (RD&D), government risk-taking in specific first commercial scale projects can be crucial. Denmark decided to do so around 2000, and established a position in OWP as a first mover. From the UK case we can see that a more competitive strategy, leaving risk with firms, has not delivered first mover advantage. However, after the RD&D phase in Denmark, the UK's strategy for competitive bidding has played an important role in scaling up the industry while driving down costs from 2015 on (see Appendix, Figure A2). This suggests that in the promotion of a new low-carbon technology, a government can achieve first mover advantage by government risk-taking in the RD&D phase through the nature of policy instruments, while more competitive policy instruments seem particularly effective in the subsequent market formation phase.

Section 4.1 has highlighted that early on in the technology life cycle, Denmark used obviously non-market policy instruments to implement OWP (i.e., 5 MW Vindeby, 1991) and scale up OWP (via 40 MW Middelgrunden, 2000) to commercial scale (160 MW, Horns Rev 1, 2002). After the wave of liberalisation of energy markets, such obviously non-market policy instruments are against the grain of EU legislation. This implies that past patterns of the timing and nature of policy instruments, specifically government-intervention in the early phase of research, design and demonstration, might be hard to replicate in future introductions of low carbon energy technologies, like electrolysis. In the future, policy instruments with a low market orientation (left side of Table 1, section 2.2) might no longer be allowed under EU law. This could slow down the introduction of new low carbon energy technologies in the EU.

With this research, focussing on risk allocation, we have built on the comparative literature concerning the deployment of renewables as well as on the literature on policy instruments. The analysis illustrates that the topics can be linked and give insight into correlations at least for industries which, like the OWP industry, require large and riskful investments. OWP investment risks are large because of the offshore nature of the projects and the importance of scale to drive down costs. For similar large investments, for instance in electrolysers to green the production of hydrogen, this paper may inform policy makers and strategists on how to effectively allocate risk through policies in which phase of the technology life cycle.

The limitations of our research are that we cannot claim to have investigated fully all relevant independent factors that determine the choices of policy instruments. A myriad of circumstances may cause ruling governments to implement or rather delay certain policy instruments, not all of them related to the domestic institutional constellation. Also, identifiable other relevant domestic independent factors, like geophysical opportunities (the presence and availabilty of shallow sea beds, suitable for the OWP technology of the day) or privatisation of the energy sector, most certainly interfere but we cannot quantify exactly how much. These are all factors that merit further investigation in future analyses.

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CRediT authorship contribution statement

Gerrit Rentier: Conceptualization, Data curation, Writing – original draft, Writing – review & editing. **Herman Lelieveldt:** Conceptualization, Methodology, Supervision, Validation, Writing – review & editing. **Gert Jan Kramer:** Conceptualization, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

Table 2
Abbreviations used in this article.

AUC	Auction (auction schemes)	INV	Investment grants
BOS	Building obligation scheme	LME	Liberal market economy
CfD	Contracts for Difference	ODP	Open door policy
CME	Coordinated market economy	OWF	Offshore wind farm
FIP	Feed in premium	OWP	Offshore wind power
FIT	Feed in tariff	QOS	Quota obligation schemes

(*continued on next page*)

Table 2 (*continued*)

FITT	Feed in tariff technology specific	QOST	QOS technology specific
GEN	Generic policies	SPC	Project specific policy
GRM	Grid connection by market	TAX	Tax incentives
GRS	Grid connection socialised	VoC	Varieties of capitalism

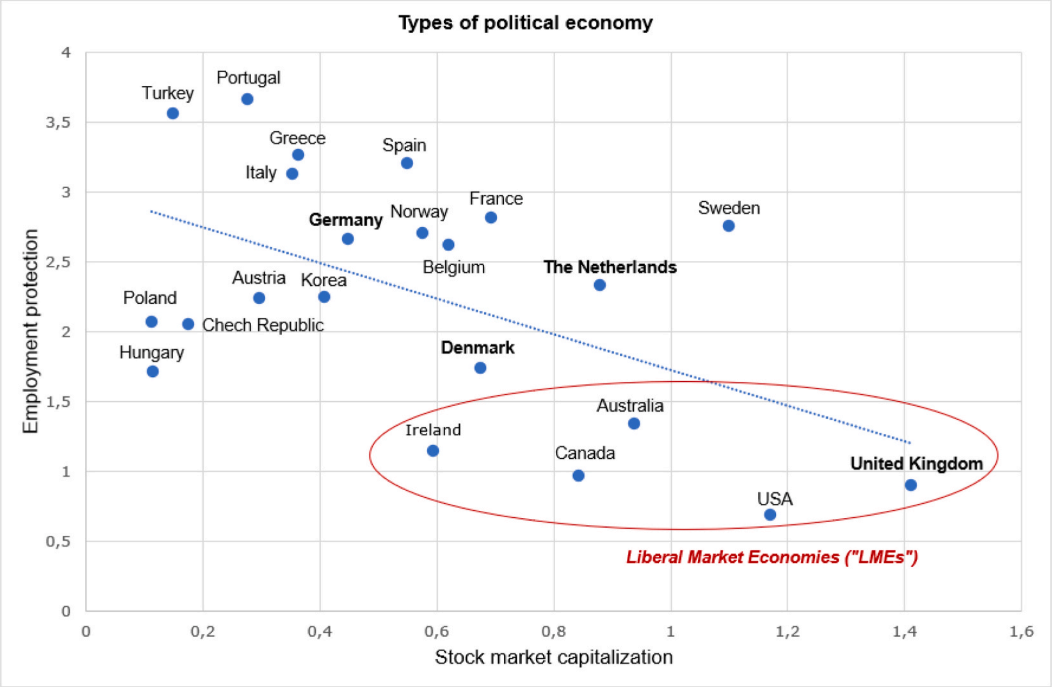
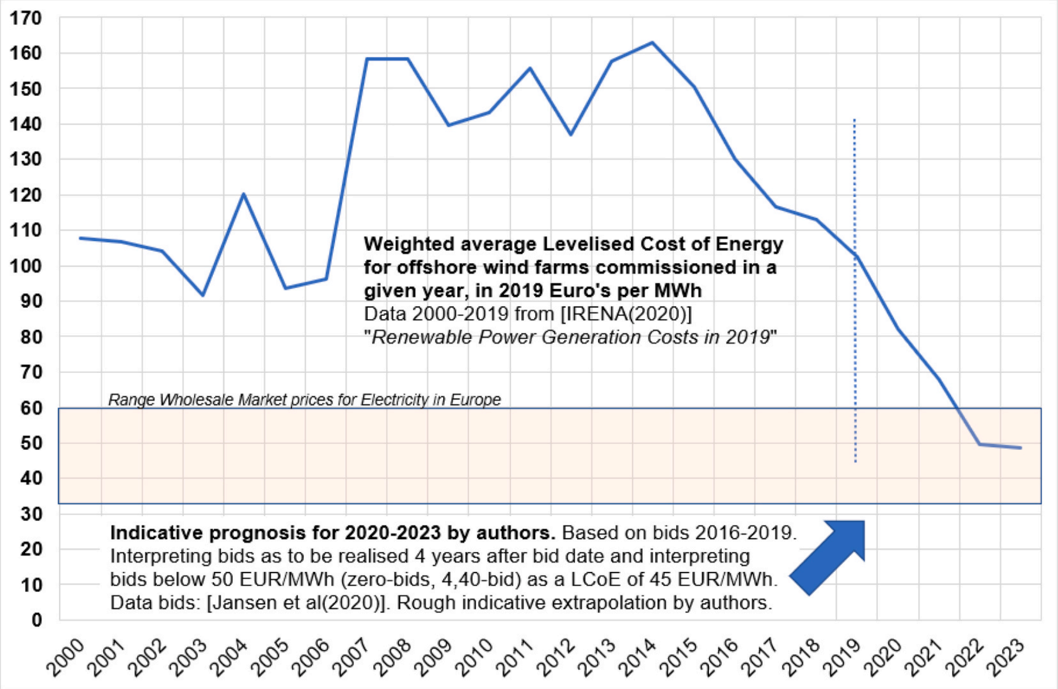


Fig. A1. Employment protection 1990–2005 from OECD Employment Outlook. Stock market capitalization of indigenous firms excluding mutual funds as a share of GDP 1990–2005 from OECD. Data from Tables in [Schneider&Paunescu(2012)], Annex 1.



Weighted average Levelised Cost of Energy for offshore wind farms commissioned in a given year, in 2019 Euro's per MWh
Data 2000-2019 from [IRENA(2020)]
"*Renewable Power Generation Costs in 2019*"

Indicative prognosis for 2020-2023 by authors. Based on bids 2016-2019. Interpreting bids as to be realised 4 years after bid date and interpreting bids below 50 EUR/MWh (zero-bids, 4,40-bid) as a LCoE of 45 EUR/MWh. Data bids: [Jansen et al(2020)]. Rough indicative extrapolation by authors.

Fig. A2. Weighted average Levelised Cost of Energy for OWP 2000–2019 in 2019 Euro's per MWh (Source: [IRENA 2020]) plus prognosis until 2023 based on accepted bids for subsidies (Source [Jansen et al. (2020)]). Graph by authors..

References

Araujo, 2017. Low Carbon Energy Transitions: Turning Points in National Policy and Innovation". Oxford University Press. Araújo, K. M.

Ćetković, Buzogány, 2016. Varieties of Capitalism and clean energy transitions in the European Union: when renewable energy hits different economic logics. Clim. Pol. 16 (5), 642–657. S. Ćetković, A. Buzogány.

DEA, 2006. Offshore wind power: Danish experiences and solutions". Danish Energy Authority.

DEA, 2012. New Danish Energy Agreement: 50% of Electricity Consumption from Wind Power in 2020". Danish Energy Agency, Copenhagen. Retrieved from the Internet May 10th, 2020 at. https://www.mynewsdesk.com/danish-energy-agency/pressreleases/new-danish-energy-agreement-50-percent-of-electricity-consumption-from-wind-power-in-2020-1781435.

Dukan, Kitzing, 2021. The impact of auctions on financing conditions and cost of capital for wind energy projects. Energy Pol. 152, 112197. Đukan, M., & Kitzing, L.

Egli, 2020. Renewable energy investment risk: An investigation of changes over time and the underlying drivers". Energy Pol. 140, 111428.

Energeia, 2005. Aanvragen voor windmolenparken op zee gestegen naar meer dan vijftig. Energeia newsletter retrieved from the Internet January 9th 2022 at. https://energeia.nl/nieuws/40019384/aanvragen-voor-windmolenparken-op-zee-gestegen-naar-meer-dan-vijftig.

Energeia, 2011. SDE Offshore Wind Kleine Én Grote Zonnepanelen Happen Naar Adem. Energeia newsletter retrieved from the Internet January 9th 2022 at. https://energeia.nl/nieuws/40039439/sde-offshore-wind-kleine-en-grote-zonnepanelen-happen-naar-adem.

European Commission, 2014. Guidelines on State Aid for Environmental Protection and Energy 2014-2020 (2014/C 200/01)". European Commission. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52014XC0628%2801%29.

Fitch-Roy, 2016. An offshore wind union? Diversity and convergence in European offshore wind governance". Fitch-Roy, O., *Climate Policy* 16 (5), 586–605.

Hall, P.A., Soskice, D., 2001. An introduction to varieties of capitalism". In: Varieties of Capitalism: the Institutional Foundations of Comparative Advantage. Oxford University Press, New York.

Hall, S., Foxon, T.J., Bolton, R., 2016. Financing the civic energy sector: how financial institutions affect ownership models in Germany and the United Kingdom". Energy Res. Social Sci. 12, 5–15.

Higgins, Foley, 2014. The evolution of offshore wind power in the United Kingdom". In: Renewable and Sustainable Energy Reviews, vol. 37, pp. 599–612. Higgins, P., & Foley, A.

Iea, 2019. Offshore Wind Outlook 2019. International Energy Agency, Paris.

IRENA, International Renewable Energy Agency, Abu Dhabi, 2020. Renewable Power Generation Costs in 2019. https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019. (Accessed 1 July 2020).

IRENA, GWEC, 2013. 30 Years of policies for wind energy: lessons from 12 wind energy markets. In: International Renewable Energy Agency (IRENA) and Global Wind Energy Council (GWEC) retrieved from Internet January 9th 2022 at. https://www.irena.org/publications/2013/Jan/30-Years-of-Policies-for-Wind-Energy-Lessons-from-12-Wind-Energy-Markets.

Jansen, M., Staffell, I., Kitzing, L., Quoilin, S., Wiggelinkhuizen, E., Bulder, B., Riepin, I., Müsgens, F., 2020. Offshore wind competitiveness in mature markets without subsidy". Nat. Energy 5 (8), 614–622.

Klepper, 1997. Industry life cycles. Ind. Corp. Change 6 (1), 145–182. S. Klepper.

Krohn, 2000. The wind turbine market in Denmark. Danish Wind Turbine Manufacturers Association. S. Krohn.

Larsen, J.H., Soerensen, H.C., Christiansen, E., Naef S, S., Vølund, P., 2005. Experiences from Middelgrunden 40 MW offshore wind farm. In: Copenhagen Offshore Wind Conference, pp. 1–8. Copenhagen, October 2005.

Leiren, Reimer, 2018. Historical institutionalist perspective on the shift from feed-in tariffs towards auctioning in German renewable energy policy. Energy Res. Social Sci. 43, 33–40. Leiren, M. D., & Reimer, I.

MacKinnon, D., Dawley, S., Steen, M., Menzel, M.P., Karlsen, A., Sommer, P., Hansen, G. H., E Normann, H., 2019. Path creation, global production networks and regional development: a comparative international analysis of the offshore wind sector. Prog. Plann. 130, 1–32.

Markard, J., Petersen, R., 2009. The offshore trend: structural changes in the wind power sector". Energy Pol. 37 (9), 3545–3556.

Mazzucato, 2014. The Entrepreneurial State: Debunking Public vs. Private Sector Myths". M. Mazzucato, Anthem Press.

Meyer, 2004. Development of Danish wind power market. Energy Environ. 15 (4), 657–673. Meyer, N. I.

Mitchell, 2000. *The England and Wales non-fossil fuel obligation: history and lessons"*, Mitchell, C. Annu. Rev. Energy Environ. 25 (1), 285–312.

Mitchell, Connor, 2004. Renewable energy policy in the UK 1990-2003. Energy Pol. 32, 1935–1947. Mitchell, C., Connor, P.

Nkomo, 2018. *Germany: WWEA Policy Paper Series PP-02-18-B"*, F. Nkomo, World Wind Energy Assocation Policy Paper Series, Retrieved from the Internet January 9th 2022 at. https://wwindea.org/wp-content/uploads/2018/06/Germany_Full.pdf.

OECD, 2000. Regulatory Reform in Denmark: Regulatory Reform in the Electricity Sector". OECD, 2000.

How do policies mobilize private finance for renewable energy? A systematic review with an investor perspective", Polzin, F., Egli, F., Steffen, B., Schmidt, T., 2019. Appl. Energy 236, 1249–1268.

Portman, M.E., Duff, J.A., Köppel, J., Reisert, J., Higgins, M.E., 2009. Offshore wind energy development in the exclusive economic zone: legal and policy supports and impediments in Germany and the US". Energy Pol. 37 (9), 3596–3607, 2009.

Power Technology, 2008. Horns Rev Offshore Wind Farm. Power-Technology, *Denmark"*. Retrieved from Internet at January 8th 2022 at. https://www.power-technology.com/projects/hornsreefwind/.

PWC, 2010. Meeting the 2020 renewable energy targets: filling the offshore financing gap. Price Waterhouse Coopers report retrieved from the Internet January 9th 2022 at. https://www.pwc.co.uk/assets/pdf/filling-the-offshore-wind-financing-gap.pdf.

Reichardt, K., Rogge, K., 2015. How the policy mix impacts innovation: findings from company case studies on offshore wind in Germany". Environ. Innov. Soc. Transit. 18, 62–81.

Reichardt, K., Negro, S., Rogge, K., Hekkert, M., 2016. Analyzing interdependencies between policy mixes and technological innovation systems: the case of offshore wind in Germany". Technol. Forecast. Soc. Change 106, 11–21.

Rentier, G., Lelieveldt, H., Kramer, G.J., 2019. Varieties of coal-fired power phase-out across europe. Energy Pol. 132, 620–632.

RVO, 2015. Offshore Wind Energy in the Netherlands". Netherlands Enterprise Agency RVO retrieved from the Internet January 9th 2022 at. https://www.rvo.nl/sites/default/files/2015/03/Offshore wind energy in the Netherlands.pdf.

Schneider, M.R., Paunescu, M., 2012. Changing varieties of capitalism and revealed comparative advantages from 1990 to 2005: a test of the Hall and Soskice claims". Soc. Econ. Rev. 10 (4), 731–753.

Smit, T., Junginger, M., Smits, R., 2007. Technological learning in offshore wind energy: different roles of the government". Energy Pol. 35 (12), 6431–6444.

Twoz, 2010. Eindrapport taskforce windenergie op zee. Taskforce Windenergie op Zee, retrieved from the Internet at January 9th 2022 at. https://zoek.officielebekendmakingen.nl/blg-65611.pdf.

Uk Government, 2020. *Contracts For Difference"*, UK Government. *Policy Paper* March 2, 2020, Retrieved from the Internet May 24th 2020 at. https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference.

UNFCCC, 2015. Historic Paris agreement on climate change: 195 nations set path to keep temperature rise well below 2 degrees celsius. In: United Nations Framework Convention on Climate Change. December 15th, 2015, Retrieved from Internet, January 2018. https://unfccc.int/news/finale-cop21.

van der Loos, H.A., Negro, S.O., Hekkert, M.P., 2020. Low-carbon lock-in? Exploring transformative innovation policy and offshore wind energy pathways in The Netherlands. Energy Res. Social Sci. 69, 101640.

Van der Loos, A., Normann, H.E., Hanson, J., Hekkert, M.P., 2021. The co-evolution of innovation systems and context: offshore wind in Norway and The Netherlands". Renew. Sustain. Energy Rev. 138, 110513.

van Est, R., 1999. Winds of Change: a Comparative Study of the Politics of Wind Energy Innovation in California and Denmark". International Books, Utrecht.

Verhees, B., Raven, R., Kern, F., Smith, A., 2015. The role of policy in shielding, nurturing and enabling offshore wind in The Netherlands (1973–2013). Renew. Sustain. Energy Rev. 47, 816–829.

Woodman, Mitchell, 2011. Learning from experience? The development of the renewables Obligation in England and wales 2002–2010. Energy Pol. 39 (7), 3914–3921. Woodman, B., & Mitchell, C.

Wpm, 2002. Attracting Investors Offshore in Denmark". Wind Power Monthly. Retrieved from Internet January 7th 2022. https://www.windpowermonthly.com/article/958334/attracting-investors-offshore-denmark.

Wpm, 2017. DONG and EnBW Break Records with Subsidy-free German Bids". Retrieved from Internet February 5th 2022. https://www.windpowermonthly.com/article/1431441/dong-enbw-break-records-subsidy-free-german-bids.