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Developing the industrial capacity for energy transitions: resource formation for offshore wind in Europe

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Abstract

As energy transitions progress from formative to growth phases, issues related to resource formation increase in importance. In this paper we address a type of resource formation that has received scant attention in the sustainability transitions literature to date: developing the industrial capacity to manufacture and deliver key complementary assets (i.e. components and services) to for example wind power projects. Such upstream value chain elements constitute a significant share of capital expenditure and offer important job and value creation opportunities for different regions and countries. Empirically we study the build-up of industrial capacity to supply key complementary assets to the European offshore wind power market in the 2000-2019 period through three phases (formative, take-off, growth). We provide explanations to observed spatio-temporal patterns of industrial capacity development by considering 1) industry life-cycle dynamics, 2) pre-existing assets and industrial relatedness, and 3) home market opportunities.

Keywords: renewable energy, industrial development, upstream suppliers, Europe, offshore wind power

Introduction

New research topics emerge as the energy transition moves into an 'acceleration phase' and the deployment of renewable energy technologies, such as wind power and solar PV, expands strongly (Markard et al., 2020). One pertinent topic is resource formation (Karltorp, 2014), which includes the technology and equipment for manufacturing various components and providing services such as logistics and maintenance (Bergek et al., 2008) to renewable energy (RE) technologies such as solar PV and wind turbines. In sustainability transition research to date, focus has been on the innovation dynamics related to the core energy technologies, such as solar PV panels or wind turbine generators (WTGs) (Binz & Truffer, 2017; Joern Huenteler et al., 2016). By contrast there has been limited research on upstream value chain dynamics, referring here to industrial development associated with the manufacturing and provision of services (Andersen et al., 2020; Mäkitie et al., 2022) often labelled 'complementary assets'. Complementary assets are crucial for the functioning of core technologies and for reducing the overall costs of renewable energy projects.

The balance between deployment (often relying on public financial support) and industrial development can be important for the political and social acceptability of energy policy (Eicke & Weko, 2022; Vona, 2019), given that industrial development implies value capture and job creation. Providing complementary assets to, for example, wind farms, offers important 'green growth' opportunities also for regions and countries that do not have companies involved in the manufacturing of core technologies (MacKinnon et al., 2019). Offshore wind power (OWP) is a case in point because of its significant 'green growth' potential, reflecting that it has a highly complex value chain (BVG Associates, 2010).

In this paper, we study the build-up of industrial capacity (IC) to supply complementary assets to offshore wind power (OWP) in Europe in the 2000-2019 period. We understand IC as the ability to produce components/goods and deliver services to a given industry. OWP was first deployed in

1991, diffused rapidly especially since around 2008, and is foreseen to expand substantially in coming decades (IRENA, 2019), requiring a vast number of (specialised) components and services (BVG Associates, 2010). In 2020, the European Commission (EC) launched the EU Strategy on Offshore Renewable Energy, spelling out a target of increasing Europe's OWP capacity from 12GW (in 2020) to at least 60GW by 2030 and to 300GW by 2050. An estimated 800 billion Euros will be needed to meet the 2050 objectives, which according to the EC (2020) will *"(...) create new opportunities for industry, generate green jobs across the continent, and strengthen the EU's global leadership in offshore energy technologies.*" Further, the REPowerEU Plan (EC, 2022) highlights the need to strengthen the OWP supply chain and accelerate permitting processes, with the aim of achieving industrial development, more rapid deployment, and enhanced energy security. The latter includes the supply of key components and services, which has arguably become even more politically pertinent following recent geopolitical events in Europe (Kivimaa & Sivonen, 2023).

Against this background, we pose the following research questions: *where has the industrial capacity to deliver complementary assets to the offshore wind power sector developed in Europe over time, and how can this development be explained?*

In addressing these questions, we contribute to a better understanding of the industrial dynamics of sustainability transitions (Andersen et al., 2024), especially in terms of the evolution of industrial capacity around complementary assets. Our paper does this in two ways. First, it provides a first-of-its kind empirical analysis of the spatio-temporal build-up of IC for the manufacturing and provision of key upstream complementary assets to a rapidly diffusing RE technology. Our analysis is based on a comprehensive database (4C Offshore) of OWP projects and supply chains and organised in three phases (formative, take-off, growth). We expand on this mapping by developing aggregated country-level 'IC scores' that we match with OWP market deployment. This allows us to assess industrial performance vis-à-vis domestic market size. Such insights regarding the patterns and explanations of "green" industrial development are important for both policymakers and researchers seeking to understand why some countries are more likely to succeed in creating and capturing value around renewable energy technologies, while others are not.

Second, we examine the identified patterns of OWP IC development by mobilizing three explanatory factors from the innovation/sustainability transitions and economic geography literatures: 1) life-cycle dynamics and the emergence of dominant designs and associated industrial dynamics; 2) pre-existing industrial assets embedded in companies and infrastructures whereupon (related) diversification into OWP may have occurred; and 3) domestic market formation underpinned by supportive national policies. While these factors have been used in previous research to explain country-level industrial and innovation system developments associated with OWP in Northern Europe (e.g. Dedecca et al., 2016; MacKinnon et al., 2019; Mäkitie et al., 2018; Poulsen & Lema, 2017; Steen & Hansen, 2018; van der Loos et al., 2020; Wieczorek et al., 2015), systematic comparison of IC formation processes between countries and over time is lacking. Overall, we find that these inter-related explanatory factors provide solid explanatory power to understand why the build-up of IC for complementary assets to OWP projects in Europe has taken place as it has in the two first decades of the 2000s.

Developing industrial capacity for upscaling renewables

Many factors influence how and why such technologies and industries emerge and develop in some places (regions, countries) and not in others. Based on innovation studies/sustainability transitions and economic geography research that has had an empirical focus on the OWP sector, we examine in the following three interrelated explanatory factors for the build-up of IC and its spatial pattern over time.

Industry life cycles and innovation dynamics

Innovation scholars argue that technologies evolve through different phases (Markard, 2020; Rotmans et al., 2001) which differ in terms of IC formation. In the *formative* or *nascent* phase, few actors are involved in technology development, sales are limited, focus is mostly on R&D and experimentation, and several designs are usually explored (Utterback & Abernathy, 1975). Specialized supply chains are lacking, and technologies typically rely on public funding and support mechanisms to compete in commercial markets. In the *growth* or *acceleration* phase, deployment increases, more actors become involved, and industry shakeouts typically occur. A dominant technological design usually emerges, thereby diminishing technological diversity, whereas innovation focus shifts from product to process (Utterback & Suárez, 1993). In terms of IC, expanding supply chains with dedicated and specialized actors are a prerequisite for growth. In the *stabilization* or *mature* phase, sales are high, technological development becomes mainly incremental (Anderson & Tushman, 1990), while fully-fledged supply chains are in place with specialized and established actors in all segments.

Such stylized life-cycle dynamics have been shown to apply also for OWP, however mainly with attention to the emergence of dominant designs and lead firms (e.g. Afewerki & Steen, 2023; Dedecca et al., 2016; Markard & Petersen, 2009). In complex product-based systems (CoPS)- and project-based industries, such stylized life-cycle dynamics may, however, differ from products that more readily become standardised and mass-produced (Afewerki & Steen, 2023; Malhotra & Schmidt, 2020). This implies that radical innovation dynamics can continue to occur, especially on the sub-system level (i.e., components, services). Whether or not this applies to non-core (i.e. complementary asset) technologies has however not been empirically investigated. This also has an important geographical dimension in that some value chain activities are likely to become anchored to particular territories (e.g. due to proximity effects) while others may be more footloose (Hipp & Binz, 2020). Other aspects that may influence the spatio-temporal patterns of IC development include first-mover advantages (e.g. enabled by access to domestic markets) (Kim & Lee, 2011), and the extent to which an emerging industry has similarities (or not) with already existing industries, allowing for firm level diversification by specialized or multi-industry firms (Steen & Hansen, 2014).

Relatedness and pre-existing industry structures

Over time, innovation and industrial dynamics tends to follow evolutionary trajectories whereby novelty emerges through diversification and combinatorial innovation, whereas territories develop industry structures with corresponding knowledge (and other) assets linked to particular production methods, technologies, markets or natural resources (Frenken et al., 2012; Grillitsch & Hansen, 2019). A key mechanism here is that firms often diversify into markets which are technologically related to their existing activities (Breschi et al., 2003), allowing them to exploit extant knowledge assets and other resources (Klepper & Simons, 2000) in exploration endeavours. Relatedness, referring here to the degree of similarities in technological knowledge and artefacts between industries, allows firms and other actors to form synergies and redeploy resources (e.g. knowledge regarding markets and technologies) between industries (Helfat & Lieberman, 2002). Technological relatedness is thus a significant factor that can explain why, how, and where new industries emerge (Neffke et al., 2011). For sectors with highly complex value chains that transcend multiple sectoral boundaries, there are multiple opportunities for firms from various industries to enter. Lead firms entering a new industry market may furthermore reduce the barriers for other firms such as suppliers to diversify to the same market (Acs & Terjesen, 2013).

Relatedness however also concerns similarities in customer and collaboration networks, whereby a firm can use its existing networks and knowledge about them to enter new (industry) markets (Tanner, 2014; Tanriverdi & Venkatraman, 2005). Diversification towards institutionally related industries is more likely because it enables actors` reuse of existing practices, whereas diversification to institutionally unrelated industries might entail more resistance (Content & Frenken, 2016). Therefore, while a technologically related emerging industry may offer a diversification opportunity for firms in established industries, diversification may be inhibited by significant differences in sector-specific institutional and market contexts, as shown in previous research on OWP (e.g. Mäkitie et al., 2018). Learning and adaptation processes to such non-technological issues may be relatively easier in home-market contexts (Steen & Hansen, 2014). Moreover, mere geographic proximity to new markets and business opportunities may also play a role (Boschma, 2005). In large (engineering) project-based sectors, such as OWP, this includes for example opportunities related to civil construction and infrastructure provision for logistics services.

Domestic market opportunities

Domestic markets positively influence industry formation and development, notably by facilitating local interactive learning and user-producer linkages (Fagerberg, 1992; Freeman, 1987), as well as international competitiveness (Castellacci, 2012). However, user-producer interaction may also form across borders, particularly when domestic demand is limited (Murmann et al., 2015). Access to international markets may therefore compensate for lacking domestic market opportunities, as demonstrated in previous research on OWP in Europe (Normann & Hanson, 2018; van der Loos et al., 2020). The importance of home markets, however, differs between industries, depending amongst other on the degree of technological complexity, standardisation, and reliance on user-producer interactions (Fagerberg, 1992; J. Huenteler et al., 2016). In industries relying predominantly on codified knowledge, science and technology-based learning, and standardized valuation of products, markets are potentially global with limited geographical variation (Hipp & Binz, 2020). By contrast, home markets play a more significant role in industries that to greater extent rely on user-producer interactions, product customization, or adaptation to local demand (J. Huenteler et al., 2016; Malhotra & Schmidt, 2020). In such industries, innovation processes continue to benefit from proximity between producers and users (Davies, 1997; J. Huenteler et al., 2016). Home markets, or geographical proximity to markets, therefore remain important across the industry life cycle when considering complex technologies (O'Sullivan, 2020). Yet, even within such industries, firms might still access international markets without relying on a significant domestic market (Rohe, 2020). Several mechanisms have been shown to facilitate such market access, including access to pilot and demonstration projects or the presence of large (domestic) internationalizing firms (Tsouri et al., 2021; van der Loos et al., 2020).

One way in which governments can stimulate industry development while expanding renewables is thus to ensure (sheltered) market formation, which in turn can foster learning, directionality and resource mobilisation (Nilsson et al., 2021). For instance, government policies supporting the German Energiewende have attempted to cut emissions while stimulating industrial development (Johnstone et al., 2021). The newly launched European 'Green Deal Industrial Plan' (EC, 2023) and the US' Inflation Reduction Act both aim to straddle these aims. Embedding market creation policies as part of wider policy mixes however tends to be associated with large costs. Governments may thus choose alternative approaches, and only foster some resources (e.g. knowledge creation) while relying on access to international markets (Peters et al., 2012; Tsouri et al., 2021). From a regional or national perspective such an approach may make sense as long as external markets are accessible (Binz et al., 2016).

Summary of explanatory factors

As discussed in the previous sub-sections, we understand IC development as a process of resource formation necessary for technology upscaling. Here we focus on complementary assets (such as cables or foundation structures) that are necessary for a core technology (such as WTGs) to function. In the analysis that follows we examine three theoretical explanations that have been employed to analyse the emergence and development of new industries, including previous studies of OWP: technology and industry life-cycle dynamics, relatedness and resource redeployment from pre-existing industries, and the presence of domestic market opportunities. In the analysis we use these in an explorative way, guided by the assumption that all three factors provide explanatory purchase. In discussing our findings (section 6) we critically assess how these factors may be related in the case studied, and whether they differ with regards to explanatory power.

Research setting: the offshore wind power industry

The offshore wind power industry in Northern Europe

IRENA (2019) predicts a global growth in OWP from 28 GW cumulative installed capacity in 2018 to 1000 GW by 2050. Strong continued deployment is expected especially in (Northern) Europe and Asia (especially China) for the remainder of the current decade (GWEC, 2022). We limit our empirical analysis to deployment in Europe, where the North Sea has been the main sea basin for OWP deployment and will remain so towards 2030 (Wind Europe, 2017). Our analysis covers the timespan January 2000 – April 2019[1]. Prior to 2000 was an early innovation phase (the first

[1] Our last available dataset from 4C Offshore is from April 2019, hence this period.

'offshore' turbines were installed in Denmark and Sweden in the early 1990s) with technology and policy experimentation (Dedecca et al., 2016). By the end of 2019, cumulative installed OW capacity in Europe was 22GW, with the bulk of this developed in the UK (9,9GW), Germany (7,4GW), Denmark (1,7GW), Belgium (1,6GW) and the Netherlands (1,1GW) (Wind Europe, 2020).

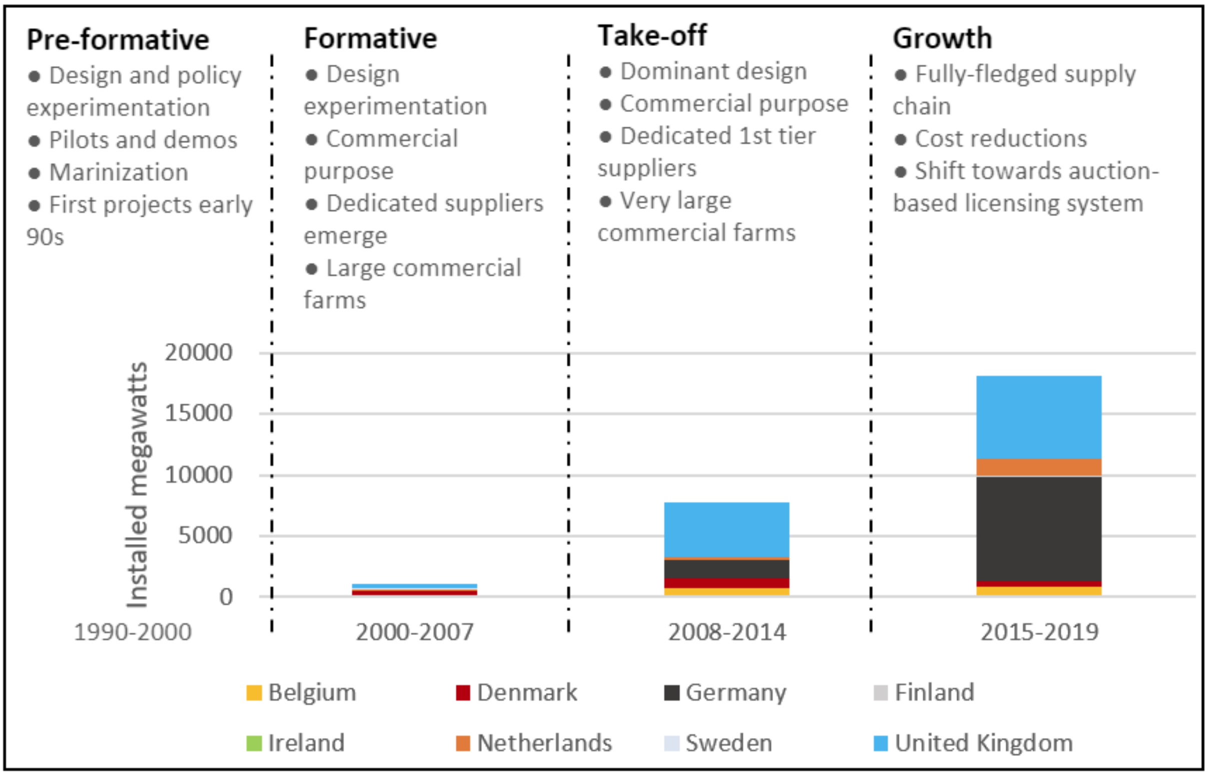

Figure 1 Offshore wind deployment and phases in Europe in 2000-2019. Sources: Markard and Petersen (2009), Dedecca et al. (2016), 4C Offshore (2019)

We used the cumulative OWP deployment in Europe to distinguish three phases of development: a *formative phase* (2000-2007), an intermediate *take-off phase* (2008-2014), and a *growth phase* (2015-2019). By the end of the formative phase, Europe had reached approx. 1GW of cumulative installed OWP capacity deployment, with Denmark and UK having the largest markets. This phase saw the first large-scale commercial OWP projects (e.g. 108MW Egmond aan Zee in the Netherlands) and emergence of dedicated suppliers (Dedecca et al., 2016), both having been essential to achieving the necessary cost reductions (Wind Europe, 2019) to allow for the subsequent take-off phase. We used a ten-fold deployment increase (i.e. to cumulative 10GW) as marking the end of the take-off phase, which saw the first very large OWP projects (e.g. 504MW Greater Gabbard in the UK), dominant designs becoming settled, and a full dedicated supply chain coming into place. The largest markets were UK, Germany, Denmark and Belgium. The growth phase since around 2015 and thereafter has entailed continued specialisation and scaling in the supply chain, and substantial deployment notably in Germany and the UK, followed by the Netherlands, Belgium and Denmark. The first GW-scale project in Europe, the 1,218MW Hornsea Project One (UK), was commissioned in 2019.

Until 2019, OWP deployment in Europe mainly occurred in a handful of countries, and only a few countries had steady market growth. Domestic market opportunities thus varied between countries and over time. A general 'further, deeper, larger'[2] trend (Steen & Hansen, 2014; Wind Europe, 2020) has increasingly made its mark on the OWP sector since the take-off phase. Importantly, the OWP is a project-based sector, and suppliers in Denmark and the UK had access to a domestic market throughout the last two decades. Since the take-off phase there has been massive deployment in Germany and the UK. Suppliers from other countries had very small (e.g. Sweden, Finland) or practically non-existent (e.g. Norway, France) home markets in the period studied.

The structure and organization of the OWP industry

OWP projects are delivered through various stages, requiring the integration of diverse knowledge fields and supply chain activities (see Figure 2). Large energy companies and utilities who own OWP projects (often together with financial investors) typically oversee project development, planning and management (Afewerki & Steen, 2023). The WTG original equipment manufacturers (OEMs) are important actors in the industry. OWP has greatly benefitted from several decades of onshore wind turbine developments, with the same three bladed on-wind designs dominating both onshore and offshore. In Europe, most OWP projects in the period studied were served by established onshore wind turbine developers from Germany and Denmark, with Siemens Gamesa and MHI Vestas having 68,1% and 23,5% (respectively) shares of the cumulative market by the end of 2019 (Wind Europe, 2020).

The OWP supply chain is nevertheless largely been decoupled from its onshore wind counterpart (Wüstemeyer et al., 2015) and has been so for at least a decade (Dedecca et al., 2016; EWEA, 2011). Whereas early stage OWP projects made use of 'marinated' onshore solutions, rampant failures and maintenance challenges led to an increasing recognition that bespoke equipment was needed to withstand the harsh sea environment (Steen & Hansen, 2014). Geographically, the OWP supply chain manufacturing capacity is mainly located in coastal regions with proximity to offshore deployment sites. This reflects the importance of logistics costs and port infrastructure for a sector such as OWP (Wind Europe, 2021), where massive components of steel and concrete need to be manufactured, assembled, and transported out to location at sea.

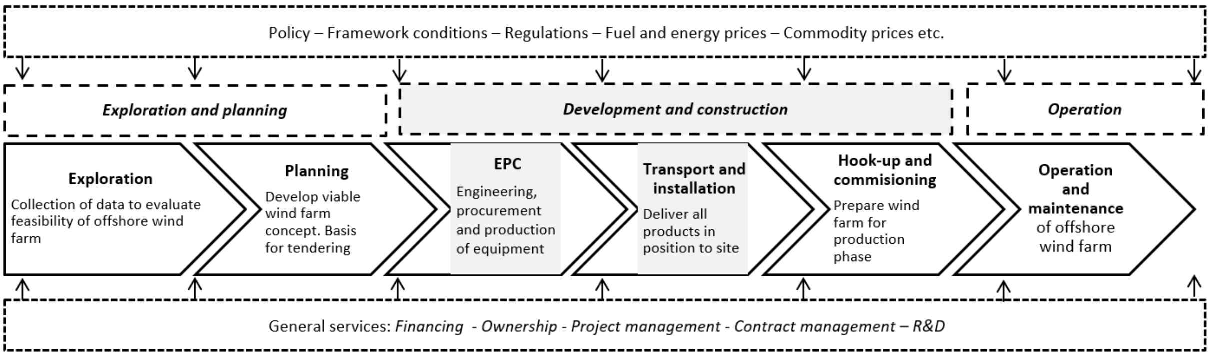

FIGURE 2 OFFSHORE WIND POWER VALUE CHAIN. ADAPTED FROM STEEN AND HANSEN (2014)

The importance of the supply chain for OWP costs is evident in the break-down of capital and operational expenditures (CAPEX and OPEX, respectively). According to one recent overview (CORE, 2023) of cost elements to OWP levelized cost of energy, CAPEX accounts for roughly 66% of total

[2] Further from shore (requiring e.g. longer cables, HVDC cables), larger turbines in greater quantities (requiring larger foundations, more demanding installation), deeper waters (requiring e.g. more massive foundation structures).

costs, whereas OPEX constitutes around 28%.[3] The turbine accounts for around 29% of total cost (and almost half of CAPEX), signifying its core technology status. Yet turbines do not function in isolation – they require complementary assets that represent significant CAPEX shares, such as foundation structures to rest on and cables to connect them to the grid, as well as services such as installation.

The main technological components in an OWP project are turbines, foundations, substations, and array and export cabling (in the 'EPC' segment of the value chain, Figure 2). Regarding foundations, monopile structures have dominated the market to date, but also jacket, gravity-based, suction buckets and various floating structures have been used depending on sea-level depth and seabed conditions. Most OWP farms plants also have large (transformer) substations with high voltage alternating current (HVAC) or direct current (HVDC) electric systems. Array cables connect the turbines to a substation, while export cables connect the substation to an onshore substation. All components require transportation and installation performed by companies employing different types of vessels (in the 'Transport and installation' value chain segment), as well as operations and maintenance related activities. In this paper we focus on the complementary assets the 'EPC' and 'Transport and installation' segments in the development and construction phases of the OWP value chain (i.e. CAPEX).

Material and methods

Our main source of data is the 4C Offshore database (April 2019 update) which provides information about a wide range of products and services that go into OWP projects globally. Our analysis is mainly focused on seven key complementary assets provided to OWP projects: manufacturing (i.e., components) of (1) foundations, (2) array cables, (3) export cables and (4) substations, and installation (i.e., services) of (5) turbines, (6) foundations, and (7) export cables. This limitation was done for two reasons. First, these value chain segments constitute approx. 40% (see Appendix B) of total OWP project CAPEX and thus represent a considerable share of the commercial opportunity and value capture for the supplier industry. Second, we found the database to be most consistent and reliable in these categories. We limited our analysis to commercial scale OWP projects (thus excluding demonstration and single turbine projects).

To enable the use of the database (a spreadsheet with almost 22 000 entries before the above-mentioned steps) for our purposes, data cleaning and quality assurance was required (see Appendix A for details). This left us with 1659 unique entries of suppliers providing components and services to European OWP projects (2000-2019), all with information on i) country origin of the supplier company, ii) year of provisioned component(s)/service, iii) type and amount/number of component(s)/service, and iv) country of recipient OWP project for provisioned component(s)/service. Our analysis of IC development is thus on the country level with annual aggregates. Our findings are presented with descriptive statistics (frequencies and percentages).

We then identified dominant companies in each of the studied value chain segment throughout the three phases. Additional data on country of origin, founding year, relevant mergers and

[3] Similar figures are presented in other estimates of cost breakdowns (see Appendix B).

acquisitions, company presence in other industries than OWP, location of facilities, and investments in production/installation capacity on these companies was compiled from websites, reports and media. This data allows us then to assess whether IC development occurred based on pre-existing industrial assets and firm diversification.

To contextualise our findings based on 4C Offshore data, we draw on various secondary material including previous research (including our own research on OWP in Norway, Denmark, Germany, France, the Netherlands and the UK (e.g. Afewerki & Steen, 2023; Hansen & Steen, 2011; Jolly et al., 2023; MacKinnon et al., 2019; Mäkitie et al., 2018; Steen & Hansen, 2014; van der Loos et al., 2021)), OWP industry and market reports, government documents, company websites and media articles. When exploring the three explanatory factors (life-cycle, relatedness, home market) we also draw on this secondary data.

Further, to assess cumulative (over the 2000-2019 period) country level provision of complementary assets to European OWP projects, we develop a simplified metric that we label the 'IC score'. The IC score was calculated by multiplying country level[4] aggregate market shares of the six key complementary assets as described previously, with the addition of substation manufacturing[5], with the relative share of these components and services in the overall CAPEX of OWP projects. Segment level CAPEX values are averages of estimates provided in previous research and industry reports (see Appendix B for details). We then compare each country's IC score with domestic OWP deployment (MWs installed). This enabled us to identify whether a country has primarily positioned itself in terms of IC development or OWP deployment, or both.

Results

In this section we present our findings and analysis in three parts. First, using Sankey diagrams (see Figure 3), which is an oft-used tool to depict process flows, we present the general overview of in which countries different OWP complementary assets (components and services) were 'produced', and in which countries they were delivered/deployed over three phases of OWP development in Europe.

[4] We do this for Belgium (BE), France (FR), Denmark (DK), Germany (DE), Italy (IT), Netherlands (NL), Norway (NO), Spain (ES), Sweden (SE) and United Kingdom (UK). Other countries, such as Finland (FI), Greece (GR), Poland (PL), Singapore (SG), China (CN), South Korea (KR) and Japan (JP), were omitted from this part of the analysis due to their limited overall supplies to OWP in Europe.

[5] The reason we do not include substations in the first part of the analysis is that not all OWP projects have them, or they are not identifiable from the data.

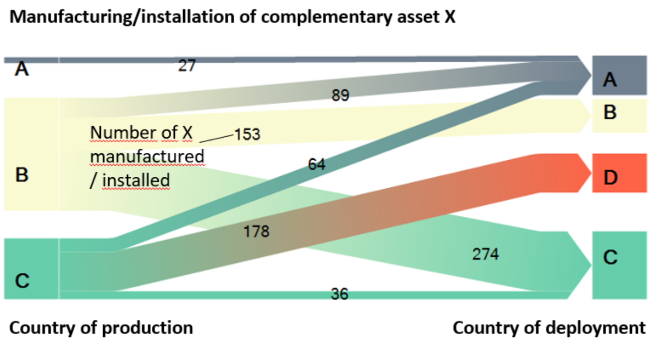

FIGURE 3 SANKEY ILLUSTRATION OF EMPIRICAL FINDINGS FIGURES 4-9. COMPONENTS (COMPLEMENTARY ASSETS) ARE MANUFACTURED OR INSTALLED BY COMPANIES ORIGINATING FROM COUNTRIES (E.G. A, B) TO THE LEFT, AND DEPLOYED IN COUNTRIES (E.G. C, D) TO THE RIGHT. NUMBERS REPRESENT E.G. TOTAL NUMBER OF TURBINE FOUNDATIONS BEING SUPPLIED FROM COUNTRY X TO COUNTRY Y.

Second, we discuss these findings at the country level. Third, we summarize results with the help of the country-level IC score to illustrate IC development vis-à-vis OWP market formation over time.

Industrial capacity development for complementary assets to offshore wind power

We first present the overview of IC-development and deployment connected to turbine installation, and turbine manufacturing and installation, and subsequently for array cable manufacturing and export cable manufacturing and installation.

Turbine foundations (Figure 4) have been manufactured mainly by Danish, German and Dutch companies. In the formative phase, SIF (NL) in a joint venture with Smulders (BE) and Bladt Industries (DK) were the main manufacturers. More firms entered the market in the take-off phase, including EEW Special Pipe Construction, Cuxhaven Steel Construction and Amgau (all DE). In the growth phase, these German companies supplied their expanding domestic market and also gained large market shares in the UK. Especially EEW Special Pipe Construction emerged as a market leader, and in 2014 formed a joint venture with Bladt Industries to manufacture foundations in the UK. In 2017 Bladt sold its stake to EEW. SIF (NL) also continued to grow.

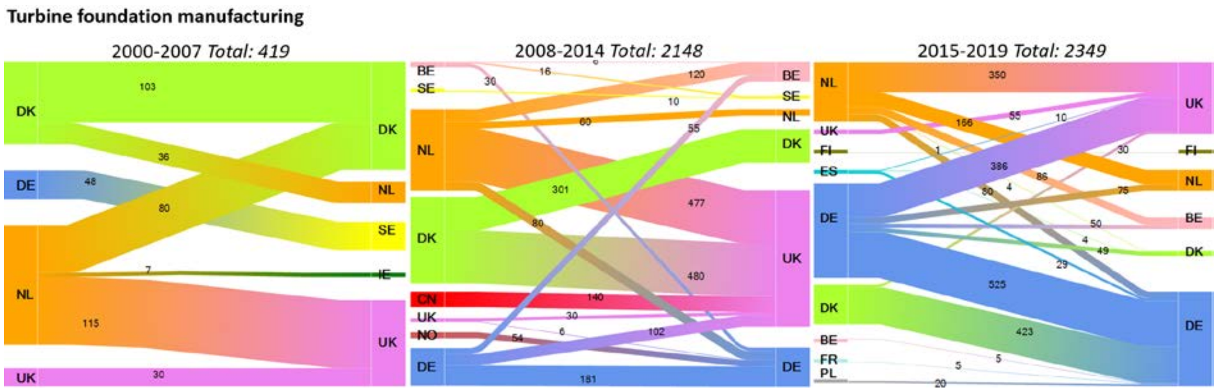

FIGURE 4 TURBINE FOUNDATION MANUFACTURING. VALUE = NUMBER OF FOUNDATIONS MANUFACTURED. NOTE THAT TOTAL MARKET SIZE EXPANDS FROM PHASE TO PHASE. SOURCE (DATA): 4C OFFSHORE (2019)

In ***turbine foundation installation*** (Figure 5) Norwegian (Eide) and UK (MPI Offshore) firms were heavily involved in the formative phase alongside Danish and Dutch companies. Dutch and Norwegian companies supplied the Danish market, while Danish and UK firms were dominant in the UK market. In the take-off phase, Dutch companies (Ballast Nedam, Seaway Heavy Lifting) took key positions, notably in the UK market. Also, A2SEA (DK) and MPI Offshore (UK) retained their position. In the growth phase, new companies overtook the main markets (UK and Germany). GeoSea (BE) became a clear market leader with more than 700 foundations installed, followed by Van Oord (NL). Earlier leaders Ballast Nedam, MPI Offshore and Seaway Heavy lifting had smaller market shares, while Eide (NO) went bankrupt in 2016. Most of the active firms were new companies with roots in the existing maritime/offshore sectors but becoming increasingly specialised as suppliers to OWP.

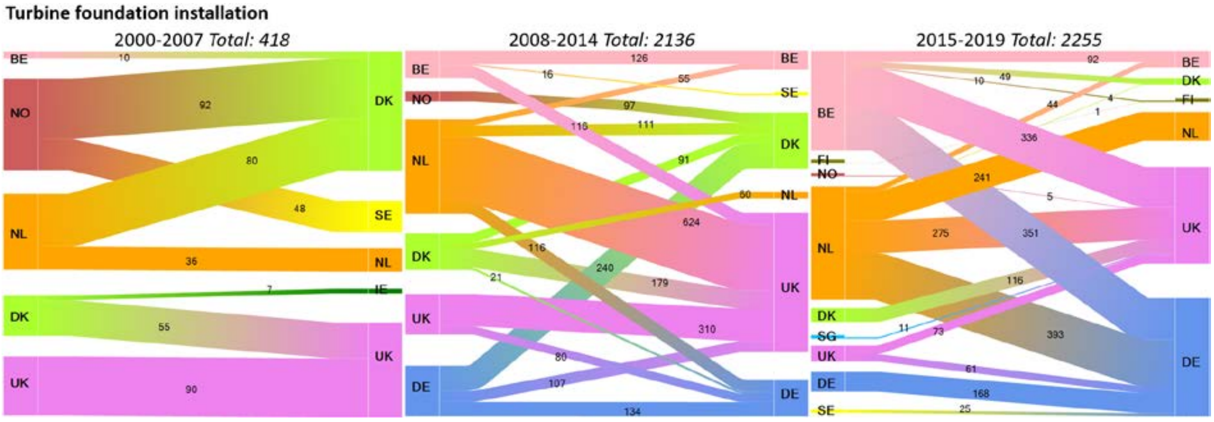

FIGURE 5 TURBINE FOUNDATION INSTALLATION. VALUE = NUMBER OF FOUNDATIONS INSTALLED. NOTE THAT TOTAL MARKET SIZE EXPANDS FROM PHASE TO PHASE. SOURCE (DATA): 4C OFFSHORE (2019)

In the ***turbine installation*** segment (Figure 6) Danish firms (especially A2SEA) were main installers in the formative phase, both domestically and in the UK. A2SEA retained this position also in the take-off phase. In a form of seeming vertical integration, the company was acquired by OWP developer DONG Energy (later Ørsted) and Siemens in a joint venture in 2009. MPI Offshore and Seajacks (both UK) also captured significant market shares, especially in their home market. In the growth phase market shares became more dispersed, with Norwegian (especially Fred. Olsen Renewables), Belgian (e.g. GeoSea, part of the DEME industry group, acquired A2SEA in 2017) and Dutch companies (especially Van Oord) as segment leaders. Belgian firms served their domestic and the German market, Norwegian companies mainly installed turbines in German waters, while Dutch companies serviced especially domestic and UK markets. Danish companies operated in UK and Germany (but not domestically), and UK firms domestically and in Germany. Contrasting the gradual consolidation of firms in the turbine foundation manufacturing and installation segments, IC development in turbine installation has dispersed somewhat broadly in Northern Europe, notably in countries with strong maritime traditions.

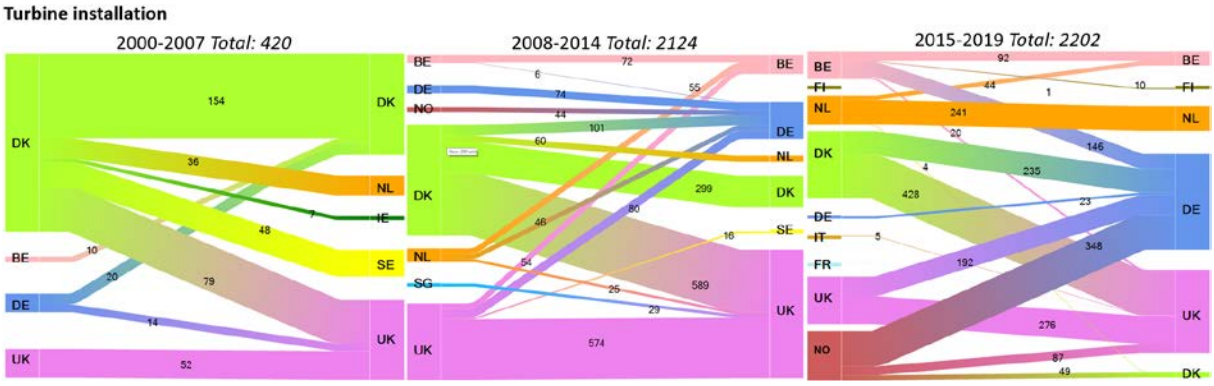

FIGURE 6 TURBINE INSTALLATION. VALUE = NUMBER OF TURBINES INSTALLED. NOTE THAT TOTAL MARKET SIZE EXPANDS FROM PHASE TO PHASE. SOURCE (DATA): 4C OFFSHORE (2019)

In ***array cable manufacturing***[6] (Figure 7), the established cable producers Swedish ABB High Voltage Cables, French Nexans and Italian Prysmian were early movers in the formative phase. In the take-off phase, other established (i.e. diversifying) cable manufacturers from several European countries entered the market, making this segment highly diverse in terms of suppliers. UK-based JDR Cable Systems, Nexans (both FR and DE subsidiaries), Norddeutsche Seekabelwerke (DE), Parker Scanrope (NO) and Draka Offshore (NL, with array cable manufacturing in Norway) established positions in the market. Given this variation in the intermediate phase, it is noteworthy that consolidation occurred in the growth phase. Market leader JDR Cable Systems (UK) was acquired by Polish TFKable, while Draka Offshore (NL/NO) and Norddeutsche Seekabelwerke (DE) were acquired by Prysmian (IT) in 2014 and 2018 respectively. ABB High Voltage Cables (SE) was bought by NKT Cables (DK) in 2016, and in the same year Parker Scanrope (NO) was sold to Bridon (UK). By the growth phase, the market leaders JDR Cable Systems (UK) and the German subsidiary of Nexans and Norddeutsche Seekabelwerke (DE) had reached an even-sided split of the market between UK and Germany, mainly supplying their domestic markets.

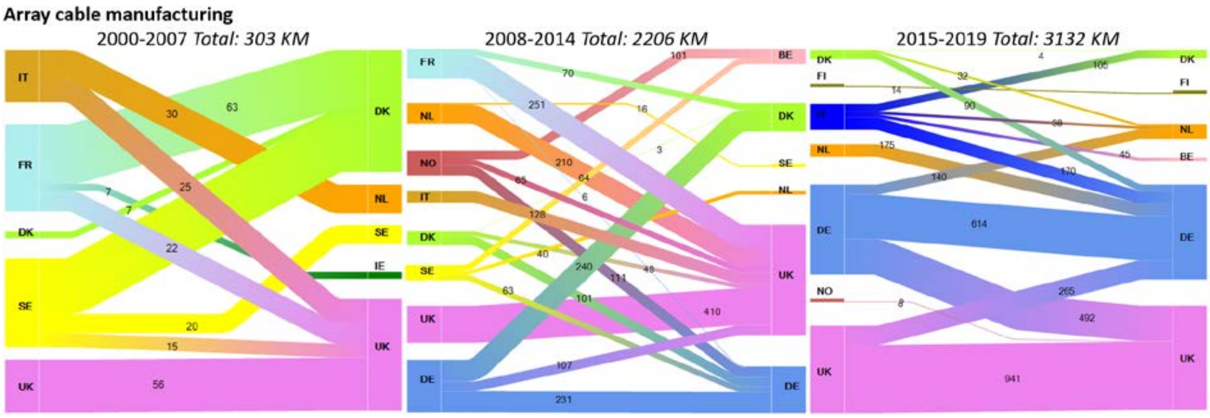

FIGURE 7 ARRAY CABLE MANUFACTURING. VALUE = KILOMETRE OF CABLE MANUFACTURED. NOTE THAT TOTAL MARKET SIZE EXPANDS FROM PHASE TO PHASE. SOURCE (DATA): 4C OFFSHORE (2019)

In ***export cable manufacturing*** (Figure 8) French, Italian and UK firms dominated the formative phase, many of which remain dominant throughout the three phases. By the growth phase, however, Denmark had taken a commanding position in the market through strong performance of NKT Cables and its acquisition of ABB. Prysmian (IT) was the other large producer in the growth phase, supported by its ownership of Norddeutsche Seekabelwerke (cable manufacturing).

[6] Array cable installation was not included due to uncertainties with this data.

Meanwhile, Nexans lost much of its market position over time, and only received some orders through its German subsidiary in the growth phase. By then, the cable export market was dominated by Danish firms, catering largely to the UK market.

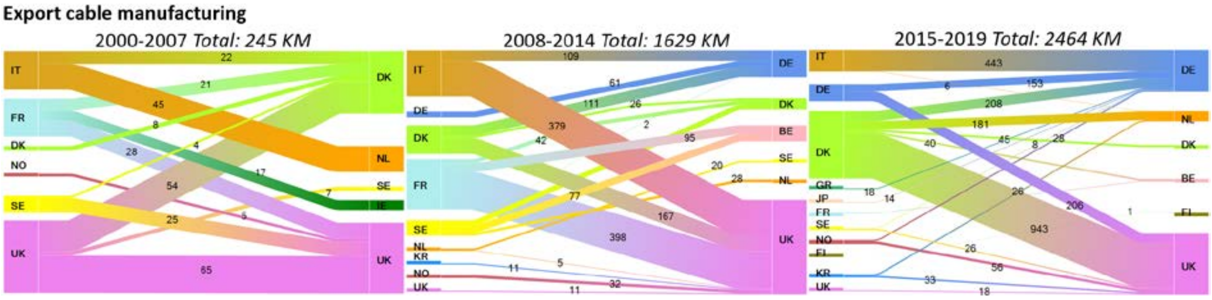

FIGURE 8 EXPORT CABLE MANUFACTURING. VALUE = KILOMETRE OF CABLE MANUFACTURED. NOTE THAT TOTAL MARKET SIZE EXPANDS FROM PHASE TO PHASE. SOURCE (DATA): 4C OFFSHORE

In the formative phase, ***export cable installation*** (Figure 9) was controlled by UK and Danish firms, supplying their domestic markets. However, many specialized maritime companies entered later. In the take-off phase, the market leader was Visser & Smit (NL), renamed later as VBMS, and subsequently became a part of the Boskalis group (NL). UK companies (e.g. Subocean Group, Global Marine Systems) maintained their major market shares. Interestingly, in the growth phase several vertically integrated cable companies, such as Prysmian (IT), captured a notable market share, as did de novo specialized maritime companies, such as Tideway and Jan de Nul (both NL). Of the UK-based companies only DeepOcean (a UK-subsidiary of a Norwegian parent company) remained in the market. Consequently, out of the value chain segments covered, export cable installation was internationally the most diverse one in the growth phase, both in terms of country of origin (IC) and deployment (market).

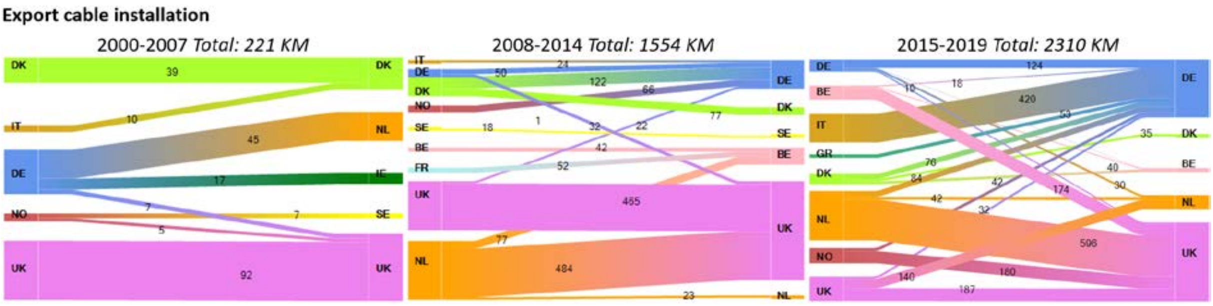

FIGURE 9 EXPORT CABLE INSTALLATION. VALUE = KILOMETRE OF CABLE INSTALLED. NOTE THAT TOTAL MARKET SIZE EXPANDS FROM PHASE TO PHASE. SOURCE (DATA): 4C OFFSHORE

Main features and comparison of industrial capacity development

The above results of IC development for provision of OWP complementary assets displays, first, large variation in countries of origin as well as access to domestic and international markets, and second, that the OWP production network is complex and transcends multiple national boundaries. Certain countries have nevertheless dominated the build-up of IC for complementary assets, unlike in the core technology (turbines) segment (see Section 3.2). Table 1 lists the three top countries for each complementary asset through the three phases. From a life-cycle perspective, these findings suggest first mover advantages, as at least one country was consistently in top three (in manufacturing or installation of a complementary asset) throughout the three phases. Turbine foundation manufacturing is an extreme case in that three countries (NL, DK, DE) were consistently dominant in this segment. In all segments, the top country in the growth phase was top three in the take-off phase, during which dominant designs emerged and increasing specialisation (to varying extent) occurred in the upstream supply chain.

In terms of types of companies, cable manufacturing (both export and array) and installation is dominated by diversifiers (established firms) serving multiple sectors. Other value chain segments have a mix of de novo firms and diversifiers. However, de novo companies are mostly visible in the installation of turbines and turbine foundations, where installing increasingly large structures in deeper waters further from shore demanded purpose-built and highly specialised vessels. Nonetheless, several de novo firms in these segments, such as Fred. Olsen Renewables (NO), are spin-offs or subsidiaries in established companies. In other words, relatedness and pre-existing industrial assets appear to have played a significant role in the development of IC for complementary assets in the European OWP sector.

In the formative phase, both components and services were often provided by multi-industry firms, whereas there was a broader variety in technological solutions. Increasing standardization and the consolidation of dominant designs in the take-off phase is particularly visible in the turbine foundation segment (where monopiles became the dominant design) in which a few companies dominate manufacturing and installation respectively, having invested in scale-oriented fabrication and fit-for-purpose vessels for monopile installation. Specialised foundation and turbine installers also emerged. The cable manufacturing and installation segments are as noted dominated by multi-industry (diversifying) firms that also serve other sectors (e.g., power, petroleum). This may explain the diversity of export cable manufacturers even in the growth phase. Regardless, there is increasing specialisation occurring also in this part of the value chain (BVG Associates, 2019).

To compare the IC build-up for complementary assets across countries, we developed an aggregate IC score based on share of supplies and share of OWP capital expenditure (CAPEX) (see Section 4 for more detail). Note that in addition to the supply chain segments covered in our analysis so far, this aggregate also includes the manufacturing of (transformer) substations which on average constitutes around 7% of the CAPEX for an OWP farm. We juxtapose this proxy indicator of IC capacity development with domestic market size. Figure 10 illustrates IC development in relation to domestic market growth over the three phases in the five countries (Denmark, United Kingdom, Germany, Netherlands, Belgium) with largest OWP deployment in Europe 2000-2019. Figure 10 also includes France, Italy, Norway, Sweden and Spain. These have in common that they developed relatively limited IC and small or non-existent domestic markets in the 2000-2019 period.

TABLE 1 TOP THREE COUNTRIES IN IC PER VALUE CHAIN SEGMENT PER LIFE-CYCLE PHASE. *ORDER OF APPEARANCE = POSITION 1-3. BOLD = LEADING POSITION IN GROWTH PHASE. ITALICS = ONE OF TOP THREE COUNTRIES THROUGHOUT ALL PHASES.

		Phases and lead countries*			***Industry dominance***				
		2000-2007 Form.	**2008-2014 Take-off**	**2015-2019 Growth**	**Diversifiers or *de novos* in take-off phase?**	**Diversifiers or *de novos* in growth phase?**	**Multi-industry or specialised firms in growth phase?**	**Three top suppliers in growth phase – country, type, and year of founding in parenthesis**	**Pre-existing assets**
	Largest markets	DK, UK, NL	UK, DE, DK	DE, UK, NL					
Lead countries per phase (bold= lead country in growth phase	Turbine foundation manufacturing	*NL*, *DK*, ***DE***	*DK*, *NL*, **DE**	**DE**, *NL*, *DK*	Diversifiers (incl. subsidiaries and JVs)	Mix (diversifiers)	Specialised	EEW (DE, subsidiary 2008/1936), SIF (NL, diversifier, 1948), Bladt (DK, diversifier, 1965)	Main companies diversified from various steel manufacturing. Specialised fabrication plants for OWP.
	Turbine foundation installation	NO, ***NL***, UK	***NL***, UK, DE	***NL***, BE, DE	Mix	Mix	Specialised	GeoSea (BE, diversifier, 2003), Van Oord (NL, diversifier, 1868), Seaway Heavy Lifting (NL, de novo/JV, 2009)	Many diversifiers with specialised vessels, but remain engaged in O&G and other maritime activities. Some de novos use converted vessels.
	Turbine installation	***DK***, UK, DE	***DK***, UK, NL	***DK***, NL, NO	De novos (incl. subsidiaries, spin-offs)	Mix	Specialised	A2Sea (DK, de novo, 2000), Fred Olsen Windcarrier (NO, de novo subsidiary, 2005), MPI Offshore (de novo, 2003)	Similar to turbine foundation installation. Several diversifiers, spin-offs, mostly using specialised vessels.
	Array cable manufacturing	FR, SE, *UK*	**DE**, *UK*, FR	**DE**, *UK*, IT	Diversifiers	Diversifiers	Multi-industry	JDR Cable Systems (UK, diversifier, 1994), Nexans Deutschland (DE, diversifier, 1960s), Norddeutsche Seekabelwerke (DE, diversifier, 1899)	All lead companies are diversifiers serving multiple industries.
	Export cable manufacturing	UK, FR, *IT*	FR, *IT*, **DK**	**DK**, *IT*, DE	Diversifiers	Diversifiers	Multi-industry	ABB (DK, diversifier, 1988/1800s), NKT Cables Group (DK, diversifier, 1891), Prysmian (IT, diversifier, 1879)	Same as array cable manufacturing.
	Export cable installation	*UK*, DE, DK	**NL**, *UK*, DK	**NL**, IT, *UK*	Mix	Diversifiers	Multi-industry	Visser & Smit Marine Contracting (NL, de novo (/spin off), 2007/1867), Tideway B.V (NL, diversifier, 1991), Prysmian Powerling (IT, diversifier, 1879)	Similar to export and array cable manufacturing. Lead companies serve several markets.

Figure 10 reflects that all countries with a relatively sizeable domestic market (i.e., more than 1000 MW of installed OWP during 2000-2019) developed notable IC for complementary assets, and did so within several supply chain segments. Countries with no or very limited home markets (e.g., Spain, Sweden, Italy, France, Norway) found a position within specific value chain segments. IC developments in these countries were largely based on diversification from existing industries, such as cable manufacturing in France/Italy and maritime installation services from Norway.

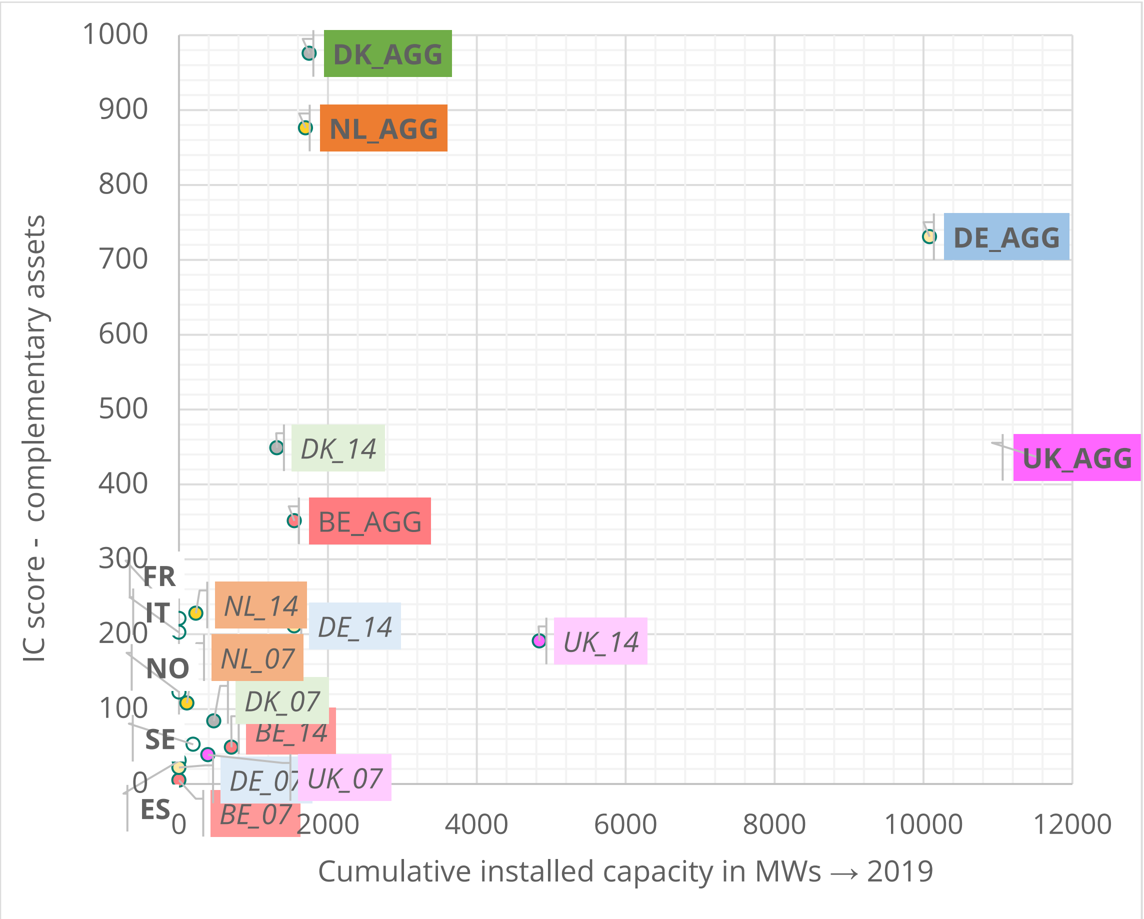

Figure 10 Cumulative industrial capacity vs. size of domestic market until 2019. Note that Belgium (BE), Denmark (DK), the Netherlands (NL), Germany (DE), and the UK have additional data points for years 2007 and 2014. Sources: Wind Europe (2020), 4C Offshore (2019)

Despite its market size the UK developed considerably less IC than Denmark, the Netherlands and Germany, whereas its IC is comparable to Belgium which has a much smaller domestic market. The UK therefore underperformed in developing IC compared with other Northern European countries with sizable domestic OWP deployment, underpinning previous research (see e.g. Afewerki et al., 2019; MacKinnon et al., 2019) showing that the UK has relied heavily on imports (see also Tables C.1 and C.2). Relative to market size, Denmark and the Netherlands developed the most sizable IC for complementary assets to OWP, whereas Germany has strong IC development especially since its domestic market emerged. In general, UK suppliers mainly served their domestic market, whereas the opposite is true for the Netherlands, Denmark and Belgium (see Table C.1). This overall impression is strengthened but also nuanced when considering to what extent OWP projects were served by domestic or foreign suppliers (i.e. imports) in the different countries. Both Germany and the UK relied heavily on imports, whereas Denmark and the Netherlands in some segments relied mainly on domestic suppliers (see Table C.2).

Discussion

OWP is a complex product system sector where learning and innovation dynamics rely heavily on user-producer interaction supported by geographical proximity (Binz & Truffer, 2017; Tsouri et al., 2021). Also not to be underestimated, the geographical concentration of suppliers to OWP reflects the importance of geographical proximity and logistic costs when large quantities of massive components need to be moved from manufacturing sites to locations in the sea for installation (Afewerki et al., 2019; Poulsen & Lema, 2017). Given these characteristics of the OWP sector, the observed spatio-temporal patterns of IC build-up are generally as anticipated and in line with previous research and market analysis (e.g. BVG Associates, 2019; MacKinnon et al., 2019). In the following, we discuss our three proposed explanations for how IC has been built up around OWP in Europe.

With regard to industry life-cycle and innovation dynamics (Markard, 2020; Utterback & Suárez, 1993), we observed different dynamics of industrial development in the three identified phases. In the formative phase was characterised by few firms from a small set of countries, while in the later stages, with strong growth occurring, firms from more countries entered the OWP value chain. In turbine foundation manufacturing and installation, and to some extent in array cable and export cable manufacturing, industrial capacity for complementary assets has however become fairly concentrated in a few countries (the Netherlands, UK, Germany and Denmark).

Moreover, and as expected based on previous work by Joern Huenteler et al. (2016) and Hipp and Binz (2020), we observed that the patterns of IC development differed between key components and services over time. That is, we see clear consolidation in value chain segments with high technological complexity and dominance of specialised firms, such as in the turbine installation segment where considerable product innovation (purpose-built vessels) has occurred. In the latter segment, 'new' highly specialised suppliers appear to have undermined the competitive advantage of incumbents (Lee & Malerba, 2017). However, consolidation was also observed for certain low-tech segments such as foundation manufacturing, indicating that companies have achieved specialisation in mass production and benefited from exploiting economies of scale (i.e. important process innovation) (Utterback & Abernathy, 1975). Such benefits may effectively hinder the entrance of new producers. Industry consolidation also occurred in export and array cable manufacturing, which relies on sophisticated manufacturing processes.

Our country-level analysis suggests that there were important first-mover advantages in this sector, whereby countries that entered the industry (from the supply-side) in the formative or (especially) take-off phase also came to dominate in the growth phase. That life-cycle dynamics for complementary assets differ between value chain segments implies that countries and regions can couple onto industries and benefit from value creation and capture (including employment opportunities) without achieving industrial leadership in the core technology, nor by fostering domestic lead markets (Rohe, 2020; Tsouri et al., 2021).

Moving on to the second explanation, our analysis largely supports previous research that emphasise the importance of pre-existing know-how and manufacturing capabilities for gaining a foothold in the OWP supply chain. Many companies that became key supply chain actors in the OWP sector diversified from other sectors such as offshore engineering/construction or petroleum, indicating the importance of relatedness (Breschi et al., 2003; Neffke et al., 2011) for "making it" in this capital-intensive, complex, and high-risk industry (Mäkitie et al., 2018). In some segments, such as in the manufacturing and installation of cables, these diversifying incumbents continue to serve also other industries (e.g. power, petroleum). In other segments, such as foundation manufacturing, lead firms were generally diversifiers that have developed branch plants specialised in serving the OWP market. In the installation service segments we observed a greater share of new firms. However, many of these are spin-outs from established companies, underpinning the importance of pre-existing assets and related diversification for build-up of IC to deliver complementary assets to the European OWP market.

Finally, regarding home market opportunities, our analysis shows that all countries (Belgium, Denmark, Germany, the Netherlands, the UK) with a sizeable domestic market (i.e. more than 1000 MW cumulative capacity by 2019) have developed IC in several value chain segments, and notably in manufacturing. In contrast, countries with very small or non-existing domestic markets (e.g. Sweden, France, Norway) have only managed to take a (relatively minor) position in some segments. Furthermore, in some value chain segments, countries have developed substantial IC without seemingly benefiting from a local market for those particular segments. Notable examples are turbine foundation manufacturing from Denmark and cable installation from the Netherlands.

While access to a domestic market has clearly mattered, there is no clear connection between domestic market size and IC development. This is demonstrated by the UK (limited IC development vs domestic market), and the largely export-oriented IC development of Denmark and the Netherlands. Of the four countries that developed the largest IC during 2000-2019 (Germany, UK, Denmark, Netherlands), all but Germany had a sizeable home market in the formative phase. This suggests that a home market in the formative phase was beneficial but not necessary for developing IC for complementary assets. In Denmark and the Netherlands, access to a domestic market in the formative phase appears to have supported the development of IC later, catering to international markets in the growth phase. In contrast, however, Germany had notable IC development and domestic market formation only in the take-off and growth phases. Regardless of differences between countries, an interpretation of these findings is that the policies and policy targets that have secured OWP deployment in those countries have also provided actors in the supply chain with confidence to invest in capabilities, manufacturing infrastructure, vessels, and so forth, within those same countries. We consider this to be an important finding given that this deployment has been conditioned on public financial support. Job creation and industrial activity in turn may have triggered positive feedback in the form of societal and political acceptance (e.g. Vona, 2019).

On a final note, a general shift from feed-in-tariffs to more competitive, auction-based feed-in-premiums/contracts for difference to support OWP projects in Europe, occurred in the latter part of the time period studied (MacKinnon et al., 2021; Vieira et al., 2019). In Europe, free market regulations have furthermore meant that legally binding local content requirements have not been used (van der Loos et al., 2022). The exception is the UK, where a local content framework came into force from 2015 for all wind farm projects achieving final investment decision from then on.

For these projects, developers would need to report on their ‘UK content’, implying a certain local content push (ibid.). However, based on our data, there are no clear indications that this policy change had any significant effects of the UK share of the components and services covered in our analysis.

Conclusion

Our aim in this paper was to explore the development of industrial capacity (IC) for complementary assets to offshore wind power (OWP) in Europe in the 2000-2019 period, and thereby contribute to a better understanding of resource formation processes as part of accelerating energy transitions (Bergek et al., 2008; Karltorp, 2014). A key contribution of this paper has been to unpack how such resource formation processes include the development and upscaling of the IC to deliver key upstream components and services. To date, this value chain-related industrial development has received scant attention in the sustainability transitions literature. We show how upstream value chains are comprised by a diverse set of complementary assets, which are critical components of offshore wind power (OWP) projects that have significant impacts on overall costs of energy, and offer important value creation and job opportunities for different regions and countries in the energy transition. As proposed by Andersen et al. (2020), stronger attention to industry development in sustainability transition research can help us better understand how sustainability transitions are also associated with a changing industrial and economic landscape. Here, our study has contributed with an empirical analysis of such industrial dynamics, focusing on complementary assets in particular (Andersen et al., 2024).

A key finding is that industrial dynamics in sustainability transitions can be shaped by several interlinking factors, including industrial and technology life-cycle dynamics, pre-existing industrial assets, and formation of domestic markets, including through public policy. Several of these factors have been found relevant in single country case studies previously, and a key contribution in this paper is that we validate their importance across a wider set of countries. As a result, our paper thus points to a need to pay more attention to the complexities of industrial dynamics in sustainability transitions, and the development of IC around complementary assets in particular to be able to advice policy and research regarding the realization of industrial opportunities in relation to sustainability transitions.

Despite the exploratory nature of our analysis, we point to several lessons regarding this topic which, we believe, have important implications for both theory and policy. First, access to a domestic market, as well as physical proximity to other nearby (national) markets, has clearly been important for development of IC. Moreover, countries that came to dominate in the take-off phase, when dominant designs emerged and increasing specialisation occurred in the value chain, largely remained dominant also in the growth phase. Furthermore, IC development largely occurred on the basis of pre-existing assets via firm diversification and spin-outs. In the case of sectors with "spatially sticky" knowledge bases (Binz & Truffer, 2017), such as OWP, the development of a local industry has a good chance to go hand in hand with a local deployment of technologies if relevant pre-existing industrial competences, enabling related diversification, are in place. This suggests that technologies like OWP with typically geographically concentrated production networks, in contrast to technologies like solar PV with a more global production network (Hipp & Binz, 2020), have a better chance to contribute to realization of local "green growth" opportunities – the economic benefits that can be crucial for securing public acceptance for transition policies. Our findings give support to arguments that supporting early movers, developing a home market, and building on existing infrastructure and resources *can* be helpful if the goal is to stimulate domestic value capture or job creation.

Second, our analysis has shown that important industry and innovation dynamics that are part and parcel of sustainability transitions may be overlooked when focusing solely on core technologies. Attention to complementary assets is particularly relevant for the upscaling of complex environmental technologies, such as OWP. In particular, countries located physically close to the markets (see above point) can strive for building IC related to complementary assets rather than targeting core technologies. Naturally, a key policy implication is that decision makers may look beyond core technology suppliers when designing industrial policy connected to the energy transition.

Third, our paper shows that an international perspective is needed to fully understand the industrial dynamics of an environmental innovation. While, e.g., domestic deployment policies played a role in the development of national industrial development, development of IC around OWP was ultimately international and shaped by a wider interplay between actors and policies across countries (Binz & Truffer, 2017; Wieczorek et al., 2015). Policymakers seeking to accelerate the development and deployment of environmental technologies should consider multi-lateral coordination and potential division of labor between countries, which may be particularly important for more complex technologies (Malhotra & Schmidt, 2020).

Fourth, countries differ with regards to the balance between IC and domestic market development. Some countries with early domestic markets became large exporters (e.g. Denmark, Netherlands) whereas notably the UK relied heavily on imports. This suggests that despite domestic markets, the development of IC takes place unevenly, with some countries being able to realize high domestic economic activities, while others must suffice with meager local benefits. This highlights that while coordination can accelerate sustainability transitions, countries ultimately compete for capture value from environmental technologies.

This paper has limitations that should be addressed in future research. First, our analysis disregarded the core WTG technology (nacelle, tower and blades), and future research could thus compare IC development for complementary assets and core technology. Second, our analysis focused on a single sector. Future studies that include IC development for more "footloose" sectors could shed light on a potentially differing role of domestic markets and relatedness compared to what we observed in our case. Third, a more granular regional-level analysis of IC build-up would be highly interesting, for instance due to sub-national (i.e. inter-regional) competition for industrial development. Finally, future studies could explore the role of wider policy mixes, including innovation policy, for IC development.

References

4C Offshore. (2019). *Windfarms Database*. https://www.4coffshore.com/windfarms/?gad=1&gclid=Cj0KCQjwk96lBhDHARIsAEKO4xaYv1IwAdM4L3KnYImIoxinjslLQekuXRapsUwgLQAnBTzFXrPGTVAaAhHAEALw_wcB

Acs, Z. J., & Terjesen, S. (2013). Born local: toward a theory of new venture's choice of internationalization. *Small Business Economics*, *41*(3), 521-535. https://doi.org/10.1007/s11187-012-9446-8

Afewerki, S., Karlsen, A., & MacKinnon, D. (2019). Configuring floating production networks: A case study of a new offshore wind technology across two oil and gas economies. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, *73*(1), 4-15. https://doi.org/10.1080/00291951.2018.1494209

Afewerki, S., & Steen, M. (2023). Gaining lead firm position in an emerging industry: A global production networks analysis of two Scandinavian energy firms in offshore wind power. *Competition & Change*, *27*(3-4), 551-574. https://doi.org/10.1177/10245294221103072

Andersen, A. D., Mäkitie, T., Steen, M., & Wanzenböck, I. (2024). Integrating industrial transformation and sustainability transitions research through a multi-sectoral perspectiv. *TIK Working Papers on Innovation Studies, No. 20240206*.

Andersen, A. D., Steen, M., Mäkitie, T., Hanson, J., Thune, T. M., & Soppe, B. (2020). The role of inter-sectoral dynamics in sustainability transitions: A comment on the transitions research agenda. *Environmental Innovation and Societal Transitions*, *34*, 348-351. https://doi.org/10.1016/j.eist.2019.11.009

Anderson, P., & Tushman, M. L. (1990). Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change. *Administrative Science Quarterly*, *35*(4), 604-633. https://doi.org/10.2307/2393511

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, *37*(3), 407-429. https://doi.org/10.1016/j.respol.2007.12.003

Binz, C., & Truffer, B. (2017). Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts. *Research Policy*, *46*(7), 1284-1298. https://doi.org/10.1016/j.respol.2017.05.012

Binz, C., Truffer, B., & Coenen, L. (2016). Path Creation as a Process of Resource Alignment and Anchoring: Industry Formation for On-Site Water Recycling in Beijing. *Economic Geography*, *92*(2), 172-200. https://doi.org/10.1080/00130095.2015.1103177

Boschma, R. (2005). Proximity and Innovation: A Critical Assessment. *Regional Studies*, *39*(1), 61-74. https://doi.org/10.1080/0034340052000320887

Breschi, S., Lissoni, F., & Malerba, F. (2003). Knowledge-relatedness in firm technological diversification. *Research Policy*, *32*(1), 69-87. https://doi.org/10.1016/s0048-7333(02)00004-5

BVG Associates. (2010). *A Guide to an Offshore Wind Farm*. BVG Associates. http://www.bvgassociates.co.uk/Portals/0/publications/Wind_Farm_Guide_Final_LR.pdf

BVG Associates. (2014). *UK offshore wind supply chain: capabilities and opportunities*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/277798/bis-14-578-offshore-wind-supply-chain-capabilities-and-opportunities.pdf

BVG Associates. (2017). *Norwegian supply chain opportunities in offshore wind*. https://www.bluemaritimecluster.no/download?objectPath=/upload_images/52B2387462CE4ECF999501313BB3B282.pdf

BVG Associates. (2019). *Opportunities in offshore wind for the Norwegian supply chain*. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwitjPGTlanzAhWUyYsKHQQbD-cQFnoECAcQAQ&url=https%3A%2F%2Fwww.norwep.com%2Fcontent%2Fdownload%2F38193%2F280069%2Fversion%2F6%2Ffile%2FOffshore_Wind_Supply_Chain_Opportunities_2019-03-05.pdf&usg=AOvVaw2vVYS8kxoM6aA_BKLgRmH3

Castellacci, F. (2012). Firm's internationalisation in the service industries: Evidence from Norway. . In H. Hveem & C. H. Knutsen (Eds.), *Governance and knowledge : the politics of foreign investment, technology and ideas*. Routledge.

Content, J., & Frenken, K. (2016). Related variety and economic development: a literature review. *European Planning Studies*, *24*(12), 2097-2112. https://doi.org/10.1080/09654313.2016.1246517

CORE. (2023). *Wind farm costs*. Catapult Offshore Renewable Energy, BVG Associates. https://guidetoanoffshorewindfarm.com/wind-farm-costs

Davies, A. (1997). The Life Cycle of a Complex Product System. *International Journal of Innovation Management*, *01*(03), 229-256. https://doi.org/10.1142/s1363919697000139

Dedecca, J. G., Hakvoort, R. A., & Ortt, J. R. (2016). Market strategies for offshore wind in Europe: A development and diffusion perspective. *Renewable and Sustainable Energy Reviews*, *66*, 286-296. https://doi.org/http://dx.doi.org/10.1016/j.rser.2016.08.007

EC. (2020, 19.11.2020). *Boosting Offshore Renewable Energy for a Climate Neutral Europe* https://ec.europa.eu/commission/presscorner/detail/%20en/ip_20_2096

EC. (2022). *REPowerEU Plan*. Brussels: European Commission Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF

EC. (2023). *A Green Deal Industrial Plan for the Net-Zero Age*. Brussels: European Commission Retrieved from https://commission.europa.eu/system/files/2023-02/COM_2023_62_2_EN_ACT_A%20Green%20Deal%20Industrial%20Plan%20for%20the%20Net-Zero%20Age.pdf

Eicke, L., & Weko, S. (2022). Does green growth foster green policies? Value chain upgrading and feedback mechanisms on renewable energy policies. *Energy Policy*, *165*, 112948. https://doi.org/https://doi.org/10.1016/j.enpol.2022.112948

EWEA. (2011). *Wind in our Sails. The coming of Europe's offshore wind energy industry*. E. W. E. Association.

Fagerberg, J. (1992). The Home Market Hypothesis Re-examined: The Impact of Domestic UserProducer Interaction on Export Specialisation. In B.-Å. Lundvall (Ed.), *National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning*. Pinter.

Freeman, C. (1987). *Technology, policy, and economic performance : lessons from Japan*. Pinter Publishers.

Frenken, K., Izquierdo, L. R., & Zeppini, P. (2012). Branching innovation, recombinant innovation, and endogenous technological transitions. *Environmental Innovation and Societal Transitions*, *4*(0), 25-35. https://doi.org/10.1016/j.eist.2012.06.001

Grillitsch, M., & Hansen, T. (2019). Green industry development in different types of regions. *European Planning Studies*, *27*(11), 2163-2183. https://doi.org/10.1080/09654313.2019.1648385

GWEC. (2022). https://gwec.net/wp-content/uploads/2022/06/GWEC-Offshore-2022_update.pdf

Hansen, G. H., & Steen, M. (2011). *Vindkraft til havs. Teknologi- og industriutvikling fra et norsk bedriftsperspektiv* (978-82-93198-00-0).

Helfat, C. E., & Lieberman, M. B. (2002). The birth of capabilities: market entry and the importance of pre-history. *Industrial and corporate change*, *11*(4), 725-760. https://doi.org/10.1093/icc/11.4.725

Hipp, A., & Binz, C. (2020). Firm survival in complex value chains and global innovation systems: Evidence from solar photovoltaics. *Research Policy*, *49*(1), 103876. https://doi.org/https://doi.org/10.1016/j.respol.2019.103876

Huenteler, J., Schmidt, T. S., Ossenbrink, J., & Hoffmann, V. H. (2016). Technology life-cycles in the energy sector - Technological characteristics and the role of deployment for innovation. *Technological Forecasting and Social Change*, *104*, 102-121. https://doi.org/10.1016/j.techfore.2015.09.022

Huenteler, J., Schmidt, T. S., Ossenbrink, J., & Hoffmann, V. H. (2016). Technology life-cycles in the energy sector — Technological characteristics and the role of deployment for innovation. *Technological Forecasting and Social Change*, *104*, 102-121. https://doi.org/https://doi.org/10.1016/j.techfore.2015.09.022

IRENA. (2019). *Future of Wind. Deployment, investement, technology, grid integration and socio-economic aspects*. I. R. E. Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf

Johnstone, P., Rogge, K. S., Kivimaa, P., Farné Fratini, C., & Primmer, E. (2021). Exploring the re-emergence of industrial policy: Perceptions regarding low-carbon energy transitions in Germany, the United Kingdom and Denmark. *Energy Research & Social Science*, *74*, 101889. https://doi.org/https://doi.org/10.1016/j.erss.2020.101889

Jolly, S., Steen, M., Hansen, T., & Afewerki, S. (2023). Renewable energy and industrial development in pioneering and lagging regions: the offshore wind industry in Southern Denmark and Normandy. *Oxford Open Energy*. https://doi.org/10.1093/ooenergy/oiad010

Karltorp, K. (2014). *Scaling up renewable energy technologies. The role of resource mobilisation in the growth of technological innovation systems* (Publication Number 3745) Chalmers University of Technology]. Göteborg.

Kausche, M., Adam, F., Dahlhaus, F., & Großmann, J. (2018). Floating offshore wind - Economic and ecological challenges of a TLP solution. *Renewable Energy*, *126*, 270-280. https://doi.org/https://doi.org/10.1016/j.renene.2018.03.058

Kim, J., & Lee, C.-Y. (2011). Technological regimes and the persistence of first-mover advantages. *Industrial and corporate change*, *20*(5), 1305-1333. https://doi.org/10.1093/icc/dtr048

Kivimaa, P., & Sivonen, M. H. (2023). How will renewables expansion and hydrocarbon decline impact security? Analysis from a socio-technical transitions perspective. *Environmental Innovation and Societal Transitions*, *48*, 100744. https://doi.org/https://doi.org/10.1016/j.eist.2023.100744

Klepper, S., & Simons, K. L. (2000). Dominance by birthright: entry of prior radio producers and competitive ramifications in the U.S. television receiver industry. *Strategic Management Journal*, *21*(10-11), 997-1016. https://doi.org/10.1002/1097-0266(200010/11)21:10/11<997::AID-SMJ134>3.0.CO;2-O

Lee, K., & Malerba, F. (2017). Catch-up cycles and changes in industrial leadership:Windows of opportunity and responses of firms and countries in the evolution of sectoral systems. *Research Policy*, *46*(2), 338-351. https://doi.org/https://doi.org/10.1016/j.respol.2016.09.006

MacKinnon, D., Dawley, S., Steen, M., Menzel, M. P., Karlsen, A., Sommer, P., Hansen, G. H., & Normann, H. E. (2019). Path creation, global production networks and regional development: A comparative international analysis of the offshore wind sector. *Progress in Planning*, *130*, 1-32. https://doi.org/10.1016/j.progress.2018.01.001

MacKinnon, D., Karlsen, A., Dawley, S., Steen, M., Afewerki, S., & Kenzhegaliyeva, A. (2021). Legitimation, institutions and regional path creation: a cross-national study of offshore wind. *Regional Studies*, 1-12. https://doi.org/10.1080/00343404.2020.1861239

Malhotra, A., & Schmidt, T. S. (2020). Accelerating Low-Carbon Innovation. *Joule*, *4*(11), 2259-2267. https://doi.org/https://doi.org/10.1016/j.joule.2020.09.004

Markard, J. (2020). The life cycle of technological innovation systems. *Technological Forecasting and Social Change*, *153*, 119407. https://doi.org/https://doi.org/10.1016/j.techfore.2018.07.045

Markard, J., Geels, F. W., & Raven, R. (2020). Challenges in the acceleration of sustainability transitions. *Environmental Research Letters*, *15*(8), 081001. https://doi.org/10.1088/1748-9326/ab9468
Markard, J., & Petersen, R. (2009). The offshore trend: Structural changes in the wind power sector. *Energy Policy*, *37*(9), 3545-3556. https://doi.org/10.1016/j.enpol.2009.04.015
Murmann, J. P., Ozdemir, S. Z., & Sardana, D. (2015). The role of home country demand in the internationalization of new ventures. *Research Policy*, *44*(6), 1207-1225. https://doi.org/http://dx.doi.org/10.1016/j.respol.2015.03.002
Mäkitie, T., Andersen, A. D., Hanson, J., Normann, H. E., & Thune, T. M. (2018). Established sectors expediting clean technology industries? The Norwegian oil and gas sector's influence on offshore wind power. *Journal of Cleaner Production*, *177*, 813-823. https://doi.org/10.1016/j.jclepro.2017.12.209
Mäkitie, T., Hanson, J., Steen, M., Hansen, T., & Andersen, A. D. (2022). Complementarity formation mechanisms in technology value chains. *Research Policy*, *51*(7), 104559. https://doi.org/https://doi.org/10.1016/j.respol.2022.104559
Neffke, F., Henning, M., & Boschma, R. (2011). How Do Regions Diversify over Time? Industry Relatedness and the Development of New Growth Paths in Regions. *Economic Geography*, *87*(3), 237-265. https://doi.org/10.1111/j.1944-8287.2011.01121.x
Nilsson, L. J., Bauer, F., Åhman, M., Andersson, F. N. G., Bataille, C., de la Rue du Can, S., Ericsson, K., Hansen, T., Johansson, B., Lechtenböhmer, S., van Sluisveld, M., & Vogl, V. (2021). An industrial policy framework for transforming energy and emissions intensive industries towards zero emissions. *Climate Policy*, 1-13. https://doi.org/10.1080/14693062.2021.1957665
Normann, H. E., & Hanson, J. (2018). The role of domestic markets in international technological innovation systems. *Industry and Innovation*, *25*(5), 482-504. https://doi.org/10.1080/13662716.2017.1310651
O'Sullivan, M. (2020). Industrial life cycle: relevance of national markets in the development of new industries for energy technologies – the case of wind energy. *Journal of Evolutionary Economics*, *30*(4), 1063-1107. https://doi.org/10.1007/s00191-020-00677-5
ORE Catapult. (2018). *Offshore Wind Industry Prospectus*. O. R. E. C. a. O. W. I. Council. https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/publications/catapult_prospectus_final.pdf
Peters, M., Schneider, M., Griesshaber, T., & Hoffmann, V. H. (2012). The impact of technology-push and demand-pull policies on technical change – Does the locus of policies matter? *Research Policy*, *41*(8), 1296-1308. https://doi.org/http://dx.doi.org/10.1016/j.respol.2012.02.004
Poulsen, T., & Lema, R. (2017). Is the supply chain ready for the green transformation? The case of offshore wind logistics. *Renewable and Sustainable Energy Reviews*, *73*(Supplement C), 758-771. https://doi.org/https://doi.org/10.1016/j.rser.2017.01.181
Rohe, S. (2020). The regional facet of a global innovation system: Exploring the spatiality of resource formation in the value chain for onshore wind energy. *Environmental Innovation and Societal Transitions*, *36*, 331-344. https://doi.org/https://doi.org/10.1016/j.eist.2020.02.002
Rotmans, J., Kemp, R., & van Asselt, M. (2001). More evolution than revolution: transition management in public policy. *Foresight*, *3*(1), 15-31. https://doi.org/10.1108/14636680110803003
Steen, M., & Hansen, G. H. (2014). Same Sea, Different Ponds: Cross-Sectorial Knowledge Spillovers in the North Sea. *European Planning Studies*, *22*(10), 2030-2049. https://doi.org/10.1080/09654313.2013.814622
Steen, M., & Hansen, G. H. (2018). Barriers to Path Creation: The Case of Offshore Wind Power in Norway. *Economic Geography*, *94*(2), 188-210. https://doi.org/10.1080/00130095.2017.1416953
Tanner, A. N. (2014). Regional Branching Reconsidered: Emergence of the Fuel Cell Industry in European Regions. *Economic Geography*, *90*(4), 403-427. https://doi.org/Doi 10.1111/Ecge.12055

Tanriverdi, H., & Venkatraman, N. (2005). Knowledge relatedness and the performance of multibusiness firms. *Strategic Management Journal*, *26*(2), 97-119. https://doi.org/10.1002/smj.435

Tsouri, M., Hanson, J., & Normann, H. E. (2021). Does participation in knowledge networks facilitate market access in global innovation systems? The case of offshore wind. *Research Policy*, *50*(5), 104227. https://doi.org/https://doi.org/10.1016/j.respol.2021.104227

Utterback, J. M., & Abernathy, W. J. (1975). A dynamic model of process and product innovation. *Omega*, *3*(6), 639-656. https://doi.org/https://doi.org/10.1016/0305-0483(75)90068-7

Utterback, J. M., & Suárez, F. F. (1993). Innovation, competition, and industry structure. *Research Policy*, *22*(1), 1-21. https://doi.org/http://dx.doi.org/10.1016/0048-7333(93)90030-L

van der Loos, A., Langeveld, R., Hekkert, M., Negro, S., & Truffer, B. (2022). Developing local industries and global value chains: The case of offshore wind. *Technological Forecasting and Social Change*, *174*, 121248. https://doi.org/https://doi.org/10.1016/j.techfore.2021.121248

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. *Renewable and Sustainable Energy Reviews*, *138*, 110513. https://doi.org/https://doi.org/10.1016/j.rser.2020.110513

van der Loos, H. Z. A., Negro, S. O., & Hekkert, M. P. (2020). International markets and technological innovation systems: The case of offshore wind. *Environmental Innovation and Societal Transitions*, *34*, 121-138. https://doi.org/https://doi.org/10.1016/j.eist.2019.12.006

Vieira, M., Snyder, B., Henriques, E., & Reis, L. (2019). European offshore wind capital cost trends up to 2020. *Energy Policy*, *129*, 1364-1371. https://doi.org/https://doi.org/10.1016/j.enpol.2019.03.036

Vona, F. (2019). Job losses and political acceptability of climate policies: why the 'job-killing' argument is so persistent and how to overturn it. *Climate Policy*, *19*(4), 524-532. https://doi.org/10.1080/14693062.2018.1532871

Wieczorek, A. J., Hekkert, M. P., Coenen, L., & Harmsen, R. (2015). Broadening the national focus in technological innovation system analysis: The case of offshore wind. *Environmental Innovation and Societal Transitions*, *14*(0), 128-148. https://doi.org/10.1016/j.eist.2014.09.001

Wind Europe. (2017). *Wind energy in Europe: Scenarios for 2030*. https://windeurope.org/wp-content/uploads/files/about-wind/reports/Wind-energy-in-Europe-Scenarios-for-2030.pdf

Wind Europe. (2019). *Wind energy in Europe in 2018*. W. Europe. https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2018.pdf

Wind Europe. (2020). *Offshore Wind in Europe. Key trends and statistics 2019*. https://proceedings.windeurope.org/biplatform/rails/active_storage/blobs/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBmQT09IiwiZXhwIjpudWxsLCJwdXIiOiJibG9iX2lkIn19--a7d2152fdbe2c4cefca9a4fdf546aa35f24a69b2/WindEurope-Annual-Offshore-Statistics-2019.pdf

Wind Europe. (2021, 27.05.2021). *Upscaling Europe's port infrastructure critical for offshore wind development* https://windeurope.org/newsroom/press-releases/upscaling-europes-port-infrastructure-critical-for-offshore-wind-development/

Wüstemeyer, C., Madlener, R., & Bunn, D. W. (2015). A stakeholder analysis of divergent supply-chain trends for the European onshore and offshore wind installations. *Energy Policy*, *80*, 36-44. https://doi.org/http://dx.doi.org/10.1016/j.enpol.2015.01.017

Appendix A Data cleaning

Data cleaning 4C Offshore followed a step-wise process resulting in 751 data rows:

1. We excluded data outside of scope, and removed rows that did not contain numerical data regarding the scale of contract (e.g. number of turbines or foundations, kilometres of cable).
2. We manually and systematically went through all data rows to remove duplicates. This was necessary as it was rather common that the database included duplicate entries: e.g. reporting that company X had gotten the contract to provide a certain number of turbines to an array, but later in data it was explained that in the end, company Y provided the turbines after all because of a given reason.
3. As part of removing duplicates, efforts were made to identify which company actually performed the work, when multiple companies were reported to have carried out the same task. This was most common because of the prevalence of EPCI contracts whereby a large contract holder usually relies on sub-contractors to fulfil tasks. In such cases, we marked the sub-contractor as the provider of the task.

Appendix B IC score calculation

IC scores were calculated as follows:

1. For each country we calculated the percentage share of total number of X (e.g., number of foundations manufactured or installed, kilometres of cable manufactured or installed) over the 2000-2019 period for the following components: turbine foundations, array cables, export cables, substations; and services: installation of export cables, installation of turbines, installation of turbine foundation. For example, country A manufactured 1621 of a total 4755 turbine foundations (a component), i.e. 29%, whereas country B provided 13% of all turbine foundation installation (a service).
2. We calculated the share of CAPEX for each of these components and services, as shown in Table B.1. This was based on cost estimates from different sources: BVG Associates (2014, 2017); CORE (2023); Kausche et al. (2018); ORE Catapult (2018) BVG Associates/The Crown Estate (2021). Some of these estimates were for total LCOE of OW power projects, including development (DEVEX), capital (CAPEX), operational (OPEX) and decommissioning (DEDEX). Also, BVG Associates/The Crown Estate provided cost breakdowns on component level (but for instance did not separate between export and array cables although these are usually different contracts both on the manufacturing and installation side). We thus recalculated the cost breakdowns for each component/service against the aggregate average.

Table B.1 Breakdown of CAPEX across segments in the offshore wind power value chain (development and construction phase)

Main segment	Average total cost segment (share of CAPEX)*		Average % of CAPEX	Comment	Incl. in IC score?
Turbine	43%	Nacelle	16%	Turbine elements = 1 contract in 4C Offshore.	No
		Rotor	9%		
		Tower	3%		
		Blade	15%		
Balance of plant	31%	Turbine foundation	14%		Yes
		Export cables	5%		Yes
		Array cables	4%		Yes
		Offshore substation	7%		Yes
		Other balance of plant	2%		No
Installation	22%	Export cable installation	4%		Yes
		Array cable installation	3%	Poor data quality in 4C, therefore excluded from analysis.	No
		Foundation installation	4%		Yes
		Turbine installation	2%		Yes
		Other installation	9%		No

**Missing 4% is DEVEX that is included in most cost estimates*

3. We then multiplied the (%) share of component/service provision with share (%) of CAPEX for that service or component and aggregated per country. This resulted in cumulative IC scores in the range of 0-1000.

Appendix C Share of supplies – domestic, export, import

TABLE C.1 COUNTRY IC – SHARE OF SUPPLY (AGGREGATE) PER COUNTRY GOING TO THE DOMESTIC MARKET (D) VS EXPORT (E). SOURCE (DATA): 4C OFFSHORE (2019)

		Country				
Complementary asset	**Domestic (D)/ export (E)**	**BE**	**DE**	**DK**	**NL**	**UK**
	D	n/a	46 %	7 %	0 %	84 %
Array cable manufacturing	E	n/a	54 %	93 %	100 %	16 %
	D	n/a	51 %	5 %	0 %	100 %
Export cable manufacturing	E	n/a	49 %	95 %	100 %	0 %
	D	26 %	53 %	39 %	5 %	82 %
Export cable installation	E	74 %	47 %	61 %	95 %	18 %
	D	11 %	48 %	30 %	14 %	95 %
Turbine foundation manufacturing	E	89 %	52 %	70 %	96 %	5 %
	D	20 %	100 %	17 %	15 %	77 %
Turbine foundation installation	E	80 %	0 %	83 %	85 %	23 %
	D	46 %	74 %	22 %	58 %	73 %
Turbine installation	E	54 %	26 %	78 %	42 %	27 %
	D	9 %	100 %	22 %	34 %	100 %
Substation manufacturing	E	91 %	0 %	78 %	76 %	0 %

IC complementary assets for...	Domestic market	>70%
	Mix domestic/export	
	Export market	>70%

TABLE C.2 HOME MARKET - SHARE OF SUPPLY (AGGREGATE) PER COUNTRY BEING PROVIDED BY DOMESTIC (D) COMPANIES VS IMPORTS (I). SOURCE (DATA): 4C OFFSHORE (2019)

		Country				
Complementary asset	**Domestic (D)/ import (I)**	**BE**	**DE**	**DK**	**NL**	**UK**
	D	0 %	50 %	3 %	0 %	49 %
Array cable manufacturing	I	100 %	50 %	97 %	100 %	51 %
	D	0 %	19 %	19 %	0 %	4 %
Export cable manufacturing	I	100 %	81 %	81 %	100 %	96 %
	D	24 %	15 %	48 %	23 %	33 %
Export cable installation	I	76 %	85 %	52 %	77 %	67 %
	D	3 %	49 %	75 %	67 %	6 %
Turbine foundation manufacturing	I	97 %	51 %	25 %	33 %	94 %
	D	69 %	22 %	17 %	72 %	15 %
Turbine foundation installation	I	31 %	78 %	83 %	28 %	85 %
	D	52 %	7 %	85 %	72 %	43 %
Turbine installation	I	48 %	93 %	15 %	28 %	57 %
	D	33 %	20 %	67 %	50 %	29 %
Substation manufacturing	I	67 %	80 %	33 %	50 %	71 %

Supply of complementary assets to home market by...	Import	>70%
	Mix import/domestic	
	Domestic	>70%

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