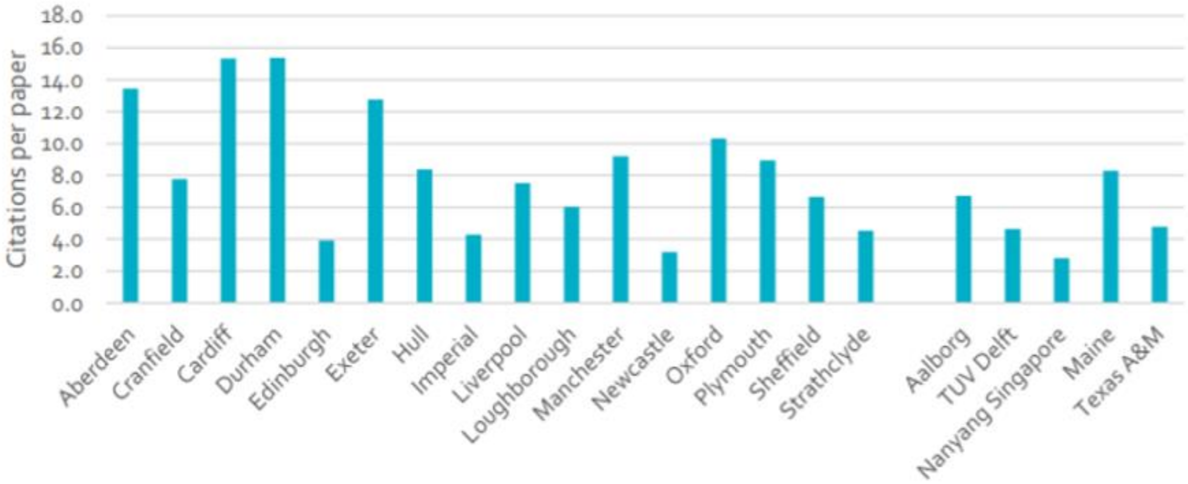
Impacts and implications of Offshore Wind Power research: A review of techno-economic, socio-technical, geotechnical and environmental applications of academic research



Joel Adam Gordon

December 2020

MESPOM, Erasmus Mundus

Contents

List of Figures

List of Tables

List of Abbreviations

AEP	Average energy production
ALE	Abnormal Level Earthquake
BACI	Before-after-control-impact
BAU	Business-as-usual
BEIS	Department for Business Energy and Industrial Strategy
BSR	Baltic Sea Region
CAGR	Compound Annual Growth Rate
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CEI	Cumulative Environmental Impact
CIA	Cumulative Impact Assessment
CWEA	Chinese Wind Energy Association.
DLT	Dieppe-Le Tre´port
EC	English Channel
EU	European Union
EEZ	Exclusive economic zone
ELE	Extreme Level Earthquake
ENR	Engineering News-Record
ESMs	Energy System Models
FLH	Full Load Hours
GIS	Geospatial Information Systems
GLAES	Geospatial Land Availability for Energy Systems
GW	Gigawatts
HEFCE	Higher Education Funding Council for England
HVAC	High-Voltage Alternating Current
HVDC	High-Voltage Direct Current
IEA	International Energy Agency
KE	Knowledge Exchange
KT	Knowledge Transfer
LCOE	Levelized Cost of Electricity
MRE	Marine Renewable Energy
MW	Megawatts
NREAPs	National Renewable Energy Action Plans

ORE	Offshore Renewable Energy
OWFs	Offshore Wind Farms
OWE	Offshore Wind Energy
OWTs	Offshore Wind Turbines
OWP	Offshore Wind Power
PCI	Projects of Common Interest
RE	Renewable Energy
RESs	Renewable Energy Sources
SEA	Strategic Environmental Assessment
SIA	Science and Innovation Audit
SSI	Soil Structure Interaction
TestGE	Techno-economic, socio-technical, Geotechnical, Environmental
TT	Technology Transfer
TWh/yr	Terawatt-hours per year

This research was carried out at the University of Manchester as part of the MESPOM Program, supported by the Erasmus Mundus Joint Master Degree (EMJMD) scholarship award.

Executive summary

The paper evaluates the impacts of Offshore Wind Power (OWP) research beyond academia, where metrics such as number of publications and citations per paper tend to dictate. University researchers have a public duty to align their research outputs towards the wider benefit of society and should be acutely aware of the social implications of their work. The study reviews the **T**echno-**e**conomic, **S**ocio-**t**echnical, **G**eotechnical and **E**nvironmental applications of university research in the area of OWE through the **TeStGE** framework, which in turn tests the waters for potential knowledge exchange (KE) and technology transfer (TT) between relevant stakeholders. The study has three underlying goals: (1) Identify the research activities of experts at leading universities; (2) assess the significance and implications of various research streams according to the TestGE method; and (3) explore pathways for facilitating knowledge exchange (KE) and technology transfer (TT) to stimulate and strengthen OWP investments, scalability and policymaking, with provisions for both society and the environment. At present, little attention is given to evaluating cumulative environmental impacts (CEIs), while ecosystems are rarely considered as integrated systems, leaving the offshore industry exposed to harming vulnerable marine habitats and species. There are few policymaking mechanisms available for securing a pathway towards a more integrated offshore grid, which is fundamental for delivering the full benefits of offshore wind, both in terms of cleaner and more affordable energy. The study finds that financing barriers also accompany governance challenges. As technological advancements in industrial production turbine design helps offshore wind farms (OWFs) to reach deeper ocean waters, geotechnical risk factors have only been partially understood. Technology transfer is needed to enable the application of multiple turbine designs to help secure a lower levelized cost of electricity (LCOE). Knowledge exchange (KE) is required to ensure that OWP is deployed in the right locations under the right conditions. can benefit from a wider diversity of research, beyond what is typically attended to within engineering departments. Broadening the scope of OWP-related research activities can in turn boost the reach of academic research beyond the industrial sector, engaging a wider range of stakeholders while influencing policymaking decisions, as well as environmental awareness.

1 Introduction

1.1. Bridging techno-economic, socio-technical, political and environmental factors

University research groups across Europe, the UK, North America, the Asian-Pacific, and other regions of the world are striving to understand the techno-economic, sociotechnical and political dimensions of offshore wind power (OWP); recognising that energy generation potential is a product of "technology choice, capacity density, and locally-specific capacity factors" (Bosch *et al.* 2018). Techno-economic analysis is concerned with "processes involved in energy production and consumption as coordinated by energy markets," linking to the ways in which OWP flows through its lifecycle; from planning and project financing through to construction, retirement and decommissioning (Cherp *et al.* 2018). Estimating offshore wind power potentials and economic capacity, both at the global and country-level, lies at the core of techno-economic studies. In contrast, socio-technical factors relate to "knowledge, practices and networks" associated with offshore wind power technologies, such as turbines and transmission lines. Confronting governance challenges is another key area that is fundamental to optimising the long-term deployment of OWP, since renewable energy (RE) deployment is encouraged through transparent political processes. Finally, environmental factors – ranging from seismic impacts to climate change and ecosystem protection – also lie at the crux of multidisciplinary research.

1.2. Research aim

The study is designed to consider recent research activities aligned to the **TeStGE** framework – **T**echno-**e**conomic, **s**ocio-**t**echnical, **G**eotechnical and **E**nvironmental – and the potential impact of each research stream beyond the domain of academia. Each area has key economic, environmental, scientific or technological implications and important applications for society. Universities evolve in line with their research outputs and may thrive depending on their "contribution to the advancement of knowledge and technology" within the national economic and social context (Chais *et al.* 2017). The scope of university research impacts highlights the value of the TestGE framework, which is applied to assess how knowledge exchange (KE) and technology transfer (TT) may be achieved to support the growth of the offshore wind power industry. The study also sets out to map recent research activities across some of the world's leading university departments with a special focus on activities in the UK, given its status as the world's leading offshore wind market.

1.3. Defining knowledge exchange and technology transfer

Knowledge exchange (KE) is a two-way process in which "social scientists and individuals or organisations" share ideas and experience; creating a flow of information exchange "between the research environment and the wider economy," which brings benefits to society (Weston 2019.). In contrast, technology transfer (TT) is typically a process that begins with "the disclosure of an invention followed by its patent registration, licensing, commercial use of the licensed technology, and, finally, royalties received by the university" (Chais *et al.* 2017). Through this process, scientific knowledge is transferred between institutions or organisations for advancement and subsequent commercialisation. TT usually takes place through the establishment of university 'spin-out' companies based on university intellectual property (IP) and licensing of this IP to other companies in the marketplace (McMillan, 2016). As such, KE covers a broader range of activities (e.g. publications and events, collaborative research and consultancy) than TT, which mainly relates to patents, licenses and spin-out companies.

1.4. Structure

The report begins with a brief description of the methods used in this analysis, before presenting background information on the characteristics of offshore wind power, as well as key global market trends. These sections serve to situate the study in its wider business context. A review of research activities across a sample of world-leading university departments is also presented to complement the discussion, highlighting both the global and UK context. Setions 5 to 9 present the **TestGE** framework, enabling an exploration of how KE and TT can be applied to various research areas. The conclusion reflects on current research trends, highlighting areas that are less represented due to the dominance of engineering departments as the main representatives of offshore wind power and its leading research contributors.

2 Methods

Information on OWE markets and installation/generation capacities has been sourced from some of the world's leading experts, such as the Global Wind Energy Council (GWEC), the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), MarketsandMarkets™ and WindEurope. The university departments reviewed in section 4 were chosen via findings from the SCOPUS database, with researchers selected according to their publications, patents and leadership activities across industrial research partnerships. Careful consideration was taken to also ensure a relatively balanced distribution of research interests across the main domains listed in Table 1: geotechnical, scientific, socio-technical, techno-economic and technological. The same principle was in turn applied when selecting papers from the preliminary literature review, which sampled fifteen recent publications. A total of eight papers were chosen to ensure satisfactory coverage of the **TestGE** framework; selected according to their interest level, as well as representation of different geographic regions within the study topic (The UK, France, Taiwan etc.), and finally a corresponding range of research departments from various countries. Each paper was sourced through leading journals such as *Elsevier*, *Sustainability* or *ICES Journal of Marine Science.* Finally, an evaluation of pathways for supporting KE and TT was conducted by assessing the latest activities in the UK context. This included reports to the UK higher education sector and HEFCE on university KE frameworks and good practice in TT, in addition to recommendations from Offshore Renewable Energy (ORE) Catapult, as well as other leading industrial partners and top-ranked universities.

3 Background

3.1. Characteristics of offshore wind power

Wind quality (speed and frequency) is superior at sea compared to land, as the smoother surface of sea results in stronger, less turbulent winds (Kaynia 2019). With large open spaces found offshore, wind speeds are steadier with slight increases yielding significant energy production gains. For example, a turbine operating in 15-mph wind speed can generate double the energy of the same turbine in conditions of 12-mph wind speed (AGI 2019). While onshore wind remains cheaper, it is hindered by spatial limitation and distance from urban areas; whereas offshore resources are plentiful and can be built in relative proximity to coastal cites (Kaynia 2019). These characteristics make offshore wind a significant RE resource for the future since it is more reliable than onshore wind and competes less with alternative land uses, whether urban and rural (Bosch *et al.* 2018). While offshore wind currently provides just a small fraction of the world's electricity supply, it is rapidly maturing from a technological perspective and anticipated to become a trillion-dollar business in the coming decades (IEA 2019).

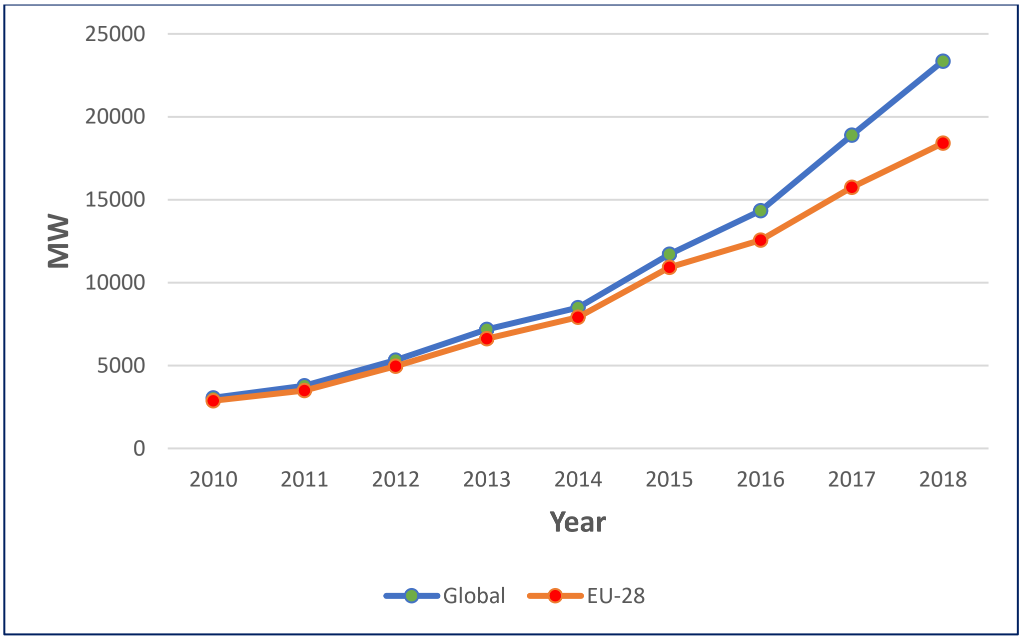
From an environmental and social perspective, there are fewer problems associated with visual impacts, noise pollution, shadow flicker and wildlife (e.g. birds and bats), resulting in less public opposition and greater levels of social acceptability (Bahaj *et al.* 2019; Bosch *et al.* 2018). While offshore wind farms (OWFs) may appear more environmentally acceptable than their onshore counterparts, limited efforts have been made to understand their environmental effects, which has prompted UK researchers to examine the cumulative environmental impact (CEI) of the world's largest OWFs. Meanwhile, "logistics, geology and public pushback" are forcing OWFs further away from coastlines into deeper waters (Powers *et al.* 2019).

3.2. Offshore wind power markets

Europe dominated the offshore wind sector for nearly two decades, accounting for virtually all deployment up until 2015 (see fig. 1). In the early 2010s, the UK and Denmark pioneered growth in the offshore market, while Germany became a significant market player after 2013 (see Appendix 1). In 2017, the UK and Germany together accounted for approximately three-quarters of European offshore wind capacity, 42% and 34% respectively (IRENA database 2019). In the same year, the European Union (EU) accounted for 86% of total installed global OWP capacity with most projects located in the North Sea, while the Baltic Sea Region (BSR) also offers suitable sites for OWFs (WindEurope 2017; Côté *et al.* 2018).

The UK offshore wind power market is regarded as an unprecedented success story (Whitmarsh *et al*. 2019), which Chinese energy policymakers have strived to emulate (Meng and Xu 2016). Germany has also performed well to offset its diminishing onshore market through offshore growth (Schulz 2019). In their comparison of the UK and China, Meng and Xu (2016) note that public participation and stakeholder integration is much stronger in the UK, while Chinese OWE application processes lack effective communication channels and make limited provisions for environmental impacts. Despite these setbacks, China has scaled up its deployment of offshore wind in the last few years and now competes directly with the UK and Germany, following the recent launched of its first 10MW offshore turbine (Yu 2019).

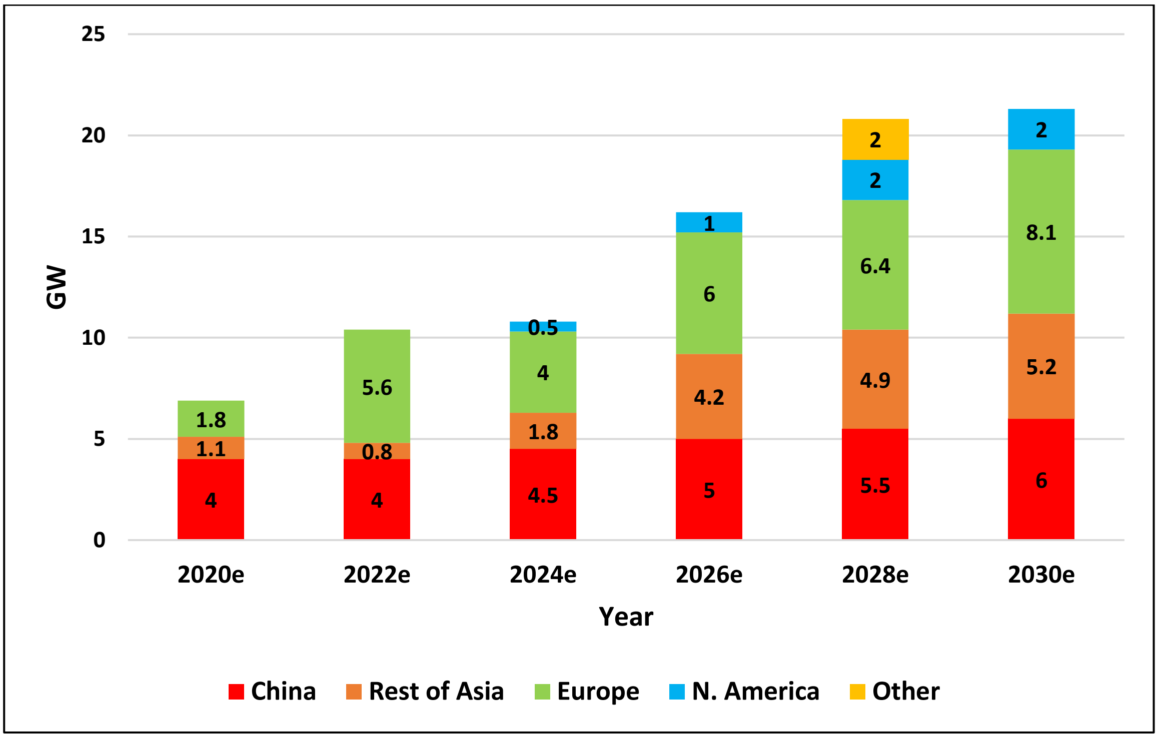
Figure 1: Global vs EU-28 Offshore wind power capacity, 2010-2018



Source: IRENA database 2019

Although growing exponentially, today's wind market is leaps and bounds away from tapping into the full potential of offshore resources, which are conservatively estimated to offer generation capacity of over 400,00 TWh/per year in the future; close to twenty times current global electricity demand (IEA 2019). The Asian Pacific region is predicted to grow to the second position in the offshore wind power market behind Europe (see fig. 2), as electricity demand levels continue to grow alongside increased urbanisation and industrialisation (MarketsandMarkets™ 2017a). Opportunities for deploying offshore wind power in the region exist in emerging markets such as China, Japan, South Korea and Taiwan, which are seeking energy alternatives to curb their CO_2 emissions (MarketsandMarkets™ 2017a). As marine renewable technologies advance and clean energy consumption becomes more pressing, offshore wind is likely to grow in the Asian Pacific, particularly in countries where governments have set strict regulations on energy efficiency.

Figure 2: Global offshore wind growth to 2030, BAU scenario



Source: Global Wind Energy Council 2019

Business as usual: Chinese installation adjusted to 1.6 GW to account for new installations in 2018 (CWEA);[1] *excluding potential of technological and market developments that could increase new capacity*

Overall, the offshore wind market is set to double in size over the next few years, as demand for new capacity additions grows (see Appendix 2). This trend will lead to a boom in the turbine

---

[1] Chinese Wind Energy Association.

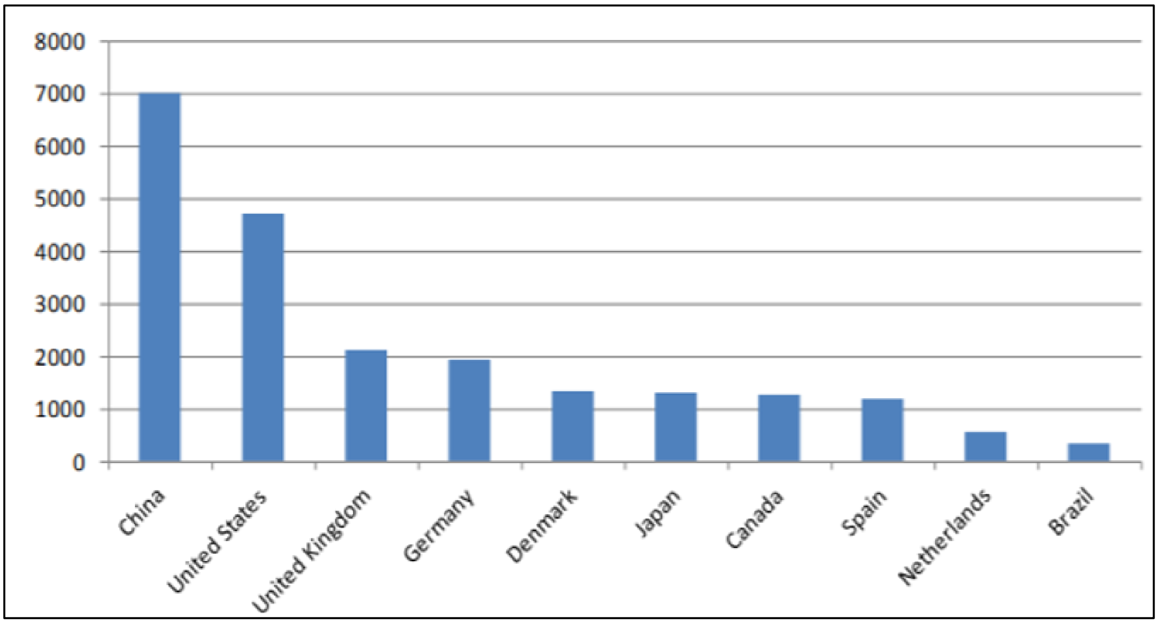
segment to help ensure the supply of key components for OWF electricity generation (nacelle, tower, rotor and blades etc.) (MarketsandMarkets™ 2017b). The global offshore support vessel market is predicted to reach a size of $25.6 billion by 2023, growing at a rate of CAGR 5.0% up to 2023, and the submarine cable system market is anticipated to reach $20.9 billion by 2023, almost doubling since 2018 with a CAGR of 12.2% (MarketsandMarkets™ 2017b). Growth in this sector is driven mainly by Europe, as the offshore grid becomes more integrated through more inter-country and island connections (MarketsandMarkets™ 2017b).

4 Academic research engagements in Offshore wind power

4.1. The global outlook

China has emerged as one of the main competitors in the offshore wind industry and from a research output perspective it has eclipsed both the United States and Europe over the course of the last decade (see fig. 3). Although China has come to dominate scientific publications, its deployment of offshore wind power has lagged the UK and Europe. However, since the mid-2010s it has steadily gained ground on its competitors. This confirms the correlation between research outputs and offshore wind power market share; however, as research quality as well as quantity must also be taken into consideration.

Figure 3. Scientific publications on wind energy, 2006-2013



Source: SCOPUS database; Gandenberger *et al.* 2015

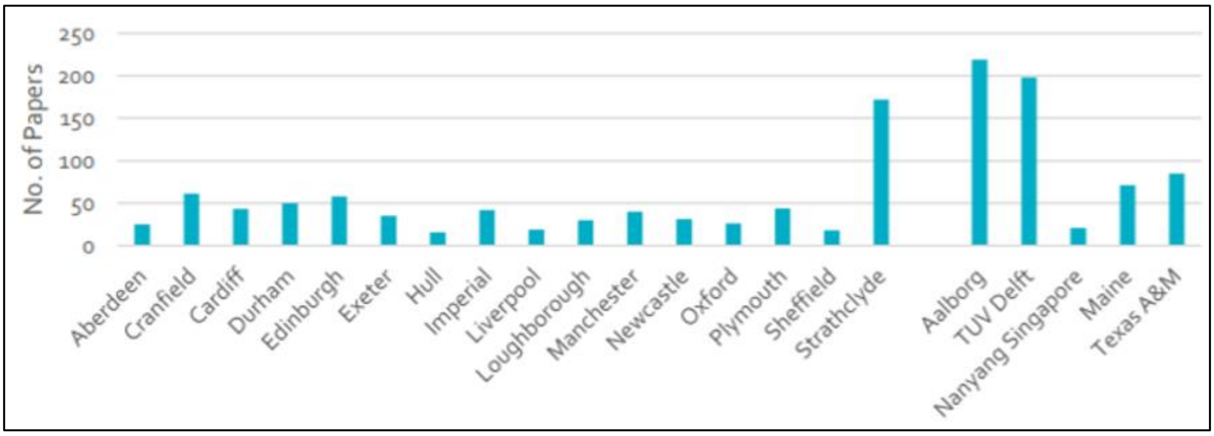
4.2. The UK context

In 2017, the UK Government's Department for Business Energy and Industrial Strategy (BEIS) carried out a science and innovation audit (SIA) on ORE. The audit covered 16 of the UK's leading universities, compiling "a detailed analysis of the quantity and quality" (see fig. 4) of

UK research on offshore wind, alongside a selection of five top international competitors (BEIS 2017). The University of Strathclyde, Glasgow,[1] leads the UK rankings by a significant margin for volume of publications with approximately 175 papers on offshore wind power since 2010, competing closely with Scandinavian (Danish) and European (Dutch) leaders. Its research is carried out by the Electronic & Electrical Engineering Department and the Institute for Energy & Environment, which is “an international leader in wind energy and the control of wind turbines and wind farms” (University of Strathclyde 2019). The Institute works in close collaboration with industrial partners through several “Industry Engagement Research Centres,” as a key partner in government and Eu funded multidisciplinary research (University of Strathclyde 2019).

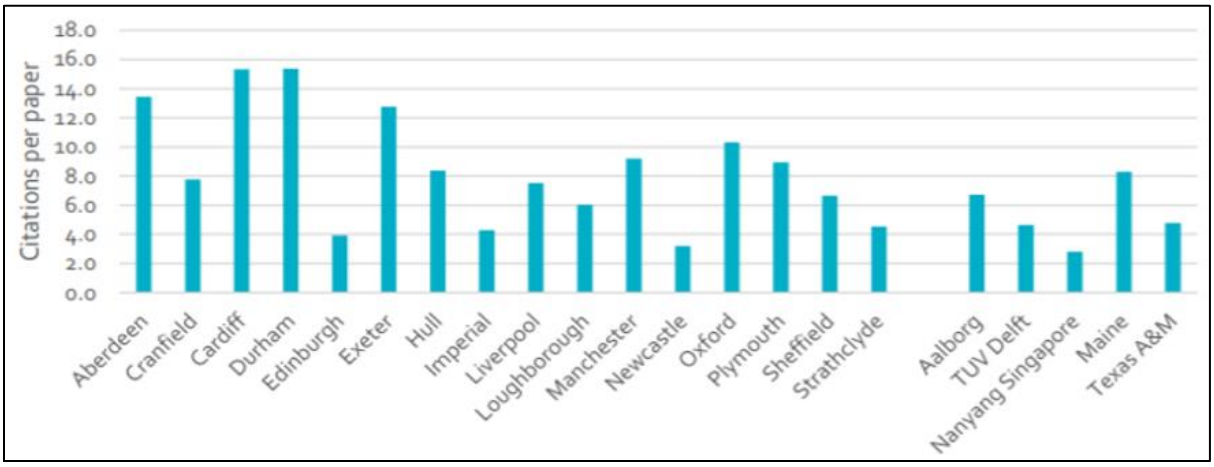
The University of Edinburgh, Cranfield University, Durham University, Imperial College London and the University of Plymouth are also well-represented in the UK context, each with approximately 50 publications each 2010. In terms of citations per paper, however, the results are quite different as the University of Strathclyde trails behind most of its UK competitors (see fig. 5). Durham University and Cardiff University are the UK’s leaders, closely followed the University of Aberdeen and the University of Exeter, as well as the Oxford, Manchester and Plymouth respectively. It is noteworthy that UK universities generally compete well with international rivals in terms of citations per paper.

Figure 4. Total publications on Offshore Wind across leading UK and international Universities since 2010



Source: SCOPUS database; BEIS 2017

Figure 5. Citations per paper on Offshore wind power across leading UK and international Universities since 2010



Source: SCOPUS database; BEIS 2017

4.3. A review of world-leading research activities

In view of the findings of the BEIS' SIA, Appendix 3 presents research activities from across half of the UK sample, summarising the details of work carried out by respective experts at eight of the UK's leading universities: Durham University (see Appendix 3.1.), the University of Exeter (see Appendix 3.2.), the University of Hull (see Appendix 3.3.), the University of Liverpool (see Appendix 3.4.), the University of Manchester (see Appendix 3.5.),[2] the University of Oxford (see Appendix 3.7.), the University of Plymouth (see Appendix 3.8.) and the University of Sheffield (see Appendix 3.9.). Two international universities are also represented within the sample for comparison (see Appendix 3.6. and Appendix 3.10.). Additionally, Cranfield University, Imperial College London and TUV Delft are represented in the subsequent analysis of offshore wind research impacts.

Table 1. Offshore wind research activities at leading universities

University	Research Department	Research category	Research interests
Durham	School of Engineering and Computing Sciences	*Techno-economic*	Reliability, availability and cost of offshore wind power
Exeter	College for Engineering, Mathematics & Physical Sciences	*Technological; scientific*	Simulation of Floating Offshore Wind Turbines
Hull	Department of Engineering	*Technological; scientific*	Sensing and measurement in offshore renewable energy systems
Liverpool	School of Environmental Sciences	*Techno-economic; socio-technical*	Governance and technical arrangements for cross-border planning and collaboration

---

[2] Two examples of lead researchers at the University of Manchester are provided according to Williamson Associates' close relationship with UoM.

Manchester	Department of Electrical & Electronic Engineering	*Technological; scientific*	Transmission technologies; electrical systems for extreme environments
Northeastern	Civil and Environmental Engineering	*Geotechnical; technological; techno-economic*	Structural modelling, risk assessments and testing for offshore wind turbines
Oxford	Department of Engineering Science	*Geotechnical; technological*	Soil-structure interaction testing and new design methods for offshore wind turbines
Plymouth	School and Engineering; School of Computing, Electronics and Mathematics	*Technological*	Physical and numerical modelling of wave-structured interaction
Sheffield	Department of Electrical & Electronic Engineering	*Technological*	Direct-drive permanent magnet wind power generators
Tufts	Department of Civil and Environmental Engineering	*Techno-economic; geotechnical; technological*	Structural systems design and performance of offshore wind turbines

Source: Author's compilation

5 Geospatial, temporal and techno-economic dimensions of OWFs

5.1. Global techno-economic potential of offshore wind power

Researchers at Imperial College's Grantham Institute for Climate Change and the Environment[2] have set out to quantify the available and exploitable OWE potential across 157 countries. This undertaking relies upon a Geospatial Information Systems (GIS) approach to estimate global offshore energy potential of wind farms (TWh/yr).[3] Such estimates lie at the heart of robust energy planning, since wind power resources are highly seasonal with unique temporal (i.e. intermittency) and spatial (i.e. geographical) characteristics (Tarroja *et al.* 2011). Bosch *et al.* (2018) find that the total offshore wind capacity potential is 85.6 TW (excluding Antarctica), and the total global offshore wind power resource is 329,600 TWh/yr for capacity factors above 20% when suitable areas for development are considered (see Appendix 4).[4] As turbine size increases and other technological developments accelerate, new OWFs reach capacity factors of 50%; placing OWP far ahead of onshore wind and solar PV and in closer competition with conventional energy sources, "as the only variable baseload power generation technology" available (IEA 2019).

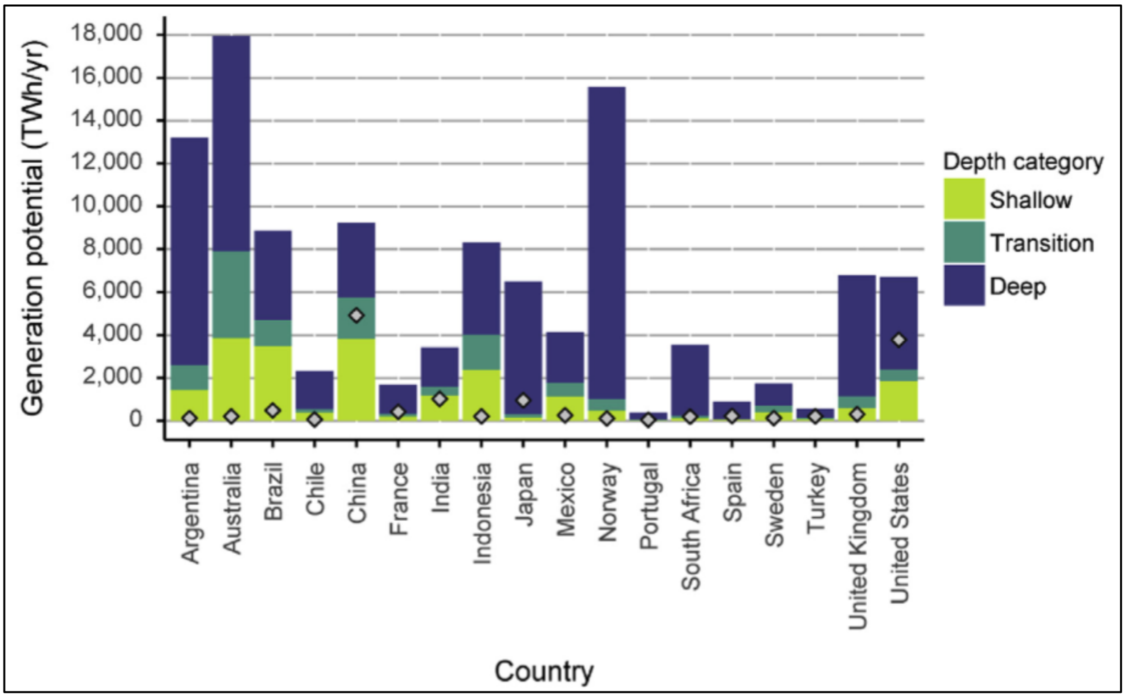
---

[3] High resolution global wind speed data sets are used to determine economically viable offshore wind energy potential, on a global and per-country basis (Bosch *et al.* 2018).

[4] The average suitable area as a percentage of the exclusive economic zone (EEZ) for each country was 37% (Bosch *et al.* 2018).

There is a vast global OWP resource potential to be exploited in deep waters (see fig. 6). According to a recent report from Engineering News-Record (ENR), as much as 80% of Europe's offshore wind resource (approx. 4,000 GW) lies in waters deeper than 60 m (Powers *et al.* 2019). Furthermore, the study indicates a common disparity between national energy predictions and global predictions, revealing a tendency for country level strategy to be based on poor estimates and incomplete information (Bosch *et al.* 2018). Countries generally tend to over-estimate their generation potentials compared to global studies (Bosch *et al.* 2018).

Figure 6. Annual average energy production of offshore wind farms



Source: Bosch *et al.* 2018

Annual average energy production (AEP) potential of offshore wind farms for different depth categories for a selection of high producing countries. Depth categories are Shallow (0-40 m), Transitional (40-60 m), and Deep (60-1000m). The overlaid point on each bar is electricity generation in 2015 according to the IEA.

Research carried out at Imperial College, London, highlights that a finer spatial and temporal resolution can provide appropriate mechanisms for optimal site selection and better long-term planning. Effective modelling process and computational techniques are pivotal for long-term energy forecasting and optimal planning decisions; however, spatial and temporal characteristics make it challenging to reliably model the capacity potential of wind energy technologies. Offshore wind power potential should be made more temporally explicit to enable researchers and policymakers to assess offshore deployment potential under time-variant factors.[5] For effective planning towards cleaner energy system, it is vital that energy system models (ESMs) can realistically characterise the technical and economic potential of OWE (Bosch *et al.* 2018). Knowledge exchange (KE) in this area is crucial to bringing offshore wind power to the correct markets under the right conditions.

5.2. Sociotechnical components of multiple future turbine designs

Further studies into the techno-economic potential of OWP have been carried out by researchers at Germany's Institute of Energy and Climate Research, in collaboration with Aachen University.[3] Caglayan *et al.* (2019) set out to apply a high spatial resolution analysis to three of the key sociotechnical aspects relevant to OWE potential: "ocean suitability,[6] the simulation of wind turbines, and cost estimation." As indicated by Bosch *et al.* (2018) and Dedecca *et al.* (2019), higher temporal and spatial resolution is required to identify prime locations compatible with the trend towards more integrated electrical gird expansion planning (Caglayan *et al.* 2019; Syranidis *et al.* 2018). Additionally, different turbine designs should be taken into consideration to efficiently capture the potential of regional energy profiles (Caglayan *et al.* 2019).

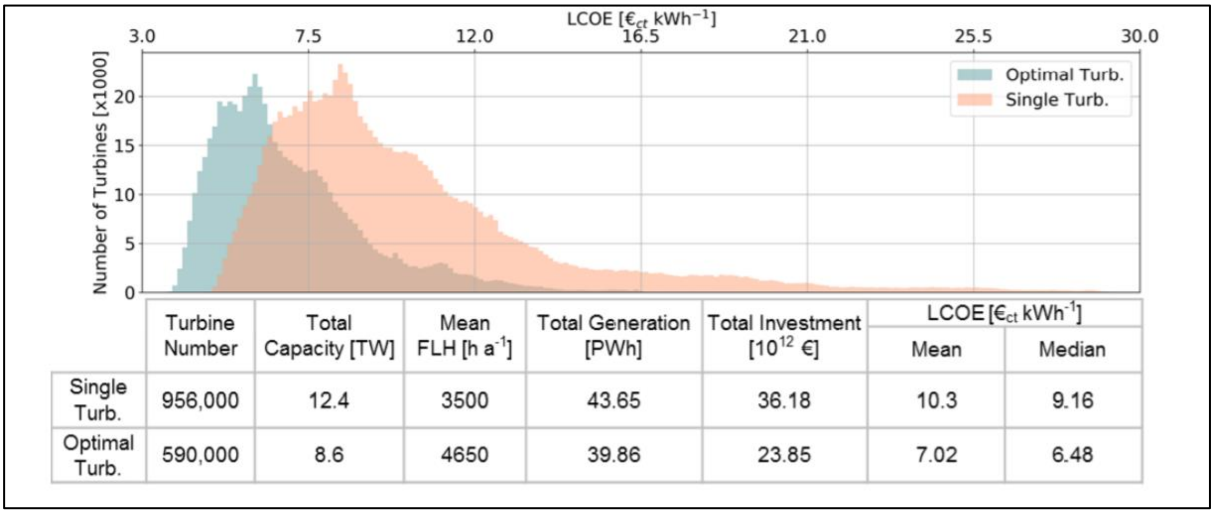
Caglayan *et al.* (2019) perform a long-term analysis of OWP potential, accounting for multiple future turbine designs within the context of European maritime boundaries up to 2050. The study confirms using a single turbine design in a large region such as Europe has a significant impact on the capacity factor, making it economically unviable to install the same turbine on a regional scale (Caglayan *et al.* 2019). For example, turbines with "smaller specific power" should be utilised in regions with relatively low wind speeds (Caglayan *et al.* 2019). Moreover, choosing a "location-specific turbine design" typically improves efficiency and performance (see fig. 7) by reducing the levelized cost of electricity (LCOE), while increasing Full Load Hours (FLH) (Caglayan *et al.* 2019). This research area is key for enhancing core aspects of OWP analysis such as capacity estimations. The study supports optimised decision-making processes for RE integration specific to offshore wind farm location and turbine design, while also identifying parameters that can be adjusted under different socio-political frameworks where constraints such as ocean eligibility may vary (Caglayan *et al.* 2019).

---

[5] For example, input variables relevant to energy potential estimates should be integrated into multidimensional sensitivity analyses for stricter verification and better projections (Bosch *et al.* 2018).

[6] Ocean eligibility analysis is performed using the open-source model, Geospatial Land Availability for Energy Systems (GLAES). When ocean eligibility analysis is applied uniformly on European maritime boundaries with a set of constraints, the study reveals suitability for 31.5% of the areas within the region of interest (Caglayan *et al.* 2019).

Figure 7. Comparison of single turbine and cost-optimal turbine design analyses



	Turbine Number	Total Capacity [TW]	Mean FLH [h a^{-1}]	Total Generation [PWh]	Total Investment [10^{12} €]	LCOE [$€_{ct}$ kWh^{-1}]	
						Mean	Median
Single Turb.	956,000	12.4	3500	43.65	36.18	10.3	9.16
Optimal Turb.	590,000	8.6	4650	39.86	23.85	7.02	6.48

Source: Caglayan *et al.* 2019

Offshore wind power performs comparably to other RES including onshore wind, since 38% of locations within the study have an LCOE under 6 $€_{ct}$ kWh^{-1} (Caglayan et al. 2019).

6 Geotechnical aspects of offshore wind power

Research conducted at the Norwegian Geotechnical Institute[4] through the "REDWIN" project[7] investigates the state of practice in seismic design of Offshore Wind Turbines (OWTs), which is increasingly relevant to site developments in East Asia (e.g. Taiwan) and the Western United States. Reviewing technical aspects of OWT design is critically important since wind turbines are vulnerable to the effects of seismic activity.[8] Although seismic activity is a significant risk factor to offshore activities, especially in earthquake-prone locations such as Japan, their impacts on structural components of OWTs remain poorly understood. The REDWIN project investigates earthquake response in the horizontal direction and response of OWTs in the vertical direction using numerical analyses (linear and nonlinear solution algorithms) of seismic soil structure interaction (SSI) of wind turbines (Kaynia 2019). When conditions are suboptimal such as regions with medium to high seismicity, or soft to medium soil conditions (soil nonlinearity), the result could be settlement and permanent tilting of OWTs, whether on caisson foundations or tripods. The result is a loss of functionality. Current design guidelines are therefore insufficient, since existing codes fail to specify any earthquake return period or measurement of radiation damping (Kaynia 2019). Furthermore, existing computational tools

---

[7] "Reducing cost of offshore wind by integrated structural and geotechnical design."

[8] Specifically, vertical earthquake excitation due to high natural frequencies in the vertical direction (Kaynia 2019).

fail to achieve reliable prediction of permanent tilt of OWTs due to earthquake loading (Kaynia 2019).

Extreme Level Earthquake (ELE) or Abnormal Level Earthquake (ALE) activity[5] could lead to blackouts and large-scale infrastructure and environmental damage, therefore geotechnical research is crucial to minimising long-term, as well as unpredictable short-term risks. With the expansion of the offshore wind market outside of Europe, it will become increasingly important to perform rigorous modelling of radiation damping, so its role in reduction of vertical seismic response of wind turbines can be better understood for optimal project planning. Radiation damping could prove significant to reducing earthquake loads and securing a more economical design driven by performance-based considerations (Kaynia 2019).[9]

7 Governance challenges of the offshore wind power grid

7.1. Transmission technologies for offshore expansion and integration

Dedecca *et al.* investigate developments in "offshore transmission and wind power generation" in the context of the North Sea, highlighting the obstacles for achieving an integrated offshore regional grid (2018). The offshore grid is classified as "a multilevel, multi-actor system" that requires "a governance decision-making approach," yet it currently operates without any "proven governance framework," which also rings true for the European power system in general (Dedecca *et al.,* 2018). This is one of the principle research gaps and current limitations to the expansion of OWP, making it one of the focal points of this report. Research into governance structures for offshore wind relates to assessing generation and transmission technologies (HVAC, point-to-point HVDC, and multiterminal HVDC),[10] as well as welfare distribution, making grid integration both a technical and social project.

At present, governance is the main barrier to developing integrated transmission lines, while the "relative cost and performance" of various transmission technologies is also a key determinant of European grid integration (Dedecca *et al.* 2017). Expansion planning models should account for these aspects by considering technology choices, benefits (economic, ecological and operational), risk factors, in addition to "intertemporal" determinants of "path dependence and lock-in" (Dedecca *et al.* 2018). As well-documented in the case of fossil fuels,

---

[9] Hysteretic damping should also be taken into consideration.

[10] High-Voltage Alternating Current (HVAC) and High-Voltage Direct Current (HVDC). Dedecca *et al.* explain that while "HVAC and HVDC point-to-point cables are connected to AC nodes, HVDC multiterminal cables are connected to DC nodes with AC/DC converters between AC and DC nodes" (2018).

path dependence and lock-in are key factors to the deepening climate crisis, which can likewise prevent the optimal long-term deployment of renewable energy sources (RESs) (Kemp-Benedict, 2014; Aghion *et al.* 2019). Irrespective of integrated governance limitations, Europe has substantial “intra-country transmission capacity investments,” especially across Denmark, Germany, Great Britain and the Netherlands (Dedecca *et al.* 2018). Governance is often an overlooked area of RE deployment yet remains fundamental for delivering the vast benefits of the offshore gird to society, including cleaner energy and cheaper long-term costs. The study has demonstrated the pathway Europe should take strides towards a governance framework that can ensure the expansion and integration of the offshore grid.

Figure 8. 2030 initial system, with initial offshore wind farms and their point-to-point connectors

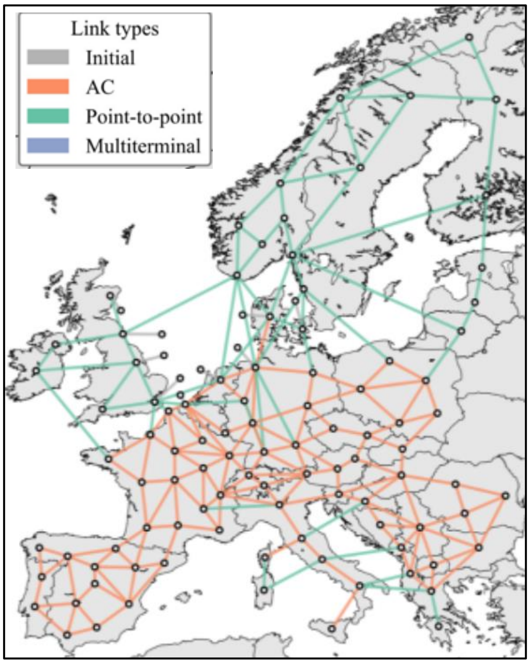
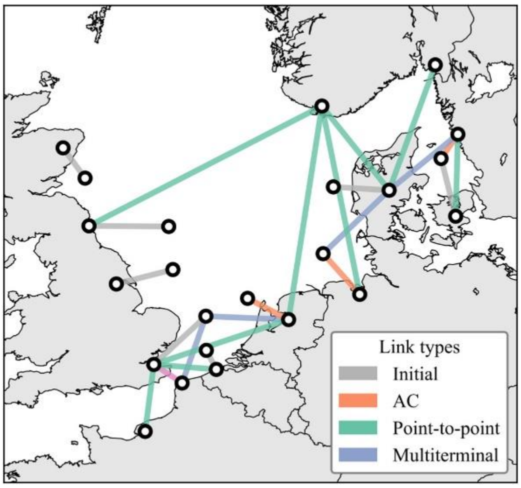


Figure 9. Unconstrained Large-scale RES scenario grid in 2030



Source: Dedecca et al. 2018

The clustered European grid model of e-Highway2050 has 103 onshore and 11 offshore nodes, using HVAC and point-to-point HVDC transmission lines.

7.2. Socio-economic and climate benefits of offshore grid governance

Governance challenges related to European energy have been at the forefront of energy policy research for the past decade and offshore wind power is becoming part of the debate. The implications of an integrated offshore grid are multifaceted, with far reaching effects on climate change targets, as well as socio-economic outcomes. As such, investments into the offshore energy sector should consider social and environmental objectives, in addition to techno-economic efficiency (Dedecca *et al.* 2019). Researchers at Delft's University of Technology[6] have carried forward this area of research by examining governance challenges linked to the integrated expansion of the European offshore grid. The study addresses this area in view of the impacts of the Clean Energy Package and in respect to activities in the North Sea. While the onshore gird is already relatively well-established with limited opportunities for integrated projects; the offshore grid is considered a 'blank slate' with vast potential for integration (Dedecca *et al.* 2019).

At present, projects linked to the offshore grid governance expansion framework exhibit significant inertia, with revision of the Energy Union governance delayed until 2026. Nevertheless, the trend towards increased cross-border project activities in Europe reveals the potential for regional governance and cooperation to mature over the long-term, moving the offshore sector towards pan-European governance (Dedecca *et al.* 2019). However, post-Brexit UK and Norway are two of the key countries pivotal for accelerating the integration of offshore projects and their participation in European organisations is irregular, lagged and subject to uncertainty (Dedecca *et al.,* 2019). A transition to pan-European governance offers significant techno-economic, social and climate benefits, but can only be made viable if streamlined decision-making processes are secured alongside technological maturity and industrial growth.

Transmission technologies and innovation are fundamental to the realisation of an integrated offshore European grid (Dedecca *et al.* 2018). At the same time, integrated offshore networks must retain enough governance and operational flexibility to adapt to respective regional characteristic for grid optimisation (Dedecca *et al.* 2019). While some European countries may stand to gain significantly more than others, countries that do not participate directly in the offshore grid will also be notably affected. For these reasons, understanding prospects and possibilities for regional governance pathways is increasingly important for delivering RE to society and can help consolidate European Projects of Common Interest (PCIs).[11]

8. Integrated assessment principles for OWF project financing

8.1. Addressing information asymmetries in the offshore wind sector

At Taiwan's Institute of Natural Resources Management, National Taipei University, Tseng *et al.* have undertaken a comprehensive review of offshore wind power in terms of project financing, providing "an integrated assessment that employs Equator Principles, life cycle

---

[11] "PCIs are cross border infrastructure projects that link the energy systems of EU Member States" (European Commission 2019).

assessment, risk assessment, materiality analysis, credit assessment, and ISAE 3000 assurance" (2017). The study applies the Equator Principles (EPs)[12] to wind farm project financing, which account for a range of factors: "environmental and social standards, grievance mechanisms, independent review, covenants, independent monitoring, reporting, and transparency" (Tseng *et al.* 2017). This research area is important for minimising "information asymmetry,"[13] as well as the transaction costs of OWF financing, adding weight to the effort to "mobilise green finance investments" in favour of national renewable energy policies (Tseng *et al.* 2017). Results can improve stakeholder decision making, from the policymaking arena to the investment and development side of OWFs.

Tseng *et al.* build an integrated assessment framework (see fig. 10) to strengthen coherence across Taiwan's emerging offshore wind power sector, which is currently lacking investment confidence and economic incentives (2017). The framework moves beyond the "5P" principles – People, Purpose, Payment, Protection and Protection – which are typically evaluated by financial institutions to decide the credit line of a loan (Kao and Sung, 2017). An integrated assessment framework stands to reduce the time of project development, while improving communication between stakeholders and lowering transaction costs (Tseng *et al.* 2017). Such benefits are highly desirable in the global context and required to boost investment confidence and funding mechanisms.

An integrated assessment framework has been shown to increase stakeholder engagement, providing local practitioners with knowledge of risks and better access to incorporating environmental and social management into decision-making processes. Creating interactions of this nature, which are compatible with the "multi-stakeholder principles" of Environmental Impact Assessment (EIA), brings together otherwise disparate groups such as investors, engineers, trade unions and fishermen (Hartley and Wood 2005). The Taiwanese case sheds light on the problem of information asymmetry when it comes to OWF project financing. Eliminating information asymmetry is crucial to creating synergies between stakeholders, encouraging the involvement of all relevant stakeholders at the planning stage and during the construction process of OWFs. When information becomes more transparent with costs and

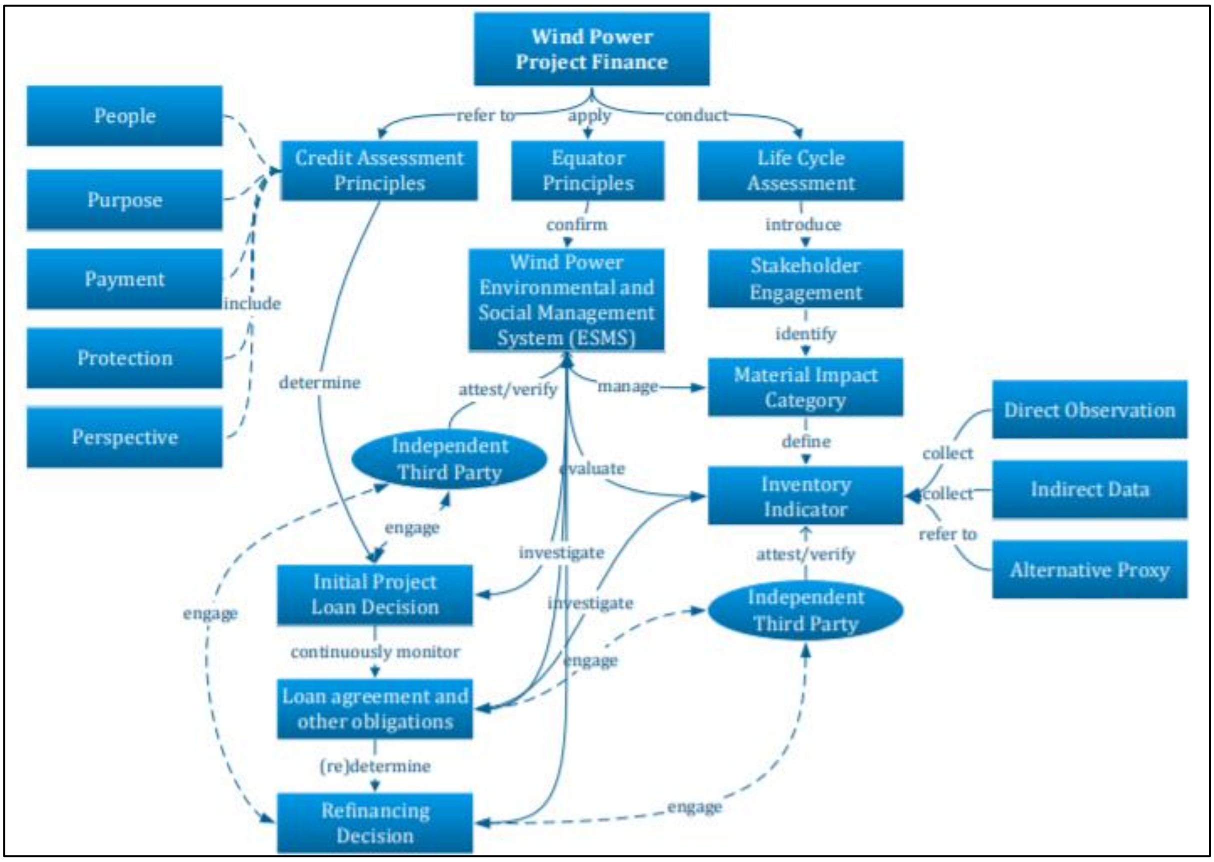
---

[12] "The Equator Principles (EPs) is a risk management framework, adopted by financial institutions, for determining, assessing and managing environmental and social risk in projects and is primarily intended to provide a minimum standard for due diligence and monitoring to support responsible risk decision-making" (Equator Principles 2019).

[13] "A condition wherein one party in a relationship has more or better information than another" (Bergh *et al.* 2019).

benefits better understood, financing of OWP can take place in a less risk-adverse environment. Consolidating effective financing mechanisms in sync with robust governance frameworks forms a major part of the recipe for driving OWP deployment towards targets put forth in National Renewable Energy Action Plans (NREAPs).

Figure 10. Integrated Assessment for OWF Project Financing



Source: Tseng *et al.* 2017

9. Environmental compliance and protection of marine habitats

9.1. Cumulative Environmental Impacts of OWFs in the UK

Researchers at Cranfield University’s School of Water, Energy and Environment have reviewed the Environmental Statements of the world’s largest OWFs[14] to critically examine the current state of Cumulative Impact Assessment (CIA) practise in the UK. The purpose of their research[7] is to assess the strengths and weaknesses of CIA practise, as recent studies have indicated the threat of OWFs to ecosystem processes. Willsteed *et al.* apply a novel evaluation framework to evaluate the quality of risk assessments across a range of attributes; ranking respective CIA components and assessing environmental performance in relation to regulatory and

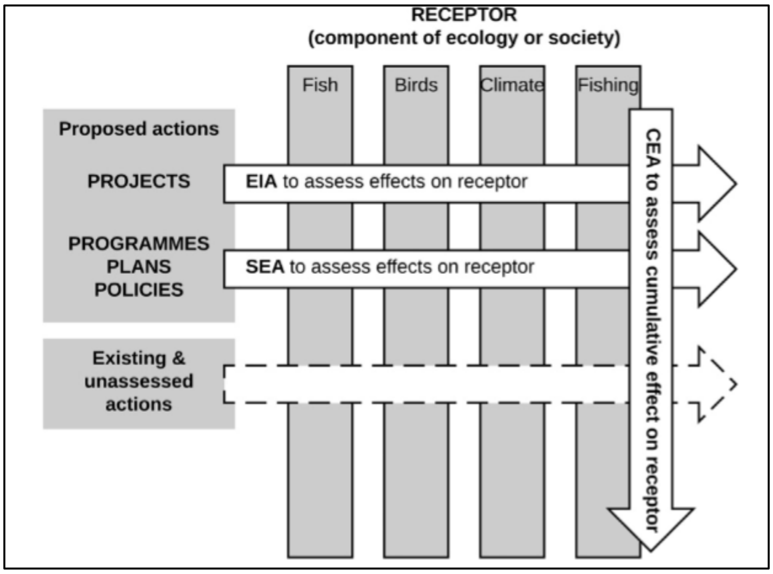
---

[14] Covering nine sites located in UK waters, which were accessed via the National Infrastructure Planning portal.

management needs for safeguarding ecosystems (2018). This area of research is important for the sector, since delays in regulatory and consenting procedures constitute a significant barrier to upscaling offshore wind power infrastructure (Willsteed *et al.* 2018).

The study finds Environmental Statements for OWFs to be subject to high variability with limited attention paid to interactions between environmental receptors, alongside inadequate assessment of current and future ecosystem pathways (Willsteed *et al.* 2018). Current CIA practise fails to secure transparency about the potential cumulative effects of OWFs, leading to delays during consenting and regulatory processes. This shortfall represents a clear gap between science and practise, adding to regulatory costs. Regulation is a financial and administrative burden to both developers and investors, which prevents the deployment of renewable energy. Such costs can be reduced through improved CIA practise including better scoping methods, tailored to provide more in-depth validation of sensitive receptors (see fig. 11) (Willsteed *et al.* 2018). The advantage of adapting more stringent CIA measures includes better ecological decision-making, cost benefits for the industry through streamlined monitoring over time, and improved decision-making capacity for faster consenting and licensing processes (Willsteed *et al.* 2018).

Figure 11. Relationship between EIA and SEA, and the theoretical role of Cumulative Effects Assessment of OWFs



Source: Willsteed *et al*, 2018

The dashed arrow indicates actions that are not subject to assessment, but which contribute to incremental change in receptor condition

A CIA-based analysis emerges as a valuable tool for both improving efficiency in planning mechanisms and securing enhanced protection for ecosystem processes. It is apparent that CIA practise, as exemplified in the UK context, requires significant refinement if decision-makers are to be provided with meaningful analyses of the cumulative effects of proposed OWF developments. If KE is successful in this area, regulatory burden can be reduced while also supporting improved regional maritime management, which is particularly valuable for countries in which offshore wind power is developing in tandem with an ecosystem-approach and marine spatial planning objectives (Willsteed *et al.,* 2018). In conclusion, CIA-based research emanating from Cranfield University's Centre for Environment, Fisheries and Aquaculture Science (Cefas) informs regulators and managers of the scale and significance of potential cumulative effects from OWF operations. This knowledge transfer (KT) helps facilitate the possibility of streamlined OWF deployment that evaluates environmental impacts.

9.2. An Integrated ecosystem approach for OWF management in France

On the other side of the English Channel (EC), French researchers have adopted an ecosystem approach to study the impact of the planned Dieppe-Le Tre´port (DLT) wind farm site, which forms part of the French government's plan to construct approximately 2900 MW of OWFs in the next decade (Pezy *et al.* 2018). As highlighted in the UK context, environmental impacts assessments (EIAs) for OWFs typically overlook ecological sensitivities by failing to account for complex ecosystem dynamics (Raoux *et al.* 2018). To better understand "biological compartments" ahead of construction at DLT OWF, Pezy *et al.* establish a sampling framework based on a "Before-after-control-impact" (BACI) design;[15] implementing a "holistic approach" to analyse impacts from OWF construction and operation (2018). The French case study[8] aims to reduce ecological information gaps for improved OWF environmental monitoring programmes.

At present, there are limited attempts and no agreed techniques for implementing a trophic network analysis of the marine environment to adequately interpret "ecosystem structure and functioning" (Pezy *et al.* 2018). Despite being a "core ecosystem component," the benthic community is typically neglected when it comes to considering environmental interactions with marine renewable energy (MRE) technology (Wilding *et al.,* 2017). Appropriate sampling strategies and data collecting should be promoted to improve environmental management,

---

[15] BACI designs are "an effective method to evaluate natural and human-induced perturbations on ecological variables when treatment sites cannot be randomly chosen" (Conner *et al.* 2016).

prioritising the protection of not only fish and mammal populations, but also the benthic community. Using trophic web modelling tools to develop an "integrated ecosystem approach," Pezy *et al.* demonstrate the relationship between demersal fish and the benthic community, through the results of fish stomach content studies (2018). This approach should be continued during the operational phases of OWFs, as such knowledge brings benefits to the management of the marine environment including fishing policies and quotas (European Commission, 2018). A quantitative modelling approach that accounts for OWF impacts across entire ecosystems is a useful tool for integrating ecological factors into maritime planning and management. The frameworks established by Pezy *et al.* (2018), as well as Willsteed *et al.* (2018) should be replicated and applied across other OWF regions for improved environmental management. This research area may also allow for a better understanding of the long-term impacts of OWFs on maritime areas and species in the context of climate change (Pezy *et al.* 2018).

10 Pathways to support knowledge exchange and technology transfer

In the area of knowledge exchange (KE) it is important to boost the "research exploitation process" by developing corporate relations, consultancy work and marketing avenues to create research exposure (Weston 2019). Having the right infrastructure in place to support the KE process includes cultivating human capital development by stimulating synergies and cross-departmental collaboration between research groups and respective departments, be they engineering, environmental or policy-based. Research conducted at Catapult Offshore Renewable Energy (ORE) has also flagged the importance of facilitating cross-sector innovation, whereby, the offshore wind industry harness knowledge practices and technology from the oil and gas, as well as the aerospace and defence industry (Louden 2019). This notion of cross-pollination applies equally within offshore wind power research fields, whereby, geotechnicians and engineers should be in conversation with social scientists and environmentalists to maximise knowledge gains, as well as innovation (Louden 2019). Understanding the innovation landscape is essential for realising effective industrial partnerships and the commercialisation of new technologies.

An entrepreneurial attitude should be internalised by university researchers, especially when dealing with potential OWP technologies. Entrepreneurship is one of the key drivers of technology transfer (TT) and a key ingredient to forming university 'spin-out' companies. Spin-out companies can be envisioned for research groups engaged with transmission and turbine technologies, as well as other structural and mechanical components of OWFs. For spin-out companies to be competitive, academics should have been immersed in an entrepreneurial culture capable of incentivising their intellectual focus towards an appreciation of market potential and socio-economic impact (Etzkowitz and Leydesdorff 2000). Schrankler has identified five key positions that university departments can consider for boosting the scope of their TT: A technology strategy manager is tasked with encouraging and supporting researchers towards the early stages of commercialisation, offering business mentoring and strategic advice; an intellectual property (IP) manager is responsible for providing legal and regulatory support in the areas of patents, trademarks, copyright and other IP; a technology marketing manager “develops a marketing plan and materials” for bringing products to the market, while identifying market niches; an office marketing manager is responsible for advertising emerging technologies and ensuring products attain an online presence relative to industrial circles; and a venture development manager is qualified to assemble an adequate team for carrying forward a spin-out company (2018). While not all these positions may be feasible for universities to consider due to costs, an amalgamation of management strategies are valuable to securing TT.

11 Conclusion

The study identified offshore wind-related research activities of experts at leading universities; assesses the significance and implications of various research streams according to the **TestGE** method; and explored pathways for facilitating knowledge exchange (KE) and technology transfer (TT), with a view towards stimulating and strengthening OWP investments, scalability and policymaking, with provisions for both society and the environment. The study finds that the OWP sector faces governance and financing challenges requiring further research attention and increased knowledge exchange if they are to be adequately addressed. As offshore wind ventures into deeper waters, geotechnical risk factors need to be better understood and careful attention should also be paid to the sustainability of materials, as turbine size increases and transmission technologies become more ambitious. Technology transfer is needed to ensure that the advantages of deploying multiple turbine designs can be captured and a lower levelized cost of electricity (LCOE) secured for the near future. Both KE and TT are pivotal and work together for driving the deployment of OWP in the right geographic regions with knowledge of temporal and spatial parameters. The report concludes that KE and TT can benefit from a wider diversity of research beyond the engineering community. Broadening the scope of research activities in the area if OWP can in turn boost the reach of academic research beyond the industrial sector, engaging a wider range of stakeholders while influencing policymaking decisions and building environmental awareness.

Reference List

Aghion, P., Hepburn, C., Teytelboym, A. and Zenghelis, D. (2019). Path dependence, innovation and the economics of climate change. In *Handbook on Green Growth*. Edward Elgar Publishing.

American Geosciences Institute (AGI). 2019. *What are the advantages and disadvantages of offshore wind farms?* [Online]. Available at: https://www.americangeosciences.org/critical-issues/faq/what-are-advantages-and-disadvantages-offshore-wind-farms (Accessed 3 December 2019).

Bergh, D.D., Ketchen Jr, D.J., Orlandi, I., Heugens, P.P. and Boyd, B.K., 2019. Information asymmetry in management research: Past accomplishments and future opportunities. *Journal of Management*, *45*(1), pp.122-158.

Bosch, J., Staffell, I. and Hawkes, A.D. (2018). Temporally explicit and spatially resolved global offshore wind power potentials. *Energy*, *163*, pp.766-781.

Chais, C., Ganzer, P.P. and Olea, P.M. (2017). Technology transfer between universities and companies: two cases of Brazilian universities. *RAI Revista de Administração e Inovação*, pp.1-13.

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E. and Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. *Energy Research & Social Science*, *37*, pp.175-190.

Conner, M.M., Saunders, W.C., Bouwes, N. and Jordan, C. (2016). Evaluating impacts using a BACI design, ratios, and a Bayesian approach with a focus on restoration. *Environmental monitoring and assessment*, *188*(10), p.555.

Côté, E.; Holton, M.; Ponder, A. N.; Sandén, J.; and Wallasch, A. (2018). *Market Analysis of the Offshore wind power Transmission Industry: Overview for the Baltic Sea Region October 2018.* Baltic InteGrid. Available at: http://www.baltic-integrid.eu/ (Accessed 3 December 2019).

Dedecca, J.G., Hakvoort, R.A. and Herder, P.M. (2017). Transmission expansion simulation for the European Northern Seas offshore grid. *Energy*, *125*, pp.805-824.

Dedecca, J.G., Lumbreras, S., Ramos, A., Hakvoort, R.A. and Herder, P.M. (2018). Expansion planning of the North Sea offshore grid: Simulation of integrated governance constraints. *Energy Economics*, *72*, pp.376-392.

Dedecca, J.G., Hakvoort, R.A. and Herder, P.M. (2019). The integrated offshore grid in Europe: Exploring challenges for regional energy governance. *Energy Research & Social Science*, *52*, pp.55-67.

Department for Business Energy and Industrial Strategy (BEIS). (2017). *Offshore Renewable Energy Science and Innovation Audit.* [Online]. Available at: https://www.ncl.ac.uk/media/wwwnclacuk/business/files/sia-report-offshore-energy.pdf (Accessed 10 November 2019).

El Mountassir, O. (2015). HVDC transmission cables in the offshore wind industry: reliability and condition monitoring. *Catapult Offshore Renewable Energy (ORE).*

Equator Principles. 2019. *The Equator Principles.* [Online]. Available at: https://equator-principles.com/about/ (Accessed 16 January 2020).

Equator Principles. (2019). The Equator Principles July 2020: A financial industry benchmark for determining, assessing and managing environmental and social risk in projects. [Online]. Available at: https://equator-principles.com/wp-content/uploads/2019/11/The-Equator-Principles-November-2019.pdf (Accessed 16 January 2020).

Etzkowitz, H. and Leydesdorff, L., 2000. The dynamics of innovation: from National Systems and “Mode 2” to a Triple Helix of university–industry–government relations. *Research policy*, *29* (2), pp.109-123.

European Commission. (2018). EU budget: Commission proposes a new fund to invest in the maritime economy and support fishing communities. [Online]. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_18_4104 (Accessed 14 January 2020).

European Commission. (2019). *New energy Projects of Common Interest for the Energy Union built of European solidarity*. [Online]. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_19_6203 (Accessed 14 January 2020).

Gandenberger, C., Unger, D., Strauch, M. and Bodenheimer, M. (2015). *The international transfer of wind power technology to Brazil and China* (No. S7/2015). Working Paper Sustainability and Innovation.

Global Wind Energy Council (GWEC). (2019). *Market Intelligence Offshore Wind Outlook 2030.* [Online]. Available at: https://gwec.net/global-offshore-wind-report-sector-has-potential-to-grow-to-200gw-of-capacity-by-2030/ (Accessed 15 January 2020).

Hartley, N. and Wood, C. (2005). Public participation in environmental impact assessment—implementing the Aarhus Convention. *Environmental impact assessment review*, *25*(4), pp.319-340.

International Energy Agency (IEA). (2017). *World Energy Balances 2017*. OECD Publishing, Paris. Available at: https://www.oecd-ilibrary.org/energy/world-energy-balances-2017_world_energy_bal-2017-en (Accessed 16 January 2020).

International Energy Agency (IEA). (2019). *Offshore Wind Outlook 2019: World Energy Outlook Special Report*. [Online]. Available at: https://www.iea.org/reports/offshore-wind-outlook-2019#abstract (Accessed 28 November 2019).

International Renewable Energy Agency (IRENA). (2019). Wind Energy Data. [Online]. Available at: https://www.irena.org/wind (Accessed 22 November 2019).

Kao, J.C. and Sung, W.P. (2017). Civil, Architecture and Environmental Engineering Volume 1: Proceedings of the International Conference ICCAE, Taipei, Taiwan, November 4-6, 2016. CRC Press.

Kaynia, A.M. (2019). Seismic considerations in design of offshore wind turbines. Soil Dynamics and Earthquake Engineering, 124, pp.399-407. Elsevier.

Kemp-Benedict, E. (2014). Shifting to a Green Economy: Lock-in, Path Dependence, and Policy Options. Stockholm Environment Institute (SEI) Working Paper No. 2014-08.

Louden, A. (2019). *Driving Cross-Sector Innovation in Offshore Wind Strategies, synergies and barriers*. Catapult Offshore Renewable Energy.

MarketsandMarkets™. (2017a). Offshore Wind Market worth $55,109.6 million by 2022. [Online]. Available at: https://www.marketsandmarkets.com/PressReleases/offshore-wind.asp (Accessed 22 November 2019).

MarketsandMarkets™. (2017b). Offshore Wind Market by Component (Turbine, Substructure, Electrical Infrastructure, & Others), Location (Shallow Water, Transitional Water, & Deep Water), and Region (North America, Europe, & Asia-Pacific) – Global Trends & Forecasts to 2022. [Online]. Available at: https://www.marketsandmarkets.com/Market-Reports/offshore-wind-market-253452593.html (Accessed 13 January 2019).

McMillan, T. (2016). *University Knowledge Exchange (KE) Framework: good practice in technology transfer*. [Online]. Available at: https://www.praxisauril.org.uk/resource/university-knowledge-exchange-ke-framework-good-practice-technology-transfer-mcmillan-2016 (Accessed 15 January 2019).

Meng, X. and Xu, W. (2016). Research on the Comparison of Offshore Wind Power Management between China and UK. In *2016 International Conference on Civil, Transportation and Environment*. Atlantis Press.

Powers, M. B., Reina, P., and Rubin, D. K. (2019). *There's a Global Gust in the Offshore Wind Energy Market.* [Online]. Available at: https://www.enr.com/articles/47244-theres-a-global-gust-in-the-offshore-wind-energy-market (Accessed 3 December 2019).

Pezy, J.P., Raoux, A. and Dauvin, J.C. (2018). An ecosystem approach for studying the impact of offshore wind farms: a French case study. *ICES Journal of Marine Science*.

Raoux, A., Dambacher, J.M., Pezy, J.P., Mazé, C., Dauvin, J.C. and Niquil, N. (2018). Assessing cumulative socio-ecological impacts of offshore wind farm development in the Bay of Seine (English Channel). *Marine Policy*, *89*, pp.11-20.

SCOPUS. 2019. Scopus database. Available at: https://www.scopus.com/freelookup/form/author.uri

Schrankler, J., 2018. The Role of University Technology Transfer. In *Medical Innovation* (pp. 31-41). Academic Press.

Schulz, F. (2019). *Germany seeks to jolt its stalled wind industry with new offshore plan.* [Online]. Available at: https://www.euractiv.com/section/energy/news/germanys-wind-industry-in-bad-health/ (Accessed 14 January 2019).

Syranidis, K., Robinius, M. and Stolten, D. (2018). Control techniques and the modeling of electrical power flow across transmission networks. *Renewable and Sustainable Energy Reviews*, *82*, pp.3452-3467.

Tarroja, B., Mueller, F., Eichman, J.D., Brouwer, J. and Samuelsen, S. (2011). Spatial and temporal analysis of electric wind generation intermittency and dynamics. *Renewable Energy*, *36*(12), pp.3424-3432.

Tseng, Y.C., Lee, Y.M. and Liao, S.J. (2017). An integrated assessment framework of offshore wind power projects applying equator principles and social life cycle assessment. *Sustainability*, *9*(10), p.1822.

University of Cambridge. (2009). *What is knowledge transfer?* [Online]. Available at: https://www.cam.ac.uk/research/news/what-is-knowledge-transfer (Accessed 15 January 2019).

University of Strathclyde. (n.d.). *Electronic and electrical engineering: Wind Energy and Control.* [Online]. Available at: https://www.strath.ac.uk/research/subjects/electronicelectricalengineering/instituteforenergyenvironment/windenergycontrol/ (Accessed 3 December, 2019).

Weston, M. 2019. *The role of Knowledge Exchange in Innovation Mike Weston Knowledge Exchange Manager*. Available at https://www.ukri.org/ (Accessed 15 January 2019).

Whitmarsh, M., Canning, C., Ellson, T., Sinclair, I. V., Thorogood, M. (2019). *The UK Offshore Wind Industry: Supply Chain Review January 2019*. [Online]. Available at: https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/publications/supply_chain_review_31.01.20.pdf (Accessed 2 December 2019).

Wilding, T.A., Gill, A.B., Boon, A., Sheehan, E., Dauvin, J.C., Pezy, J.P., O'beirn, F., Janas, U., Rostin, L. and De Mesel, I. (2017). Turning off the DRIP ('Data-rich, information-poor')–rationalising monitoring with a focus on marine renewable energy developments and the benthos. *Renewable and Sustainable Energy Reviews*, *74*, pp.848-859.

Willsteed, E.A., Jude, S., Gill, A.B. and Birchenough, S.N. (2018). Obligations and aspirations: a critical evaluation of offshore wind farm cumulative impact assessments. *Renewable and Sustainable Energy Reviews*, *82*, pp.2332-2345.

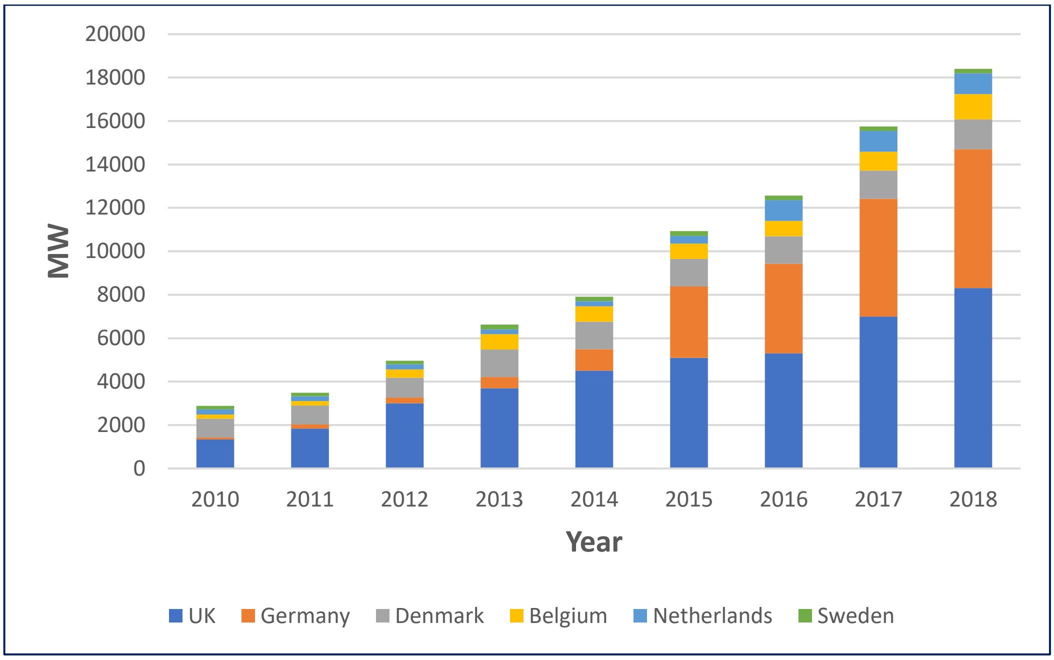
WindEurope. (2017). Local impact, global leadership: The impact of wind energy on jobs and the EU economy. [Online]. Available at: https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Local-impact-global-leadership.pdf (Accessed 2 December 2019).

Yu, Y. (2019). *China unwraps first 10MW wind turbine on landmark day.* [Online]. Available at: https://www.rechargenews.com/wind/china-unwraps-first-10mw-wind-turbine-on-landmark-day/2-1-677799 (Accessed 15 January 2020).

Appendices

Appendix 1: Trends in European offshore wind power capacity

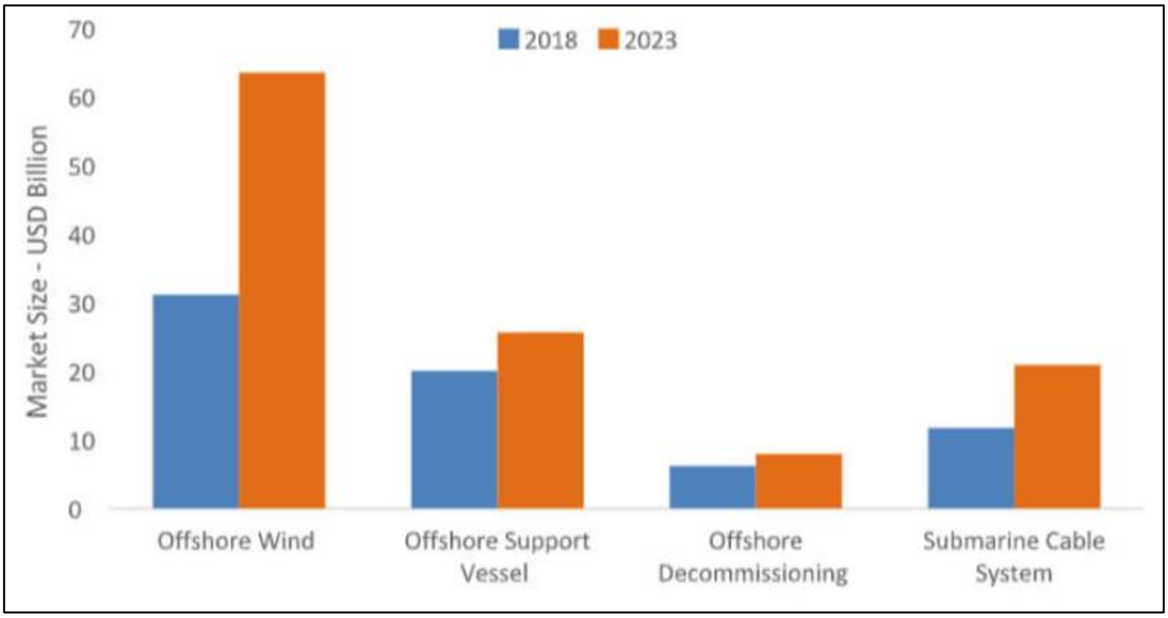
Cumulative installed capacity: Offshore wind in top 6 EU countries, 2010-2018



Source: IRENA database 2019

Appendix 2: Developments in the offshore market and associated segments

Offshore Global Market Opportunities Assessed, 2018-2023



Source: MarketsandMarkets™ 2017b

The offshore wind market is projected to reach $55.11 billion by 2022, at a compound annual growth rate (CAGR) of 15.32% from 2017 to 2022

Appendix 3: Leading Research institutions and professors

Appendix 3.1. Durham University, School of Engineering and Computing Sciences

Researcher	Professor Pete Tavner.[9]
Research Groups	Future Energy Systems (Department of Engineering);[10] (Durham Energy Institute);[11] European Academy of Wind Energy (eawe);[12] SuperGen Marine Energy Research Consortium;[13] Wind Technologies (Cambridge University pain-out company)[14]
Research projects and funding pathways	Professor Tavner's research interests align to improving the reliability, availability and cost of offshore wind power: electrical machine design, performance and condition monitoring, in addition to cost-effective connection to the electricity grid. His work is funded by Supergen Wind;[15] Sino-British Future Renewable Energy Network Systems (FRENS) Consortium;[16] the EU FP7 ReliaWind Consortium;[17] and FKI Energy Technology.[18]
Professional Body Memberships	Fellow of the Institution of Engineering Technology.

Appendix 3.2. University of Exeter, College for Engineering, Mathematics & Physical Sciences

Researcher	Professor Richard Cochrane.[19]
Research Groups	Centre for Energy and Environment, University of Exeter.
Research projects and funding pathways	Prof. Cochrane is highly active in research activities linked to the simulation of Floating Offshore Wind Turbines (aeroelastic modelling, hydrodynamics, mooring analysis). His work is funded by InnovateUK,[20] as well as EON.
Professional Body Memberships	Chartered Engineer; Fellow of the Energy Institute. Prof. Cochrane also holds the following patents: Wind turbine regenerative drive system; Vertical Axis Wind Turbine with LED display; Impovements in or relating to wind turbines; Vertical Axis Wind Turbine.[21]

Appendix 3.3. University of Hull, Department of Engineering

Researcher	Professor James Gilbert.[22]
Research Groups	Electrical and Electronic Engineering (UoH).
Research projects and funding pathways	Prof. Gilbert currently leads major projects focusing on sensing and measurement in offshore renewable energy systems. He is UoH’s project lead on the EPSRC Prosperity Partnership for offshore wind,[23] as well as EPSCR’s Supergen ORE Hub.[24] His research is also funded by the Natural Environment Research Council (NERC),[25] Siemens Gamesa Renewable Energy, Ørsted, and Offshore Renewable Energy (ORE) Catapult.
Professional Body Memberships	*Not readily available.*

Appendix 3.4. University of Liverpool, School of Environmental Sciences

Researcher	Dr. Stephen Jay.[26]
Research Groups	Co-founder of the Marine Spatial Planning Research Network;[27] Maritime Spatial Planning (MSP) Directive; Marine Planning Stakeholder Reference Group (Welsh Government); ESPON (European Spatial Planning Observation Network).[28]
Research projects and funding pathways	Dr. Jay participates in key projects funded by the European Commission and the Directorate-General for Maritime Affairs and Fisheries (DG MARE),[29] addressing ““governance and technical arrangements for cross-border collaboration in planning shared sea areas” (University of Liverpool, n.d.): Transboundary Planning in the European Atlantic (TPEA); PartiSEApate project for the Baltic region’[30] SIMCelt (Supporting Implementation of Maritime Spatial Planning in the Celtic Seas);[31] North Sea Star;[32] and the European Maritime Spatial Planning Platform (MSP).[33]
Professional Body Memberships	Royal Town Planning Institute, Chartered Member since 2008.

Appendix 3.5. University of Manchester, Department of Electrical & Electronic Engineering

Researcher	Professor Mike Barnes.[34]
Research Groups	Power Conversion Group (UoM); Institute of Electrical and Electronic Engineers (IEEE) Transactions of Energy Conversion; Holistic Operation and Maintenance for Energy from Offshore Wind Farms (HOME).[35]
Research projects and funding pathways	Prof. Barnes contributes to research in the following areas: High Voltage DC Transmission, Offshore wind power and Flexible AC Transmission Systems. His work is funded by the IEEE Power and Energy Society, and the UK Engineering and Physical Sciences Research Council (EPSRC)[36] in remit of the HOME research project.
Professional Body Memberships	Senior Member of the Institute of Electrical and Electronics Engineers (SMIEEE); Fellow of the Institution of Engineering and Technology (FIET).
Researcher	Professor Alexander C. Smith.[37]
Research Groups	Power Conversion Group (UoM); Rolls-Royce University Technology Centre (Director); IEE Professional Group PG1 (Electrical Machines); The institution of Engineering and Technology (IET); Independent Design Review Group, BAE Systems Marine Ltd.[38]
Research projects and funding pathways	Prof. Smith contributes to research in the following areas: electrical systems for extreme environments; design and analysis of electrical motors, generators, drivers and actuators. His work is funded by the Rolls-Royce University Technology Centre and the Institute of Electrical and Electronic Engineers (IEEE).
Professional Body Memberships	Senior Member of the Institute of Electrical and Electronics Engineers (SMIEEE); Fellow of the Institution of Engineering and Technology (FIET).

Appendix 3.6. Northeastern University, Civil and Environmental Engineering

Researcher	Professor Andrew T. Myers.[39]
Research Groups	Sustainable Structures Group;[40] Earthquake Engineering Research Institute; Partnership for Offshore wind power Research (POWER-US).[41]
Research projects and funding pathways	Prof. Myers works on multi-scale experimental testing of offshore wind turbines including risk assessments for turbines during storm activity and probabilistic modelling of structural and natural systems, through the POWER-US project. His work is funded by the Massachusetts Clean Energy Center.
Professional Body Memberships	American Institute of Steel Construction; American Society of Civil Engineers (Registered Professional Engineer in the State of California).

Appendix 3.7. University of Oxford, Department of Engineering Science

Researcher	Professor Byron Byrne.[42]
Research Groups	Civil Engineering Research (University of Oxford); Renewable Energy Marine Structures (REMS).[43]
Research projects and funding pathways	Prof. Byrne contributes to research in the field of offshore engineering problems, focusing on experimental and theoretical solutions to soil-structure interaction problems and new design methods for offshore wind turbines: Foundations for offshore structures; general loading of shallow foundations; offshore pipeline design. His work is funded by the EPSRC Centre for Doctoral Training (CDT); The Australian Research Council; The Department of Trade and Industry;[44] DONG Energy and other industrial partners (Alstom, EDF, RWE, SSE, Scottish Power, Statkraft, Equinor, Vattenfall, Van Ord and the Caron Trust); Technip UK Ltd.; SAFEBUCK;[45] Ward and Burke;[46] and most recently Ørsted and the Royal Academy of Engineering (5-year research project).[47]
Professional Body Memberships	Prof. Byrne's memberships are not readily available; however, his research journal affiliations include Applied Ocean Research[48] and *Géotechnique (editor and long-term contributor respectively).*

Appendix 3.8. University of Plymouth, School and Engineering; School of Computing, Electronics and Mathematics

Researcher	Professor Deborah Greaves.[49]
Research Groups	COAST Engineering Research Group;[50] Centre for Coastal and Ocean Science and Engineering (CCOSE);[51] Centre for Advanced Engineering Systems and Interactions (CAESI);[52] Partnership for Research in Marine Renewable Energy.[53]
Research projects and funding pathways	Prof. Greaves research lies at the cutting-edge of marine and offshore renewable energy, including physical and numerical modelling of wave-structured interaction. She is director of the Supergen ORE Hub funded by EPSRC and she has received research funding from GWR, EU Interreg, IEE, H20202, SWDRA, InnovateUK, in addition to other industrial and academic partners.[54]
Professional Body Memberships	Chartered Engineer; Member of the Royal Institution of Naval Architects (RINA); Fellow of the Institution of Civil Engineers; Fellow of the Women's Engineering Society (FWES).

Appendix 3.9. The University of Sheffield, Department of Electronic and Electrical Engineering

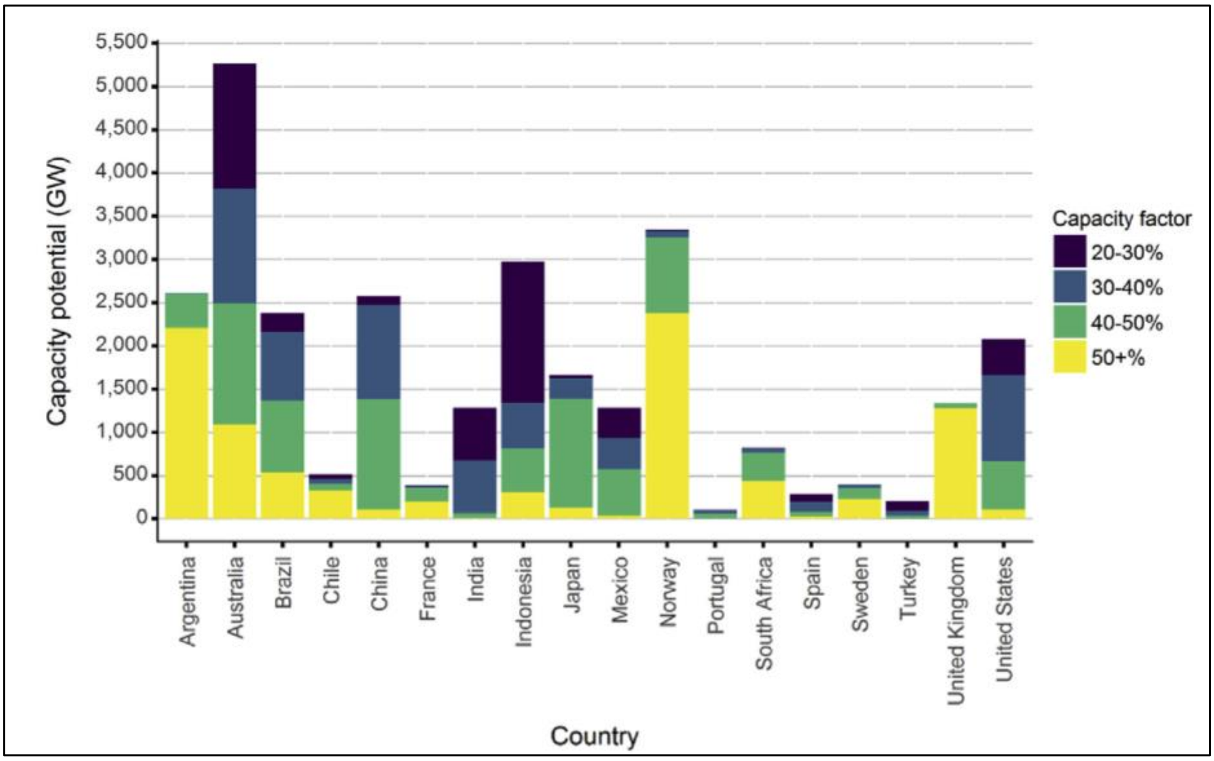
Researcher	Professor Zi-Qiang Zhu.[55]
Research Groups	Electrical Machine and Drivers Group; Sheffield-Siemens Wind Power Research Centre (S^{2}WP);[56] Sheffield Siemens Gamesa Renewable Energy Research Centre; Future Electrical Machines Manufacturing Hub;[57] Offshore Renewable Energy (ORE) Catapult Power Train Research Hub;[58] Sheffield CRRC Electric Drives Technology Research Centre
Research projects and funding pathways	Prof. Zhu's research into wind energy including direct-drive permanent magnet wind power generators is funded by Siemens Gamesa; ORE Catapult; UK/EU government (e.g. EPSRC)[59] and global industries bases in the UK, Germany, Japan, Denmark, France and China (e.g. CRRC Corporation Limited).
Professional Body Memberships	Fellow of the Royal Academy of Engineering; Fellow of IEEE, USA; Fellow of IET, UK; Chartered Engineer.

Appendix 3.10. Tufts School of Engineering, Department of Civil and Environmental Engineering

Researcher	Professor Eric Hines.[60]
Research Groups	Tufts University Offshore wind power Engineering Group; Partnership for Offshore wind power Research (POWER-US).
Research projects and funding pathways	Prof. Hine's research interests include construction, structural systems design and performance (i.e. life-cycle assessment and fatigue performance) of offshore wind turbines. His work is funded by the Massachusetts Clean Energy Center (MassCEC).[61]
Professional Body Memberships	American Society of Civil Engineers, Structural Engineering Institute; American Institute of Steel Construction; American Concrete Institute; Earthquake Engineering Research Institute.

Appendix 4: Offshore wind capacity potential

Capacity potential for a range of high potential countries with respect to average annual capacity factor



Source: Bosch *et al.* 2018

For offshore wind, as opposed to onshore wind, capacity factors over 50% are common, and several countries have significant potentials above 30% (Bosch *et al.* 2018).

End Notes

---

[1] https://www.strath.ac.uk/research/subjects/electronicelectricalengineering/instituteforenergyenvironment/windenergycontrol/

[2] The research was funded by EPSRC under the funding reference EP/N005996/1 and NERC under the funding reference NE/N018656/1

[3] This work was supported by the Helmholtz Association under the Joint Initiative "EnergySystem 2050: A Contribution of the Research Field Energy".

[4] Funded by the Norwegian Research Council, Grant number 234984.

[5] An ELE event is used to demonstrate sufficient component strength without damage, while an ALE event is used to demonstrate sufficient system capacity with possible component damage (Kaynia, 2019).

[6] The research was carried out by the Universidad Pontificia Comillas, Spain; the Royal Institute of Technology, Sweden; and The Delft University of Technology, The Netherlands, with funding from the Erasmus Mundus Joint Doctorate Fellowship in Sustainable Energy Technologies and Strategies (SETS).

[7] The research was funded through a NERC Industrial CASE Studentship (NE/L009668/1) with support from Cefas Divisional Funding. SRJ was part funded through the EPSRC/ESRC International Centre for Infrastructure Futures (ICIF) grant (EP/K012347/1). SNRB and EAW were supported by the Department for Environment, Food and Rural Affairs through the MINERVA project (ME5213).

[8] The study forms part of the doctoral research work of J.P. Pezy, funded by the ANRT (Eoliennes en mer Dieppe-Le Tre´port and the French State).

[9] https://www.dur.ac.uk/research/directory/staff/?mode=staff&id=1400

[10] https://www.dur.ac.uk/research/directory/view/?mode=centre&id=787

[11] https://www.dur.ac.uk/dei/research/windresearch/

[12] https://www.eawe.eu/

[13] https://www.supergen-marine.org.uk/supergen-phase-2

[14] http://www.bitadesign.co.uk/wind/cor_manage.htm

[15] https://www.supergen-wind.org.uk/

[16] https://shop.theiet.org/offshore-wind-turbines

[17] https://www.up2europe.eu/european/projects/reliability-focused-research-on-optimizing-wind-energy-systems-design-operation-and-maintenance-tools-proof-of-concepts-guidelines-methodologies-for-a-new-generation_1797.html

---

[18] http://www.adr-international.com/fki-energy-technology

[19] http://emps.exeter.ac.uk/renewable-energy/staff/rcc210

[20] https://www.gov.uk/government/organisations/innovate-uk

[21] https://emps.exeter.ac.uk/renewable-energy/staff/rcc210/publications

[22] https://www.hull.ac.uk/faculties/staff-profiles/james-m-gilbert

[23] https://hull-repository.worktribe.com/project/196285/prosperity-partnerships-epsrc-business-and-universities

[24] https://www.scitecheuropa.eu/1-million-research-funding-for-offshore-renewable-energy/96378/

[25] https://nerc.ukri.org/

[26] https://www.liverpool.ac.uk/environmental-sciences/staff/stephen-jay/external-engagement/

[27] https://www.msprn.net/home

[28] https://www.espon.eu/2020

[29] https://ec.europa.eu/knowledge4policy/organisation/dg-mare-dg-maritime-affairs-fisheries_en

[30] http://www.partiseapate.eu/

[31] http://www.simcelt.eu/wp-content/uploads/D3c_Scenarios-Overview-Report.pdf

[32] https://www.espon.eu/programme/projects/espon-2013/targeted-analyses/nss-north-sea-star-north-sea-spreading-transnational

[33] https://www.msp-platform.eu/

[34] https://www.research.manchester.ac.uk/portal/en/researchers/mike-barnes(9484b24e-0a22-44a0-bb9f-02083d354ce0).html

[35] http://homeoffshore.org/

[36] https://www.renewableenergymagazine.com/wind/offshore-wind-could-be-a-bonanza-for-20171110

[37] https://www.research.manchester.ac.uk/portal/en/researchers/alexander-smith(522eb302-8c86-41fd-8bb4-7382d31fc9f7).html

[38] https://www.baesystems.com/en/our-company/our-businesses/maritime

[39] https://coe.northeastern.edu/people/myers-andrew/

[40] https://web.northeastern.edu/atm/#_ga=2.188196584.1344151098.1577635037-2129557618.1577635037

[41] https://power-us.org/#power-us

[42] http://www2.eng.ox.ac.uk/civil/people/bwb-1

[43] http://www.rems-cdt.ac.uk/

---

[44] The DTI is now the Department for Business, Enterprise and Regulatory Reform and the Department for Innovation, Universities and Skills.

[45] https://safebuck.com/

[46] https://www.wardandburke.com/

[47] http://www2.eng.ox.ac.uk/civil/news/department-signs-five-year-agreement-with-orsted-to-optimise-wind-turbine-foundations

[48] https://www.journals.elsevier.com/applied-ocean-research

[49] https://www.plymouth.ac.uk/staff/deborah-greaves

[50] https://www.plymouth.ac.uk/research/coast-engineering-research-group

[51] https://www.plymouth.ac.uk/research/centre-for-coastal-and-ocean-science-and-engineering

[52] https://www.plymouth.ac.uk/research/centre-for-advanced-engineering-systems-and-interactions

[53] https://www.primare.org/

[54] https://www.supergen-ore.net/about-us/co-directors-team

[55] https://www.sheffield.ac.uk/eee/staff/academics/zq_zhu

[56] https://www.sheffield.ac.uk/eee/news/sheffield-siemens-wind-power-research-centre-s2wp-opened

[57] https://electricalmachineshub.ac.uk/

[58] https://www.offshorewind.biz/2019/04/11/ore-catapult-picks-powertrain-research-hub-academic-partner/

[59] https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/R004900/1

[60] https://engineering.tufts.edu/people/faculty/eric-hines

[61] https://www.masscec.com/