Energy Innovation Needs Assessment

Sub-theme report: Offshore wind

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Contents

Acronyms and abbreviations

Table 1. **Key acronyms and abbreviations**

Acronym/abbreviation	Definition
BEIS	Department for Business, Energy & Industrial Strategy
CfD	Contracts for Difference
CCS	Carbon Capture and Storage
EINA	Energy Innovation Needs Assessment
ESME	Energy System Modelling Environment
GHG	Greenhouse Gas
GVA	Gross Value Add
GW	Gigawatt
HVDC	High Voltage Direct Current
IP	Intellectual Property
LCOE	Levelised Cost of Electricity
MW	Megawatt
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturers
RCA	Revealed Comparative Advantage
RD&D	Research, Development, And Demonstration
WeSIM	Whole-electricity System Investment Model

Glossary

Table 2. **Key terms used throughout this report**

Term	Definition
Learning by doing	Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors such as the impact of standards which tend to increase in direct proportion to capacity increases.
Learning by research, development and demonstration	Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development and demonstration (RD&D); increases with spend in RD&D and tends to precede growth in capacity.
Sub-theme	Groups of technology families that perform similar services which allow users to, at least partially, substitute between the technologies. For example, a variety of technology families (heat pumps, district heating, hydrogen heating) have overlapping abilities to provide low-carbon thermal regulation services and can provide flexibility to the power system.
System value and Innovation value	Estimates of change in total system cost (measured in £ GBP, and reported in this document as cumulative to 2050, discounted at 3.5%) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies is compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas targets. Energy system modelling is a vital tool in order to balance the variety of interactions determining the total system costs. Innovation value is the component of system value that results from research and development (rather than from 'learning by doing').
Technology family	The level at which technologies have sufficiently similar innovation characteristics. For example, heat pumps are a technology family, as air-source, ground-source and water-source heat pumps all involve similar technological components (compressors and refrigerants). Electric vehicles are also a technology family, given that the battery is a common component across plug-in hybrids and battery electric vehicles.
Gross Value Add	Gross Value Add (GVA) measures the generated value of an activity in an industry. It is equal to the difference between the value of the outputs and the cost of intermediate inputs.

Introduction

Box 1. **Background to the Energy Innovation Needs Assessment (EINA)**

The Energy Innovation Needs Assessment (EINA) aims to identify the key innovation needs across the UK's energy system, to inform the prioritisation of public sector investment in low-carbon innovation. Using an analytical methodology developed by the Department for Business, Energy & Industrial Strategy (BEIS), the EINA takes a system-level approach, and values innovations in a technology in terms of the system-level benefits a technology innovation provides.[1] This whole system modelling in line with BEIS's EINA methodology was delivered by the Energy Systems Catapult using the Energy System Modelling Environment (ESME^{TM}) as the primary modelling tool.

To support the overall prioritisation of innovation activity, the EINA process analyses key technologies in more detail. These technologies are grouped together into sub-themes, according to the primary role they fulfil in the energy system. For key technologies within a sub-theme, innovations and business opportunities are identified. The main findings, at the technology level, are summarised in sub-theme summary reports. An overview report will combine the findings from each sub-theme to provide a broad system-level perspective and prioritisation.

This EINA analysis is based on a combination of desk research by a consortium of economic and engineering consultants, and stakeholder engagement**.** The prioritisation of innovation and business opportunities presented is informed by a workshop organised for each sub-theme, assembling key stakeholders from the academic community, industry, and government.

This report was commissioned prior to advice being received from the CCC on meeting a net zero target and reflects priorities to meet the previous 80% target in 2050. The newly legislated net zero target is not expected to change the set of innovation priorities, rather it will make them all more valuable overall. Further work is required to assess detailed implications.

[1] The system-level value of a technology innovation is defined in the EINA methodology as the reduction in energy system transition cost that arises from the inclusion of an innovation compared to the energy system transition cost without that innovation.

The offshore wind sub-theme report

The offshore wind sub-theme focusses on offshore wind, both fixed and floating platforms. This report focusses on offshore wind exclusively as it: 1) is expected to be deployed at significantly larger scale than solar and onshore wind and 2) is a relatively immature technology with greater opportunities for innovation to bring system benefits and unlock export opportunities for UK business.

Offshore wind's role in the energy system, as a variable renewable, is like that of solar and onshore wind in that it is a relatively low-cost source of low-carbon electricity. However, the ability to deploy the technology without as many practical and acceptability limits that occur onshore means that a higher potential is possible. In the future, if the available resource is less constrained, it may be possible for offshore wind to play new roles in the energy system, balancing electricity across countries, or in the production of storable renewable fuels (e.g. hydrogen).

The report has four sections:

- **Offshore wind and the energy system:** Describes the role of offshore wind in the energy system.
- **Innovation opportunities:** Provides lists of the key innovations available within offshore wind, and their approximate impact on costs.
- **Business opportunities:** Summarises the export opportunities of offshore wind, the gross value add (GVA) and jobs supported by these opportunities, and how innovation helps the UK capture the opportunity.
- **Market barriers to innovation:** Highlights areas of innovation where market barriers are high and energy system cost reductions and business opportunities are significant.

Key findings

Priority innovation areas in offshore wind

Priority innovations for the offshore wind sector are identified below. The list is not a substitute for a detailed cost reduction study. Rather, it is a guide for policymakers and key stakeholders on important areas to be considered in any future innovation programme design.

The innovation priorities below select individual or groups of the top scoring innovations. Table 3 maps the top scoring innovations to individual technology components, and Table 6 sets out the full list of innovations and their scores.

- **Grid Integration:** Grid integration innovations will reduce offshore wind energy system cost as well as the cost of transporting energy over long distances. This will increase UK offshore wind deployment by enabling a larger capacity of Offshore Wind to connect to the grid. Innovations in this sector will lessen the effect that offshore wind variability is currently having on the UK power grid. Improvements in grid integration will come from innovations in grid connection and interconnections, system services, forecasting and control as well as energy storage. Energy storage innovations could include storage of energy produced by the turbines as well as alternative fuels produced from wind energy (e.g. hydrogen).
- **Logistics, installation, smart O&M and operations:** These innovations focus on reducing the risk of offshore wind projects and reducing the cost of operation and maintenance. This will ultimately reduce financing costs and therefore LCOE. Innovations in this sector will include digitalisation and AI, improved data analysis to increase availability and performance improvements by improved control systems. Improving these operations also benefits improving the HSE, by designing out high-risk operations using remote systems.
- **Next generation turbines:** As we understand more about the interaction between wind resource and offshore turbines, the overall design of wind farms is evolving to become smarter and more efficient in cost of deployment and energy yield. Experience in composites, electrical systems and drivetrains can be utilised for future turbine designs. Innovations including new blade technology and materials, turbine components, higher voltage electrical subsystems and composites manufactures, as well as innovations in turbine control and yield optimisation can both reduce cost and increase revenue, having a significant impact on LCOE.
- **Floating offshore wind:** Floating technology is used to deploy offshore wind in sea areas that have high wind speeds but are too deep to be cost effective for fixed foundation installation. The value of innovation in this area is significant and will support the commercialisation and future deployment to enable the UK to tap into

new high wind speed resources. There is a significant expected growth in the floating offshore wind market, in the UK, wider Europe, and internationally. Innovations in this sector will include dynamic high voltage cable systems, moorings for challenging seabed conditions as well as for very deep and shallow water, foundations and new installation, maintenance and fabrication innovations.

Business opportunities to the UK

The UK's large domestic market and industry provides a strong platform to increase its market share of the European and global market, with export related activities plausibly supporting £2.4 billion GVA and 21,000 jobs per annum by 2050. In the business opportunities section below, GVA and jobs results are set out by component (Table 7).

- Economies of scale play an important role in this market, and the UK's supply chain would need to develop significantly in order to develop the required scale to be competitive internationally and capture a large export share.
- The UK's industrial strategy, combined with large scale expected domestic deployment, means the UK could conceivably become a leading international player. This unlocks the large potential export GVA and jobs opportunity associated with offshore wind.
- Innovation is also required to gain market share through first mover advantage in specific areas, such as floating platforms or specialised O&M services, as well as developing and retaining UK based IP.
- Competitiveness and market share could be increased by pursuing new areas such as floating wind or other radical innovations.
- Domestic opportunities are expected to be of a similar size to export opportunities, driven by the UK's large expected roll-out of offshore wind. Accordingly, the domestic market could plausibly support £2.6 billion GVA and 21,000 jobs per annum by 2050.

Market barriers to innovation in the UK

Opportunities for HMG support exist when market barriers are significant, and they cannot be overcome by the private sector or international partners. In the market barriers section below, the barriers are set out by component, where possible (Table 8). Offshore wind is a maturing technology, with HMG commitments until 2030 and strike prices below nuclear power it is a competitive technology. Compared to other low-carbon technologies, market barriers are therefore less severe. The main market barrier identified by industry is:

- **The skills shortage in advanced engineering and manufacturing.** Efficient management of the components in the supply chain, logistics and infrastructure planning are additional areas that lack skills in the UK, partly due to limited experience in these more complex strategic tasks.

Key findings by component

Government support is justified when system benefits and business opportunities are high, and government is needed to overcome barriers.

Table 3. **Cost and performance in offshore wind (see key to colouring below)**

Overall statistics for offshore wind: System value = £14.4 billion (range: £6.6 - £20.3 billion), 2050 export opportunity (GVA) = £2.4 billion, 2050 potential direct jobs supported by export= 21,000				
Component	**Example innovation**	**Export opportunity**	**Market barriers**	**Strategic assessment**
Turbines	Lower Wind Speed Utilisation	Medium-low		Use of some low wind speed sites inevitable. Commercialisation of technologies that exploit, and maximise outputs at lower wind speeds would increase the number and expected capacity of such sites. Turbines are one of the largest cost components and include a high degree of value add manufacturing. Export business opportunities could grow significantly if they leverage manufacturing capabilities in the UK domestic market. Without government intervention, innovation in turbines will occur at a lower scale and speed.
Foundations	New Foundation Design	Medium-low		Further optimisation and development of fixed turbine foundations, as well as substation structures can unlock larger turbine sizes. The business opportunities outside of Europe may be smaller due to the large size and replicability of foundations. Without government intervention, innovation in foundations will occur at a lower scale and speed
Moorings and anchors	Floating Wind Moorings	N/A		As floating turbines get larger and are being situated in deeper, rougher waters, reliable and cost-effective moorings are becoming essential for deployment increases to occur. Without government intervention, innovation in moorings and anchors will occur at a lower scale and speed.
Installation	Advanced Lifting	Medium-low		Turbines are getting larger, adaptations in lifting equipment will therefore need to adapt the installation process. Business opportunities for the UK are likely to be limited outside of Europe. Without government intervention, innovation in installation will occur at a lower scale and speed.
Balance of system	Long Distance Transmission	Low		Unlocking sites that are currently out of the feasible transmission distance could have a large impact on UK deployment. Innovations in long distance transmission are essential to achieving this. Balance of system is currently a relatively smaller part of overall costs resulting in a smaller business opportunity compared to other

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Component	**Example innovation**	**Export opportunity**	**Market barriers**	**Strategic assessment**
				components. Without government intervention, innovation, investment in balance of system will occur at a lower scale and speed.
Decommissioning	Repowering Life Time Extension	High		Innovation can support maximising the repowering potential while minimising costs. This is a growing business opportunity. Without government intervention, innovation in decommissioning will occur at a lower scale and speed.
Operations and maintenance	Remote O&M			As projects move further from shore, operations are likely to increase in complexity, risk and cost. This is a growing business opportunity and by 2050 could be very large as the international fleet of offshore wind grows. Innovations to enable remote O&M would create significant cost reductions and safety benefits. Without government intervention, innovation in O&M will occur at a lower scale and speed

Source: Vivid Economics, Carbon Trust

Note: This table only includes component-specific market barriers. Cross-cutting barriers are included in the market barriers section below. We only include export markets in this assessment because it is more directly linked to additional benefits to the UK economy. However an assessment of the domestic market is included in the report below.

Table 4. **Key to colouring in the key findings by component**

Business opportunities	Market barriers
High: more than £1 billion annual GVA from exports by 2050	**Critical:** Without government intervention, innovation, investment and deployment will not occur in the UK.
Medium-High: £600-£1,000 million annual GVA from exports by 2050	**Severe:** Without government intervention, innovation, investment and deployment are significantly constrained and will only occur in certain market segments / have to be adjusted for the UK market.
Medium-Low: £200-£600 million annual GVA from exports by 2050	**Moderate**: Without government intervention, innovation, investment and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
Low: £0-200 million annual GVA from exports by 2050	**Low:** Without government intervention, innovation, investment and deployment will continue at the same levels, driven by a well-functioning industry and international partners.

Source: Vivid Economics, Carbon Trust

Box 2. **Industry workshop**

A full-day workshop was held on 22nd January 2019 with delegates from the offshore wind industry. Key aspects of the EINA analysis were subjected to scrutiny, including innovation opportunity assessment, and business and policy opportunities assessment. The views of the attendees, and the evidence that they provided, has been included throughout this report.

In addition, several contextual issues were raised at the workshop:

- Innovations that enable offshore wind farms to create and store alternative energy forms (e.g. hydrogen) stretch beyond the remit of the ESME model as it only considers supply and demand of electricity.
- The cost effectiveness of pursuing innovations to individual turbine components is constantly changing as turbines change in size, location and deployment rate. Therefore, technology developers as opposed to governments should lead turbine innovation.

These overarching messages, while not fitting within the limited scope of the EINA framework, are important for consideration in setting innovation policy.

Offshore wind and the whole energy system

Current situation

UK wind deployment has risen rapidly in recent years. In 2019, the total installed capacity of offshore wind surpassed 8 GW and onshore wind 12GW.[2] This capacity mix means that on windy days a significant proportion of the UK's power can be generated by its wind farms. In 2017, the contribution of wind power to the UK energy mix was 2.2%,[3] this is equated to a 32% increase compared with 2016.[4]

Future deployment scenarios

In the coming decades, offshore wind deployment in the UK is expected to increase significantly. A recent future energy scenario, proposed by the National Grid, showed offshore wind capacity reaching 43 GW by 2050.[5] This would represent a deployment increase of ~500% over 30 years. System modelling suites, using different energy system scenarios, have suggested deployment on an even larger scale than this. For example, research carried out by Imperial College London, using the WeSIM model, suggests that offshore wind deployment could be close to 37 GW by 2030.[6] This rate was reached by modelling a high-renewables scenario that included carbon restraints and limited nuclear deployment. In July 2018, HMG announced a new contracts for difference (CfD) auction for less established technologies in May 2019 and then around every two years thereafter. Depending on the price achieved by them, these auctions will deliver between 1-2 GW of offshore wind each year in the 2020s.[7] The 2019 auction will bring forward 5.5GW of offshore wind at record low prices. The Offshore Wind Sector Deal, published in 2019 sets

[2] Renewable UK (n.d.) Wind Energy Statistics https://www.renewableuk.com/page/UKWEDhome
[3] Global Wind Energy Council (2018) Global Wind report – Annual market update 2017 https://gwec.net/policy-research/reports/
[4] BEIS (2018) UK Energy in Brief 2018 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728374/UK_Energy_in_Brief_2018.pdf
[5] National Grid (2018) Future Energy Scenarios in five minutes http://fes.nationalgrid.com/media/1357/fes-2018-in-5-minutes-web-version.pdf
[6] Whole-electricity System Investment Model (WeSIM): http://www.vivideconomics.com/wp-content/uploads/2018/06/Thermal-generation-and-reliability-final-report.pdf
[7] Wind Power Offshore (2018) UK sets out CfD auction plan from 2019 https://www.windpoweroffshore.com/article/1488500/uk-sets-cfd-auction-plan-2019

out a pathway to 30GW by 2030. [8] The announced CfD plan will be instrumental in achieving this target.

The Committee on Climate Change expect offshore wind to be the largest source of low carbon electricity in the UK by 2030.[9] This estimation is a result of its relatively low and falling costs, as well as its proven scalability. The exact level of deployment of offshore wind will, however, be dependent on numerous factors. These include overall electricity demand, the rate of development of other low-carbon technologies (e.g. nuclear and CCS), the cost of deployment, and the development of enabling technologies (e.g. batteries and other sources of flexibility).

Sub-theme system integration: benefits, challenges, and enablers

The main system benefit provided by offshore wind is the delivery of large-scale, low-carbon electricity at relatively low cost. The primary reason to deploy offshore wind is its potential to produce zero carbon electricity at scale and at an efficient cost. Other low-carbon alternatives cannot provide this because they are either too costly, or because they are limited by deployment barriers. For example, onshore wind and solar farm deployment is restricted by land availability.

Unlike solar, offshore wind farms have the capacity to produce power overnight. Offshore wind also has a higher capacity factor than onshore wind technologies. The expected scale of deployment will, however, require the energy system to become significantly more flexible if it is to cope with the increased capacity. Offshore wind farms benefit from the fact that, although wind farm clusters do exist, they are spread across the entire coast and therefore are less likely subjected to poor weather conditions simultaneously. This factor enables them to be more consistent power generators than other renewables. For example, in 2018 power output from wind energy dropped below 30% of the average output only 18% of the time, compared to 48% for solar.[10]

Large scale offshore wind implies that the effect of offshore wind power supply variation will be amplified. This suggests that there will be periods where generation significantly outstrips demand and vice versa. Development of energy storage technologies, as well as innovations in grid interconnections, will be important in managing this difference and ensuring minimum energy losses.

[8] Renewable UK (2018) UK Offshore Wind Industry Reveals Ambitious 2030 Vision https://www.renewableuk.com/news/391723/UK-Offshore-Wind-Industry-Reveals-Ambitious-2030-Vision.htm
[9] CCC (2015) Power sector scenarios for the fifth carbon budget https://www.theccc.org.uk/wp-content/uploads/2015/10/Power-sector-scenarios-for-the-fifth-carbon-budget.pdf
[10] The Carbon Trust analysis of 2018 Exelon half hour settlement data.

There are several enabling technologies and business models which can facilitate large-scale integration of offshore wind. Key technologies that could provide this within a decarbonised power system include demand side response, vehicle to grid, battery storage, bulk storage through hydrogen, and gas fired generation fitted with CCS.

Box 3. **System modelling: Offshore wind power in the UK energy system**

Following the BEIS EINA methodology, whole energy system modelling was conducted using the ESME Version 4.4 to estimate where innovation investments could provide most value to support UK energy system development.

ESME[11] is a peer-reviewed whole energy system model (covering the electricity, heat & transport sectors, and energy infrastructure) that derives cost-optimal energy system pathways to 2050. It does so while meeting user-defined constraints, e.g. 80% greenhouse gas (GHG) emissions reduction. The model can choose from a database of over 400 technologies which are each characterised in cost, performance and other terms (e.g. maximum build rates) out to 2050. The ESME assumption set has been developed over more than 10 years and is published.[12] ESME is intended for use as a strategic planning tool and has enough spatial and temporal resolution for system engineering design.

Like any whole system model, ESME is not a complete characterisation of the real world, but it is able to provide guidance on the overall value of different technologies, and the relative value of innovation in them.

The EINA Methodology prescribes the approach to be taken to assess the system-level value of technology innovation. This involves creating a baseline energy system transition without innovation (from which a baseline energy system transition cost is derived), and on a technology-by-technology basis assessing the energy system transition cost impact of “innovating” that technology. Innovation in a technology is modelled as an agreed improvement in cost and performance out to 2050.

For the EINA analysis, the technology cost and performance assumptions were derived from the standard ESME dataset[13] as follows:

- In the baseline energy system transition, the cost and performance of all technologies is assumed to be frozen at their 2020 levels from 2020 out to 2050.
- The “innovated” technology cost and performance for all technologies are assumed to follow the standard ESME dataset improvement trajectories out to 2050 (these are considered techno-optimistic).
- In the case of offshore wind technologies, the assumed “innovated” capital cost reduction is around 50% between 2020 and 2050 values, with a corresponding capacity factor improvement of 5 percentage points in the same timeframe (from 50% to 55%).

Whole system analysis using the BEIS EINA Methodology described above shows that there is significant value to the UK in continued (and accelerated) innovation in offshore wind technology.

- The modelled high-innovation cases would imply deployment by 2050 of 30 GW and 37 GW for fixed and floating offshore wind respectively.
- The cumulative[14] system benefit of innovation in offshore wind is £18.8 billion cumulatively to 2050 (discounted at 3.5%). For reference, the equivalent value for innovation in onshore wind is ~ £0.9 billion.
- Innovation in both fixed and floating offshore wind is important. This is needed now to position the UK to maximise offshore wind resource exploitation and to reduce the costs of the energy transition over the next 30 years (and potentially beyond).

Further work is required to estimate the value of innovations in offshore wind, or how these estimates may change in the case of different energy system scenarios.

[11] More details of the capabilities and structure of the ESME model can be found at eti.co.uk/programmes/strategy/esme. This includes a file containing the standard input data assumptions used within the model.
[12] The ESME assumption set has been developed is published with data sources at https://www.eti.co.uk/programmes/strategy/esme
[13] More details of the capabilities and structure of the ESME model can be found at eti.co.uk/programmes/strategy/esme. This includes a file containing the standard input data assumptions used within the model.
[15] Jamasb, Tooraj (2007). "Technical Change Theory and Learning Curves", The Energy Journal 28(3).

Box 4. **Learning by doing and learning by research**

The total system value follows from two types of technology learning:

- **Learning by doing:** Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use.
- **Learning by research:** Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D). It increases with spend in RD&D and tends to precede growth in capacity.

The EINAs are primarily interested in learning by RD&D, as this is the value that can be unlocked as a result of innovation. Emerging technologies will require a greater degree of learning by RD&D than mature technologies. Academic work suggests that for emerging technologies around two-thirds of the learning is due to RD&D, and for mature technologies around one-third is due to RD&D.[15]

To reach a quantitative estimate of the system value attributable to R&D, we apply these ratios to the system value. This implies that, as an emerging technology, around £12.4 billion of £18.8 billion system value for new offshore wind follows from R&D efforts. Note, this is an illustrative estimate, with the following caveats:

- The learning-type splits are intended to apply to cost reductions. However, in this study, we apply them to the system value. As system value is not linearly related to cost reduction, this method is imperfect. In practice, learning by R&D and learning by doing are not completely separable. It is important to deploy in order to crowd-in investment to more R&D, and R&D is important to unlock deployment.

These estimates are used in the EINA Overview Report to develop a total system value that results from innovation programmes across the energy system.

[15] Jamasb, Tooraj (2007). "Technical Change Theory and Learning Curves", The Energy Journal 28(3).

Innovation opportunities within offshore wind

Introduction

Box 5. **Objective of the innovation opportunity analysis**

The primary objective is to identify the most promising innovation opportunities within offshore wind and highlight how these innovations may be realised and contribute to achieving the system benefit potential described above. This section provides:

- A breakdown of the costs within offshore wind across key components and activities.
- A list of identified innovation opportunities, and an assessment of their importance to reducing costs and deployment barriers.

The offshore wind industry has rapidly developed in the last decade. Large-scale deployment, encouraged through significant government subsidy, drives innovation across the supply chain. A key trend has been the growth in average turbine size from ~2MW per turbine to the latest turbines of up to 10MW.

For offshore wind to become a global industry support must be given to innovations that enable turbines to be constructed in deeper waters. Such innovations would benefit the UK by enabling deployment to occur in locations that are currently too deep for wind farm construction to be economically viable. They would also provide the UK with export opportunity from emerging offshore wind market countries that are surrounded by waters too deep for current fixed wind farm development to occur (e.g. Japan, USA west coast and Taiwan east coast). Innovations in floating wind, a technology in which Scotland is a world leader, will be key in unlocking very deep-water locations (i.e. over 50 meters). The focus for this technology should be in floating foundations.

Innovations in fixed bottom offshore wind will also be important to unlock deep water locations. Currently, these are carrying less investment risk than floating wind innovations. Innovations in wind turbine foundation design as well those that decrease the costs of foundation manufacture and installations will be the main drivers of deep-water wind farm deployment. The UK has the construction and technological capacity to deliver these innovations, the key barrier is a lack of supply chain and support for it.

The following sections of the report will highlight the key innovations needed in fixed and floating wind technologies. The technologies are presented separately in order to reflect their significantly different cost structures and innovation needs.

Cost breakdown

Initial capital expenditure is one of the significant cost drivers of offshore wind. It therefore has a large impact on a farm's levelised cost of electricity (LCOE) which is calculated by dividing the lifetime costs of the wind farm by its lifetime energy yield. LCOE is one of the key cost metrics that are considered for offshore wind. In the absence of subsidy, LCOE is used to determine whether the technology can compete in the wholesale electricity market, and, whether developers will be able to recoup their initial investment upon construction. Offshore wind is relatively capital intensive compared to other renewable energy supplies. Its operational expenditure is low compared with other technologies, but it still accounts for around 40% of lifetime costs.

The following six key cost components are significant to the cost of offshore wind energy:

- **Development and project management:** This includes all services up to construction, including site and environmental surveys, development and consent services, site investigations and project planning. It also includes all project management services for the project throughout the lifetime of the assets.
- **Turbine:** The turbine portion includes the purchase of the turbine, blades and towers.
- **Balance of plant:** This includes all wind farm infrastructure that is not a component of the turbine, for example electrical components and structures; subsea cables for inter array and export; offshore substation equipment; steelwork; turbine foundations; and substation structure supply.
- **Installation and commissioning:** This includes the installation of all components mentioned above, as well as ports, logistics and support services.
- **Operation, maintenance and service:** Once commissioned, offshore assets need to be regularly maintained. This portion of cost is ongoing throughout the lifetime of the assets and includes maintenance and inspection services, vessels and equipment and O&M ports.
- **Decommissioning:** Developers are responsible for the decommissioning of the equipment at the end of its life. This portion of cost includes ports and logistics, marine operations, salvage and recycling and project management.

In addition to the above cost elements, revenue, which in the case of offshore wind is driven by yield, is a key factor in the LCOE for offshore wind.

Floating and fixed offshore wind have significantly different cost structures. This is mainly driven by the difference in foundation costs of floating, installation methodologies, available infrastructure, perceived risk, and market size.

Table 5. **Cost Model of fixed and floating offshore wind farm as a % of total cost**

Cost Element	Fixed Offshore Wind	Floating Offshore Wind
Balance of system	6%	9%
Operations and maintenance	30%	30%
Installation	13%	7%
Turbine	28%	30%
Foundations (including moorings and anchors for floating)	20%	23%
Decommissioning	3%	1%

Note: *Figures are rounded to the nearest whole number. This table uses a capital expenditure cost breakdown and assumes a 30% operations and maintenance value. The exact cost breakdown will vary on a project-by-project basis depending on factors such as project location, technologies adopted, and regulatory landscape. For balance of system and turbines, while the share of capex is a small, the contribution to system costs is significantly higher. Poor system integration can result in larger amounts of curtailment, which can effectively increase the cost per GWh; improvements in capacity factors can result in larger amounts of energy produced per unit of capital.*

Source: *Adapted from Carbon Trust*[16]

[16] Adapted from Carbon Trust (2015) Floating Offshore Wind: Market and Technology Review https://www.carbontrust.com/media/670664/floating-offshore-wind-market-technology-review.pdf

Inventory of innovation opportunities

The following areas of innovation constitute the largest opportunity for reductions in the cost of UK wind energy:

- **Grid Integration**: Smoothing the variability of wind energy and decreasing the costs of transmission would increase the capacity of existing and future offshore wind farms as well as unlock sites that are currently out of the feasible, cost effective transmission distance. Innovations that facilitate longer distance AC transmission (such as mid-point reactive compensation) and HVDC are essential to creating improvements in long distance transmission and energy storage innovations as well as better use of advanced wind modelling will reduce offshore wind variability. It is important to note that regulatory barriers, as well as specific technological knowledge limitations, need to be overcome for the UK to advance in this area.
- **Logistics, installation, smart O&M and remote operations:** Operations account for around 30% of wind farm lifetime costs. As projects move further from shore, these operations are likely to increase in complexity, risk and cost. Innovations to enable remote O&M would create significant cost reductions and HSE benefits to the maintenance of wind farms further offshore.
- **Next Generation Turbines:** The UK has knowledge from their development of composites, electrical systems and drivetrains that could be utilised to set up a leading individual wind turbine component manufacturing industry. Turbine innovations will be significant in increasing the number and expected capacity of potential wind farm sites. Potential component innovations could include gearboxes, drive trains, new materials and foundation design.
- **Floating offshore wind:** Should the UK decide that floating wind is a priority development area going forward, significant innovation opportunities exist in this space ranging from foundations, installation, logistics as well as offshore operations. Developers suggested that there is a significant opportunity to reduce cost by utilising the UK’s supply chain expertise in ship building and the maritime sector. The UK has a strong history of innovation in sectors such as shipbuilding and Oil & Gas that can be mobilised for floating wind; this could be in dry dock innovations, heavy lift or subsea operations.

Box 6. **Industry workshop feedback**

- **Grid Integration**: All industry experts agreed that this was a priority innovation for the UK due to its potential for cost reductions**.** All participants agreed that storage of wind energy was a priority for increasing plant capacity. The subject of alternative energy creation and storage co-located and integral with offshore wind farms was less conclusive. One company generated the conversation with the remainder agreeing that it would be a very lucrative innovation but also highlighting the large challenges that would need to be overcome for commercialisation to occur.
- **Logistics, Installation and Remote Operations:** There was consensus that this is a priority innovation and an area where the UK is well suited to focus innovation. Advanced wind modelling and innovative installation technologies were agreed to have the largest cost and deployment impacts.
- **Next Generation Turbines:** This was highlighted as a top three priority innovation by more companies than any other in the innovation table. All were in consensus that turbine innovations should be industry led, and that enough drivers were in place for market competition to drive innovation in this area, although within Europe and not specifically in the UK.
- **Floating Wind:** There was consensus that innovation was important, but the room was divided on how feasible it was for the UK to concentrate on it in the short term. Longer term space constraints will create a demand for floating wind. There was a consensus that the UK priorities for floating technology were relating to dynamic cable innovations to support cost reduction and deployment as well as floating O&M operations.

Industry experts at the workshop discussed the contents of Table 6 and offered feedback. The updated table was circulated afterwards amongst the industry experts with the opportunity to provide further comments, which were included.

Prioritisation of cost reduction and barrier deployment was elaborated by the Carbon Trust to reflect the importance of some innovations in the workshop interaction. The magnitude of the contribution to cost reduction and reducing deployment barriers are described in qualitative terms relative to the other innovation opportunities listed in the table:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

An indicative timeframe for each innovation is provided. The timeframe given relates to the year the technology is deployed commercially at scale (gaining 10-20% market share).

Table 6. **Innovation mapping for offshore wind**

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected by this innovation	Impact on other energy technology families	Feasible timeframe
Component-specific:						
Floating Wind						
Moorings	As floating turbines get larger and are situated in deeper and rougher waters, reliable and cost-effective moorings are essential. Greater compliance (e.g. stretchy) materials compared to chains to improve suitability for 100-150m waters and address supply chain capacity constraints.	2	4	Floating Offshore Wind	Wave Power	2020-2025
Floating Foundations	The development of new, cheaper to produce and install foundations, as well as validation of existing designs, are essential to lower the cost of floating wind. Manufacture components to avoid large-scale assembly requiring dry docks and overcome that manufacturing supply constraint.	4	2	Floating Offshore Wind	-	2025-2030
Dynamic Cables	Export and inter array cables that can withstand the dynamic motion of the foundations are essential to support the deployment of floating technology and may be a cost-saving measure for fixed foundations also.	3	4	All Offshore Wind	Wave Power	2020-2025
Turbines						
Turbines	Low wind speed yield turbines, reactive blades, increased optimisation, larger turbines, turbine controls, innovative turbine designs.	4	3	All Offshore Wind	-	2025-2030

Foundations						
Component	**Innovation opportunity**	**Contribution to cost reduction**	**Contribution to reducing deployment barriers**	**Technology affected by this innovation**	**Impact on other energy technology families**	**Feasible timeframe**
Foundation Optimisation	Further optimisation and development of fixed turbine foundations, as well as substation structures, to unlock larger turbine sizes (up to a limit).	4	3	All Offshore Wind	-	2020-2025
New Foundation Design	Further optimisation and development of fixed turbine foundations, as well as substation structures, to unlock larger turbine sizes (up to a limit).	2	3	All Offshore Wind	-	2025-2030
General:						
Wind Modelling & Resource						
Advanced Wind Modelling	How the wind moves through a wind farm during its operational life, and being able to predict this accurately in advance, allows more accurate forecasting and refined planning, and hence increased yield. Understanding this is key to reducing uncertainty and risk, and hence cost.	5	3	All Offshore Wind	-	2020-2025
Balance of Plant (Transmission)						
Longer Distance Transmission	As turbines get larger and further from shore, standard AC transmission may not be fit for purpose due to the large capex requirements, grid compliance, and transmission losses. Technical solutions for these areas will be required.	5	5	All Offshore Wind	-	2020-2025
Grid Integration	As wind farms gain a larger share of the generation market, they are likely to be required to take a greater role in system services and integration, such as frequency response.	2	3	All Offshore Wind	-	2020-2025

Grid Layout	Optimum grid layout i.e. point-to-point vs meshed vs other. However, more of a policy/regulatory issue than an innovation need.	1 (mainly policy)	1 (mainly policy)	All Offshore Wind	-	2020-2025
Component	**Innovation opportunity**	**Contribution to cost reduction**	**Contribution to reducing deployment barriers**	**Technology affected by this innovation**	**Impact on other energy technology families**	**Feasible timeframe**
Array Cables	Array cable innovation, for instance: High-voltage, alternative materials to reduce cost and failure rates etc.	2	3	All Offshore Wind	Tidal Power, Wave Power	2020-2025
HVDC Substations	With wind farms getting larger and being sited further from shore, more efficient means of transmitting energy to shore is required. HVDC has not been used offshore in the UK. Important issues, such as interconnection, have not yet been demonstrated.	5	3	All Offshore Wind	-	2025-2030
Substation Co-location	Co-location of storage and other services on the substation or foundations of larger turbines.	4	2	All Offshore Wind	-	2025-2030
Operations & Maintenance						
Remote Access	Vessels such as floating harbours, floating hotels, and others (e.g. motherships, higher wave heights, speed) that can support remote wind farms will be developed to support the installation and operational phases of wind farm development. Improved weather prediction to reduce weather risk.	4	4	All Offshore Wind	Tidal Power, Wave Power	2025-2030
Remote O&M	With farms being located increasingly further from shore, new O&M strategies and technologies will be required to operate these remote assets. This may include drones; remote inspection technologies; remote vehicles or other solutions.	5	4	All Offshore Wind	Tidal Power, Wave Power	2025-2030
O&M Optimisation	In addition to remote operations, increased understanding in wind farm operations, data capture and interpretation can lead to further optimisation of O&M strategies and	4	4	All Offshore Wind	Tidal Power, Wave Power	2020-2025

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected by this innovation	Impact on other energy technology families	Feasible timeframe
	implementation. This includes –mid-life, repowering, lifetime extension, and decommissioning. Challenges: inspecting under the mud line.					
Installation (and Logistics)						
Advanced Lifting	Turbines are getting larger, therefore lifting equipment will need to adapt. Traditionally, nacelles and towers are installed using jack-up barges, however dynamically positioned vessels are much cheaper if these can be developed.	3	2	All Offshore Wind	-	2025-2030
Innovative Installation Techniques	Technical solutions, such as self-installing turbines or other innovative installation techniques, could provide benefit.	3	3	All Offshore Wind	-	2025-2030
Assembly	Designs and manufacturing techniques that enable modular assembly to reduce the scale of assembly plant infrastructure.	3	5	All Offshore Wind	-	2025-2030
Energy Storage						
Offshore Wind Energy Storage	Energy storage and system optimisation in a general sense is being discussed under a separate topic area. However, there may be offshore wind specific energy storage or system integration technologies that could be further developed.	1	2	All Offshore Wind	-	2025-2030
Alternative Energy Storage	Stable and cost-competitive production of ammonia at the offshore wind site – providing fuel, for instance for shipping. Also reduces risk of site-to-shore transmission. Potentially leverage existing oil and gas pipelines and other infrastructure.	5	4	All Offshore Wind	-	2030-2035

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected by this innovation	Impact on other energy technology families	Feasible timeframe
Decommissioning & End of Life						
Decommissioning	Technologies that minimise the costs and risks associated with decommissioning and that minimise any environmental impacts.	3	2	All Offshore Wind	Tidal Power	2030
Repowering	Maximising the repowering potential while minimising costs.	3	4	All Offshore Wind	-	2030
Life Extension	Life-extension technologies, including leveraging fatigue and wear data monitoring.	4	3	All Offshore Wind	-	2030

Note: *The magnitude of the contribution to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities within the technology family – significantly above average (5), above average (4), average (3), below average (2), significantly below average (1). Stakeholder engagement via an expert interview has been conducted to identify and prioritise these opportunities, but further interviews and/or a workshop would be required to increase robustness.*

Source: *Frazer-Nash for BEIS, Appraisal*

Innovation opportunity deep dives

The main innovations involve cost reduction and address deployment barrier opportunities across the offshore wind technologies.

Grid Integration Innovations

Innovations in grid integrations will reduce the impact of intermittency of offshore wind energy supply. Offshore wind energy is currently intermittent. This causes issues to the UK energy grid and mandates that fossil fuel energy sources, which are non-intermittent, still be relied upon. Reducing the intermittency of offshore wind will help its deployment and reduce the UK's dependence on fossil fuels.

Innovations that support the transmission of wind energy over longer distances will be key to significantly increasing UK offshore wind deployment. The cost of offshore substations and export cables are a significant portion of overall capex, even more so for projects sited far offshore. Innovations that decrease the cost of transmission will reduce cost and make sites make the business case viable for a greater ranger of sites. Building further offshore will increase wind farm capital expenditure, however better environmental conditions will increase capacity and therefore keep LCOE largely constant.

Feedback from industry indicates that energy storage innovations offer the UK some of the highest positive cost reduction and deployment margins. Offshore wind energy storage would greatly increase UK deployment and cost reductions by smoothing the variability of offshore wind energy supply. Offshore energy storage would reduce the need to develop innovations that are currently necessary to improve grid connection.

In addition, industry views indicate that large cost reduction and deployment margins could potentially be unlocked from innovations that transform offshore wind energy. This includes innovations in electrolysis into other forms of energy that can be stored offshore, e.g. ammonia or hydrogen. While they have the potential to add large value to the UK economy, this type of innovation would be high risk as there has yet to be any proof of concept or onshore trials.

Energy storage innovations are at a very early stage of development, therefore the payback period on investment would be longer. Estimated deployment would be from ~2030. Long payback periods are due to the need for supporting infrastructure to develop in tandem with energy storage innovations for any cost savings to be realised. UK innovators could utilise existing infrastructure and knowledge from the oil and gas sector to commercialise offshore energy storage technologies at a quicker rate. For example, existing oil and gas pipelines could be used to transport/store wind energy.

Logistics, Installation and Remote Operation Innovations

Innovations that improve the logistics, installation and remote operations of offshore wind farms will lead to large cost reductions. Non-component specific expenditures represent a large proportion of the cost breakdown for offshore wind. Innovations that streamline these facilitating services would reduce health and safety risks associated with wind farm engineering, decrease turbine downtime, and reduce operational costs. These changes would lead to large cost reductions in deploying offshore wind farms further out to sea as they would reduce the need for crew transfer and the construction timescale. Innovations in this category could utilise technologies such as artificial intelligence, drones and robotics for control and command strategies.

Advanced wind modelling is a potential focus area for the UK. A better comprehension of data would reduce costs in a range of offshore wind systems. For example, it could enable developers to better understand how wind interacts with their farms to maximise output, the conditions in which crew transfers are possible thus optimising operations and real-time intricacies of wind farm output predictions for grid stability. The UK’s established competence in data manipulation would lend well to innovations in advanced wind modelling.

Wind turbines of the future

Manufacturing and technological knowledge that the UK has gained from its success in other sectors could be transferred to the offshore wind sector to enable the UK to specialise in offshore wind component manufacture. OEMs could harness the experience that the UK has in designing and producing composites, electrical systems, steelworks and drivetrains to manufacture nacelle components, novel generators, new blade materials, new foundation designs or higher voltage electrical subsystems/cables for the global offshore wind industry.

Innovations that improve turbine performance can have a significant impact on the overall LCOE and cost competitiveness of offshore wind. Developing turbines that can capture energy in low wind speed could increase the commercial viability of a greater range of seabed areas and increase the profitability of projects**.** Turbines that can be actively controlled will allow wind farm operators to further maximise yield. Industry feedback, however, indicates that this area of innovation will be furthered by industry and will not specifically benefit from government support.

Floating Wind

If floating wind is prioritised by policy makers, innovations in foundations to enable floating wind are critical to the UK. Floating wind farms are likely to become increasingly important due to higher offshore wind demand and as fixed bottom sites become more constrained for space. There will be strong demand in Scottish waters due to the water depths. Scotland has a track record in the development of floating offshore wind[17] and, along with the wider UK, could play a leading role in innovating, development and subsequent manufacturing of floating wind technologies. Floating wind has not yet reached commercial scale sites, with Hywind Scotland, a 5-turbine array, being the largest scale project in the world. The development of commercial scale projects of approximately 500MW or greater is required to demonstrate the feasibility of floating wind as a competitive energy source. Large commercial project will attract investment, both in floating wind projects and the relevant supply chains and ensure a cost reduction pathway.

Floating wind enables developers to construct wind farms in deeper waters. Innovations in floating wind are critical for enabling deployment targets to be reached as they will increase the number of potential offshore wind farm sites. Costs for floating wind are expected to come down 38% by 2050.[18]

[17] The Carbon Trust (2018) Floating Wind Joint Industry Project: Phase 1 Summary Report https://www.carbontrust.com/media/675868/flw-jip-summaryreport-phase1.pdf
[18] Wind Europe (2017) Floating Offshore Wind Vision Statement https://windeurope.org/wp-content/uploads/files/about-wind/reports/Floating-offshore-statement.pdf

Business opportunities within offshore wind

Introduction

Box 7. **Objective of the business opportunities analysis**

The primary objective is to provide a sense of the relative business opportunities against other energy technologies. To do so, the analysis uses a consistent methodology across technologies to quantify the 'opportunity'; in other words, what *could* be achieved by the UK. The analysis assumes high levels of innovation but remains agnostic about whether this is private or public. This distinction is made in the final section of the report. The two key outputs provided are:

- A quantitative estimate of the gross value added, and jobs supported associated with offshore wind, based on a consistent methodology across technologies analysed in the EINA. Note, the GVA and jobs supported are *not* necessarily additional, and may displace economic activity in other sectors depending on wider macroeconomic conditions.
- A qualitative assessment of the importance of innovation in ensuring UK competitiveness and realising the identified business opportunities. Note, the quantitative estimates for GVA and jobs supported cannot be fully attributed to innovation.

The following discussion details business opportunities arising both from exports and the domestic market. An overview of the business opportunities, and a comparison of the relative size of export and domestic opportunities, across all EINA sub-themes is provided in the overview report.

Appendix 2 provides further background to the methodology used. The business opportunities methodology and numbers presented in this section are associated with exports to other European countries and the world. Therefore, estimates exclude the role UK manufactures make within the offshore wind market in the UK, which has a substantial impact on numbers compared to if they were included.

The offshore wind industry is a young, but large and rapidly growing, industry with established producers. There are several established, multinational, companies operating across the supply chain. Key players include original equipment manufacturers (OEMs) such as Siemens Gamesa and MHI Vestas which manufacture turbines, and developers such as EON who develop and operate offshore wind farms. There is also a further ecosystem of specialised companies that produce specific components, for example JDR Cables which produce specialised sub-sea cables or provide specific services to the offshore wind industry.

The UK is currently the largest market for offshore wind, by far,[19] and has an opportunity to develop expertise supplying the domestic market, to subsequently export. 1,680 MW of capacity was added to the UK in 2017, 1,468 MW across the rest of Europe and a further 1,178 MW globally.[20] The Global Wind Energy Council reports that to date, 36% of globally installed capacity is in the UK, with a further 28.5% in Germany.[21] The UK's large roll-out of offshore wind has attracted manufacturing facilities to the UK, which it could build on and leverage to not only supply its domestic market, but export to the EU and more widely.

Given the UK's skill base, and the expected growth in the sector, our analysis shows that offshore wind exports are a large business opportunity for the UK. The offshore wind industry will continue to grow rapidly. By 2050, a fourfold increase in annual capacity constructed in Europe is expected.[22] The UK has an established comparative advantage in areas including offshore engineering (oil and gas), installation and maintenance of offshore drilling platforms, manufacture of platforms, cabling and substations, and development of offshore sites. However, compared with countries such as Germany or Denmark, the UK lacks the established supply chain for turbine manufacture. Offshore wind remains a relatively new energy technology, with an evolving market structure. Timely innovation, combined with the UK's large domestic deployment, could stand the UK in good stead to maintain current areas of competitiveness and build new strengths.

The business opportunities analysis is set out as follows

- An overview of the global market, with a focus on markets for exports
- A discussion of the UK's competitive position, with a focus on exports
- A discussion of the business opportunities from exports
- A discussion of the UK business opportunities in the UK's domestic market, including a comparison of the relative importance of export and domestic opportunities

[19] Global Wind Energy Council (2018) Global Wind report – Annual market update 2017 https://gwec.net/policy-research/reports/
[20] Ibid.
[21] Ibid.
[22] Vivid Economics calculations based on IEA Energy Transitions Program (2017) 2-degree deployment scenario

Box 8. **The UK's current offshore wind industry**

- **UK strengths include**: Blade manufacture including composite materials, cabling and substations, O&M provision, materials technology, site development and associated services, as well as offshore engineering skills from the offshore oil and gas industry.
- **Notable UK producers include**: An MHI Vestas blade manufacturing plant in the Isle of Wight (directly supporting 300 jobs, which is doubling with the addition of a second blade mould), a Siemens Gamesa turbine blade manufacture and assembly plant in Hull, directly supporting 1,200 jobs and JDR Cables, successfully exporting to multiple German offshore wind farms.
- **Key competitors include** Germany and Denmark in Europe and the US in the rest of the world.

Market overview

The North Sea is a key market for the UK, both domestically and for exports to other European countries. The UK is the world's largest single market for offshore wind, and other locations in the North Sea can be supplied from UK ports. RenewableUK figures put UK content of the UK market at 48% by value,[23] indicating almost half of the UK market is supplied by manufacturing in the UK. However, based on goods export volumes, UK content as a share of the rest of Europe drops to 6.3%.[24] International trade is substantially lower compared with trade in the European market, where the UK has roughly only 1.5%[25] market share outside of Europe. The methodology applied across the sub-themes to assess current volumes does not capture the export value of services, such as O&M, installation or planning. However, an estimate of these is made based on what the UK trades in goods and is therefore included in estimates of GVA and jobs supported. In addition, these market shares are based on goods for the wider sector of manufacturing. For example, one of the parts is pneumatic power engines that are used in wind turbines, but also includes this type of engine used in machinery that is not related to the wind industry. The particularly low exports beyond Europe will impact future values of exports, as while deployment is currently significantly higher in Europe, it is expected for this to

[23] RenewableUK (2017) Offshore Wind Industry Investment in the UK 2017 Report on Offshore Wind UK Content,https://c.ymcdn.com/sites/www.renewableuk.com/resource/resmgr/publications/Offshore_Wind_Investment_V4.pdf
[24] Based on analysis of HS Codes: 730820, 730890, 841280, 841290, 8482, 848340, 850231, 850300, 850400, 853720, and 854460.
[25] Ibid.

be overtaken by the rest of the world with the development of a more global industry. Currently, Germany and Denmark are the UK's biggest competitors across Europe and the world. Export data of wider categories, for example all turbines including those not used in offshore wind, indicates market shares of 18% and 7% respectively[26] in Europe. Narrowing down trade to just offshore wind turbines, made by the largest manufacturers, indicates vastly larger market shares to Siemens Gamesa and MHI Vestas.

Global sales in offshore wind outside of the UK are expected to increase to over £100 billion annually by 2050.[27] Demand will be driven by substitution away from carbon-intensive electricity technologies (such as coal), and an overall increase in energy demand globally. The proportion of total production that is traded internationally is expected to grow significantly as well, as costs are reduced across each of the components through innovation. Conservatively assuming larger items, such as foundations or services, are likely to be only regionally traded, still implies a near 7-fold increase from the market currently accessible to the UK. Other markets may also include application of this technology or manufacturing capabilities to similar industries, such as onshore wind and tidal stream turbines.

[26] Ibid.
[27] Offshore wind projections are subject to more uncertainty than other technologies as they rely on future deployment summaries that are subject to the development of offshore wind against other low-cost renewable technologies. Furthermore, it is possible that international competition will outcompete UK exports and prevent them from reaching significant scale.

Figure 1 **The current and future offshore wind market**

Current market for Offshore wind

- *Production:* Global offshore wind deployment was over 4GW of installed capacity in 2017, representing ~£14 bn in turnover
- *Trade:* Most UK production is currently for internal markets, with global trade around £10 bn
- *Markets:* The UK is the largest single market and Europe accounts for the majority of deployment and producers globally.

Tradability of market

- *Goods:* Offshore wind is easily traded in Europe as it is largely located in the North Sea. It's less traded globally given the large size of components.
- *Services:* Majority of service GVA and jobs supported in installation, which is mostly regionally based in the UK and Europe
- *Trends:* International trade is expected to increase sharply as demand outside of Europe increases and technological barriers are resolved.

Trends in deployment

- *Global:* Annual offshore wind deployment is expected to grow over 11-fold by 2050
- *Growth pattern:* The EU will drive growth until the 2030s, followed by other global markets post 2030
- *Uncertainty:* Global deployment will only increase by less than double if 2°C is exceeded

Global and regional market size to 2050

- *Growth trend: Near exponential growth forecast out to 2050 to meet SDS targets.* Sales growth will slightly exceed deployment growth given replacement needs
- *Key markets:* UK expected to grow to a market size of £12 bn, the rest of EU an additional £27 bn, and the rest of the world £75 bn

Source: *Vivid Economics, based on IEA 2 degrees scenario deployments*

UK's competitive position

The UK has a significant offshore wind industry, but it is currently predominantly supplying the domestic offshore wind market. The UK is the largest single market and represents 48% of cumulatively deployed capacity (in terms of GW) in the EU.[28] However, UK offshore wind exports are less than £500 million annually, and the Revealed Comparative Advantage (RCA) for goods in the wider sector is 0.54. This suggests that exports of offshore wind like parts, are not a relative strength of the UK.[29] This may be due, at least in part, to the few established offshore wind developers headquartered in the UK.[30] Regionally, the UK must compete with Germany and Denmark, who are key global producers of offshore wind-related components, and together represent approximately 10% of global exports and 25% of the European market.[31] The experts who attended the workshop noted that Denmark and Germany had received a considerable amount of public

[28] Based on deployment figures in analysis.
[29] A comparative advantage is generally associated with an RCA above 1.
[30] Martin Whitmarsh for OWIC (2019) The UK Offshore Wind Industry: Supply Chain Review https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/publications/supply_chain_review_31.01.20.pdf
[31] Based on analysis of HS Codes: 730820, 730890, 841280, 841290, 8482, 848340, 850231, 850300, 850400, 853720, and 854460.

support to establish manufacturing bases and develop innovations, which was seen as key to the development of the sector in those countries.

The UK is already competitive in a few specialised areas, and exports components including cables and blades. Currently, most blades are produced by turbine manufacturers as they need to exactly fit specifications. There are some specialised blade suppliers that manufacturer to specifications in an open tender process, where cost minimisation is also critical. In the UK, turbine blades are increasingly supplied from two facilities that supply to the turbine OEMs. Cables are another area that is already highly developed, building on from the existing UK telecoms and oil and gas industries; providing a relative comparative advantage for the UK. However, due to the proportionally smaller amount spent on cables, around 2% of capital costs, the GVA or jobs supported is smaller than other parts and does not have an easily visible impact on its corresponding component, collection, and transmission. Existing specialised manufacturing infrastructure may not be enough to be able to scale up production to meet substantially increased export demands.

International competition in offshore wind primarily comes from other European countries deploying in the North Sea, although American and Japanese companies are entering the industry as well. Offshore wind is served by a few experienced players, who are responsible for almost three-quarters of new installed turbines globally each year.[32] This shows far higher market shares than overall trade data which includes an analysis of the wider sector, beyond just offshore wind turbines. Although content may come from the UK, it is often foreign-owned. In comparison, onshore wind has been established longer and shows more dispersion between companies, suggesting that as the industry matures there may be opportunities that open the way for new competitors. This is shown in the growth in other world regions and companies due to the increasing opportunities globally.

For the UK to grow its current market share, continued innovation is required as well as leveraging its established base in the UK. The UK currently captures approximately 1.0% of the global *traded* market of offshore wind related goods. Installation and O&M services are strong in the UK and could be grown to service the broader North Sea and surrounding areas directly from UK ports. The rapid expansion of offshore wind into new markets globally presents an opportunity to capture new regions or new technologies to increase overall market shares and export values. As the UK is unlikely to compete on low-cost, high-volume production, the UK will need to continue to innovate to ensure it can maintain its competitiveness in relatively specialised versions or subcomponents of the technology. Figure 2

[32] Wind Europe (2018) Offshore Wind in Europe Key trends and statistics 2017 https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Offshore-Statistics-2017.pdf

shows projected growth in UK-captured turnover to 2050 for the European and world markets.

Figure 2 **The UK's competitive position in trade in offshore wind goods**

Current UK competitiveness

- *Market shares:*
  EU *(excl. UK) ~ 2%*
  RoW *~ 1%*
- *Strengths:* Highly skilled workforce and good logistics. Established in manufacture of blades, including composite materials, cables and complementary skill market offshore gas.
- *Weaknesses:* No established base in other areas of turbine supply.

Key EU competitor - Germany

- *Market shares:*
  EU *~ 18%*
  RoW *~ 8%*
- *Strengths*: Recognised as first mover with new innovations. Has large established export market shares, particularly for turbine supply.
- *Weaknesses:* Connection to onshore grid systems

Competitor - Denmark

- *Market shares:*
  EU *~ 7%*
  RoW *~ 1%*
- *Strengths*: Established turbine suppliers with a long history from onshore to offshore development and production
- *Weaknesses:* Does not have the large manufacturing base of other competitors to produce to the same volume and cost.

Global competitor – USA

- *Market shares:*
  EU *~ 2%*
  RoW *~ 6%*
- *Strengths:* Large country with many resources that is able to ramp up production quickly
- *Weaknesses:* Is not established in developing or deploying offshore wind

**Market shares of content by value*

Note: *Market shares based on analysis of traded goods in a broader sector than just offshore wind. HS Codes of all reviewed goods are: 730820, 730890, 841280, 841290, 8482, 848340, 850231, 850300, 850400, 853720, and 854460.*

Source: *Vivid Economics*

Box 9. **Industry workshop feedback regarding business opportunities**

- While the requirement to include UK content within the UK helps to support local producers, UK components aren't always competitive. There is not a highly functioning subcomponent supply chain.
- Attendees felt that greater policy support for innovation and manufacturing was found in Germany and Denmark, particularly in the earlier years of development of offshore wind, and that this contributed to development of the industry in those countries. Manufacturers were uncertain about UK commitment to offshore wind, which impacts longer term investment decisions.
- The very precise specifications for parts require highly specialised manufacturing plants and staff; the UK does not currently have a lot of the infrastructure in place for this.
- Areas with lower potential for intellectual property (IP) protection are likely to end up being manufactured in China or another country that can do this more cheaply. Therefore, the UK is best positioned to focus on highly technical innovation and manufacturing.
- The natural weather conditions and relatively high deployment of offshore wind in the UK provides a good opportunity to learn about and develop offshore wind turbines or their components in the UK. However, UK manufacturers would need to have the necessary supply chains in place and be cost-competitive to take advantage of this opportunity.

Table 7. **Export market shares and innovation impact – offshore wind**

Component	Tradeable market 2050 (£bn)	Current market share	2050 outlook *with* strong learning by research			
			Market share	Captured turnover	GVA from exports	Rationale for the impact of innovation
Turbines	**EU: 5.1** RoW: 12	**EU: 1.9%** RoW: 1.2%	**EU: 18%** RoW: 5.5%	**EU: £900 mn** RoW: £700 mn	**World:** £0.5 bn	High-value component with strong research potential for lower costs and higher yields. Scale and efficiency are key for manufacturing and assembly, and accelerated innovation provides a competitive edge in an industry with rapid product cycles.
Foundations	**EU: 3.7** RoW: N/A[33]	**EU: 2.5%** RoW: 0.9%	**EU: 22%** RoW: 0%	**EU: £800 mn** RoW: N/A	**World:** £0.3 bn	Development of floating platforms for deep water installation could give the UK a significant first-mover advantage and high market share.
Balance of plant	**EU: 1.1** RoW: 2.1	**EU: 2.9%** RoW: 1.0%	**EU: 26%** RoW: 4.0%	**EU: £300 mn** RoW: £80 mn	**World:** £0.1 bn	Innovation solves technological barriers to wider, deep water, implementation. Significant opportunity to be the first mover supplying floating wind and becoming a large world player.
Installation	**EU: 2** RoW: N/A[34]	**EU: 2.5%** RoW: 0%	**EU: 22%** RoW: 0%[35]	**EU: £400 mn** RoW: N/A[36]	**World**: £0.3 bn	Can leverage large domestic market to lead in installation across western Europe directly from UK ports, continued innovation in techniques is key to being competitive.
O&M and decommissioning	**EU: 14** RoW: N/A	**EU: 1.9%** RoW: 0%	**EU: 18%** RoW: 0%	**EU: £2.5 bn** RoW: N/A	**World:** £1.1 bn	Solidified UK strength in O&M service vessels, becoming large EU player. Innovation in remote operation will be key to providing low-cost O&M services.

Note: *Future market shares are not a forecast, but what UK business opportunities could be potentially. The possible market share of the UK, and rationale for the impact of innovation, are based on stakeholder input gathered in 2 workshops.*

Source: *Vivid Economics*

[33] The UK is assumed to not be able to trade foundations with the rest of the world due to their significant weight and low IP protection.
[34] The UK is assumed to not be able to trade services like installation or O&M with the rest of the world.
[35] Ibid.
[36] Ibid.

UK business opportunities from export markets

Box 10. **Interpretation of business opportunity estimates**
The GVA and jobs estimates presented below are *not* forecasts, but instead represent estimates of the potential benefits of the UK capturing available business opportunities. The presented estimates represent an unbiased attempt to quantify opportunities and are based on credible deployment forecasts, data on current trade flows, and expert opinion, but are necessarily partly assumption-driven. The quantified estimates are intended as plausible, but optimistic. They assume global climate action towards a 2 degree world and reflect a UK market share in a scenario with significant UK innovation activity.[37] More information on the methodology, including a worked example, is provided in Appendix 2, and a high level uncertainty assessment across the EINA subthemes is provided in Appendix 3.

Growth of UK exports could add £2.4 billion GVA and support 21,000 export related jobs per annum by 2050. This growth is driven by forecast deployment as a result of continued innovation to overcome remaining technological barriers. It relies on the assumption that with significant investment, the UK could increase its exports of turbines or turbine parts, over the coming decade, to match current exports of the leading global competitor. This would require a significant increase in manufacturing infrastructure over the next decade. These jobs are expected to be dispersed around the country, particularly in coastal towns where ports exist so that the turbines and parts can be moved to deployment sites. These areas may also have higher than average unemployment figures and be more in need of an economic boost, ensuring an available workforce and a greater impact on job creation. Figure 3 shows the increase in GVA by component, as well as the corresponding increase in jobs supported, Figure 4. Turbine supply, as a larger cost component, will be the second-largest source of GVA and could deliver £0.5 billion annually by 2050. O&M will be the largest source of GVA adding £1.1 billion per annum and builds on the UK's established base in specialised offshore services. These are covered in further detail in the business opportunities deep dives.

Balance of plant, including collection and transmission of power to national grids, is a key opportunity for innovation and builds on existing strengths. Balance of plant will support over 2,000 jobs per annum and is crucial in making

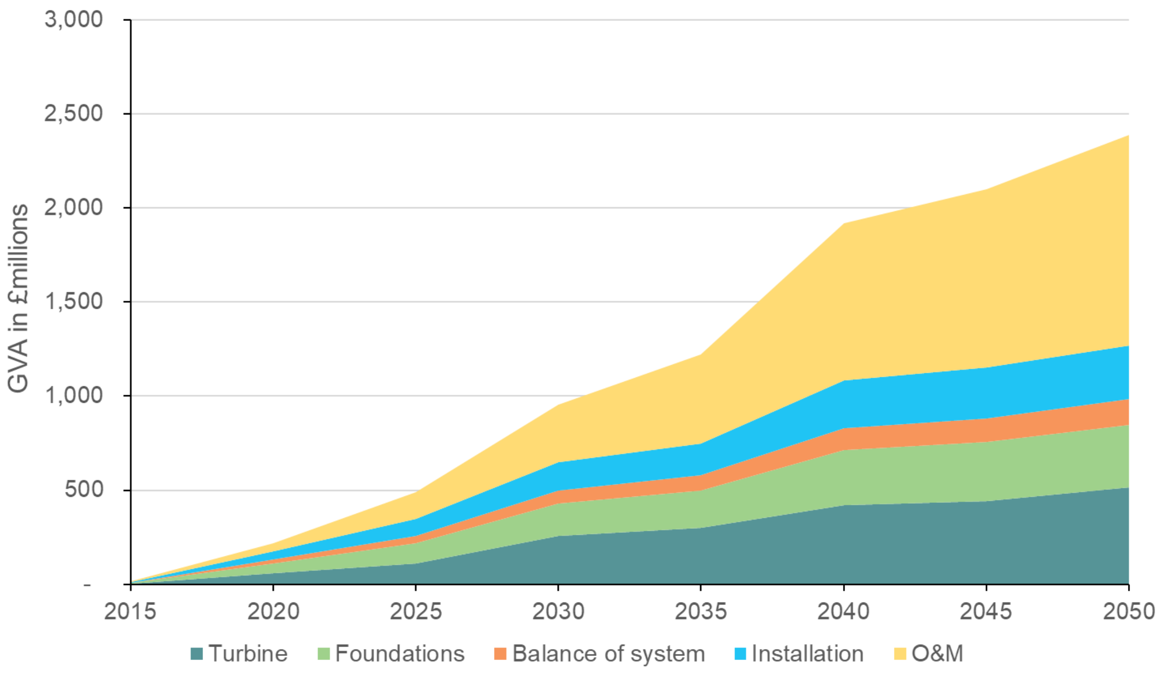
[37] Note, other IEA climate scenarios were also used as a sensitivity. Where the level of global climate action has a meaningful impact on market size, this is highlighted in the market overview section. Full results are available in the supplied Excel calculator.

offshore wind grid-accessible and meet flexibility requirements. Flexible and well-connected systems are crucial for variable technologies like offshore wind; significant innovation is required in this area to develop the required connection systems. Cables are an existing UK strength, but is a small part of balance of plant and overall costs, approximately 2% of overall costs. The UK could leverage skills and knowledge from its existing base in cables, the offshore gas and UK telecommunications industries, to further innovate and grow market shares. This component is highly globally traded and has wider applications beyond offshore wind, to be expanded to other dispersed energy technologies and thus could add significantly greater GVA to the UK if this was also considered.

Foundations in deeper waters are an emerging technology and market, with substantial expected growth resulting from delivering the required innovations. Floating platforms and novel foundations are key to accessing deeper water deployments and require radical innovation over incremental change, presenting a big opportunity for first-mover advantage. Year-on-year increases are driven by increased deployment and the ability to reach the European market in a cost-effective manner. It could support over 4,000 jobs per annum by 2050 in the European market. Driving down costs will lead to substantially increased demand for offshore wind and a thriving market. While it is less likely that the UK will be able to cost-effectively compete in manufacturing for more distant locations, beyond Europe, technology or IP developed in this area could be licensed out to other countries, adding additional jobs and value to the UK. The latter benefits are not included in this analysis.

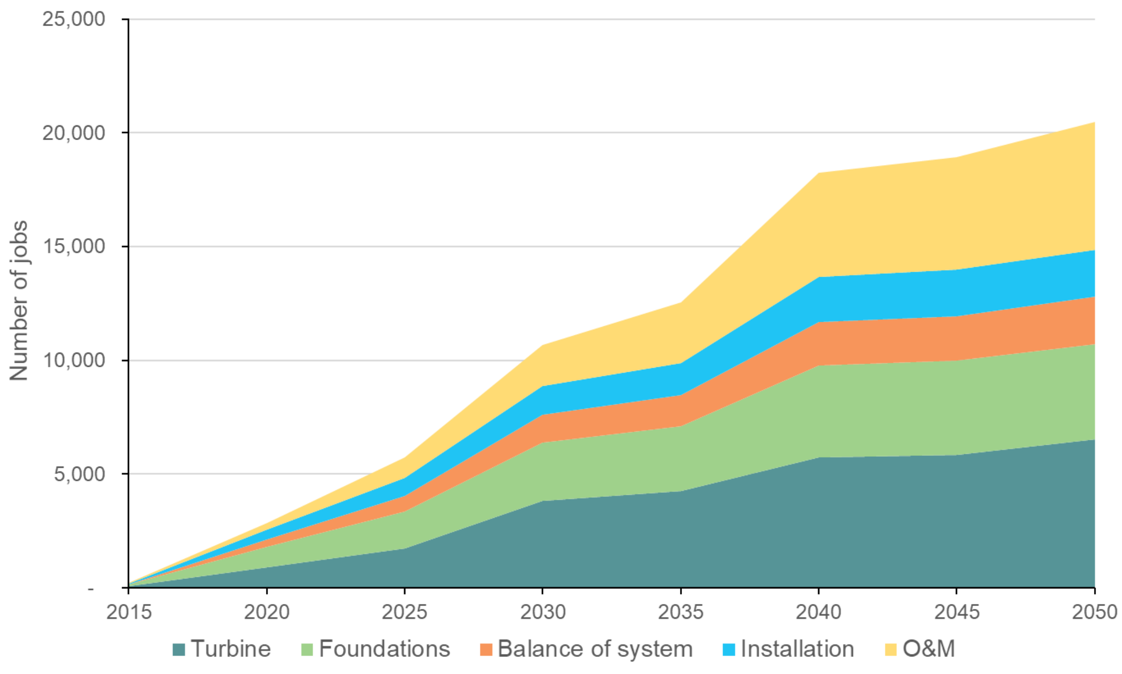
UK exports of installation services is not likely to contribute a significant amount to the UK economy compared to other components. Although installation services could build on the UK's established base in offshore engineering services, it is likely that this work would be undertaken by local workers, the energy company buying the turbines, or the main turbine producer.

Figure 3 **GVA from export markets by component – offshore wind**



Source: *Vivid Economics*

Figure 4 **Jobs supported from export markets by component – offshore wind**



Source: *Vivid Economics*

UK business opportunities from domestic markets

Discussion

The UK was the second largest market for offshore wind in 2018 behind China, with expected deployment to 2050 presenting increasing opportunities for domestic businesses.[38] The Global Wind Energy Council reports that as of 2018, 29 per cent of new global capacity was installed in the UK[38]. The UK's large roll-out of offshore wind has attracted manufacturing facilities to the UK, which have supplied and serviced its domestic market, directly supporting around 7,200 jobs[39] across the country.[40] With deployment expected to increase substantially to 2050, the UK's offshore wind market presents opportunities for domestic GVA and jobs.

Business opportunities are based on ESME deployment of 66 GW by 2050 and are aligned with the Sector Deal's target for 30 GW by 2030.[41] The ESME modelling scenario is aligned with an 80% emissions reduction target by 2050 and is relatively central in terms of the range of recent scenarios considered. A recent future energy scenario proposed by the National Grid showed offshore wind capacity reaching 43 GW by 2050.[42] However, systems modelling suites suggest greater deployment. For example, research carried out by Imperial College London, using the WeSIM model, suggests that offshore wind deployment could be close to 37 GW by 2030 and likely significantly higher by 2050.[43] The UK Committee on Climate Change (CCC) suggests that achieving a net zero target by 2050 would require 75 GW of offshore wind by 2050.[44] This could have positive implications, beyond the business opportunity estimates provided here, for total UK market size and UK content.

UK content of the UK market was 48% by value in 2017, indicating almost half of the market is supplied by UK businesses,[45] with the rationale detailed below:

[38] Global Wind Energy Council (2019) Global Wind Report 2019 https://gwec.net/global-wind-report-2018/
[39] ONS (2019) Low Carbon and Renewable Energy Economy Final Estimates https://www.ons.gov.uk/economy/environmentalaccounts/datasets/lowcarbonandrenewableenergyeconomyfirstestimatesdataset
[40] The sector also supports an estimated 6,300 indirect jobs in the supply chain, based on the ONS low-carbon and renewable energy multiplier of 1.87 for offshore wind: https://www.ons.gov.uk/economy/environmentalaccounts/datasets/lowcarbonandrenewableenergyeconomymultipliersdataset
[41] BEIS (2019) Offshore Wind Sector Deal https://www.gov.uk/government/publications/offshore-wind-sector-deal/offshore-wind-sector-deal
[42] National Grid (2018) Future Energy Scenarios in five minutes http://fes.nationalgrid.com/media/1357/fes-2018-in-5-minutes-web-version.pdf
[43] Whole-electricity System Investment Model (WeSIM) http://www.vivideconomics.com/wp-content/uploads/2018/06/Thermal-generation-and-reliability-final-report.pdf
[44] UK CCC (2019) Net-Zero Technical report: https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-Technical-report-CCC.pdf
[45] RenewableUK (2017) Offshore Wind Industry Investment in the UK 2017: Report on Offshore Wind UK Content

- The UK captured 29% of the domestic offshore wind CAPEX market in 2017, an increase of 11% from 2015[45]. This is expected to reach 49% by 2030 under a high innovation scenario, given recent progress and the sector deal's aim to increase the share of local content in manufacturing. This share is assumed to be equal across **turbine supply**, **foundations** and **balance of systems**, given data limitations on relative strengths.
- The UK currently captures 29% of the domestic **installation** market. Innovation and domestic deployment will increase this share, but the UK is expected to capture a lower share (40%) of the domestic installation market than of wider manufacturing markets, as the vessels associated with offshore wind installation tend to compete globally.[46]
- The UK currently captures 75% of domestic **operation and maintenance (O&M)** services. This share is expected to increase slightly to approximately 80% by 2030 and maintain from this point on.

Domestic deployment of offshore wind could support £2.6 billion GVA and almost 21,000 jobs per annum by 2050. This is similar to exports, which could support £2.4 billion GVA and 21,000 jobs per annum by 2050 (Figure 5 and Figure 6). In both exports and domestic markets, CAPEX contributes around 50% of GVA in 2050, with O&M contributing the remainder. CAPEX supports 70% of jobs, as jobs associated with O&M of offshore wind platforms tend to be relatively higher value per worker.

Turbine supply, foundations and installation could each support between £320 and £400 million GVA per annum by 2050. Turbine supply and foundations could support around 4,800 jobs per annum, while installation supports 2,300 jobs per annum as these jobs are of relatively higher value Figure 7 and Figure 8 show a breakdown of jobs by component.

Offshore wind deployment under the CCC's net-zero scenario could increase domestic opportunities by an additional 15%. Under this scenario, the UK deploys 75 GW of offshore wind by 2050 to achieve net-zero decarbonisation. Following this, the domestic market could support almost £3 billion domestic GVA and 24,000 domestic jobs per annum by 2050. These numbers assume UK content is not affected by the increasing domestic deployment. They could therefore be considered conservative, as additional deployment may spur additional innovation, increasing the UK's share of domestic content. Conversely, a scenario where the UK relies more on other power sources and alternative technologies such as CCUS could reduce domestic deployment and therefore associated business opportunities.

https://c.ymcdn.com/sites/www.renewableuk.com/resource/resmgr/publications/Offshore_Wind_Investment_V4.pdf

[46] Vivid Economics (2019) Accelerated electrification and the GB electricity system https://www.theccc.org.uk/wp-content/uploads/2019/05/CCC-Accelerated-Electrification-Vivid-Economics-Imperial.pdf

Quantitative results

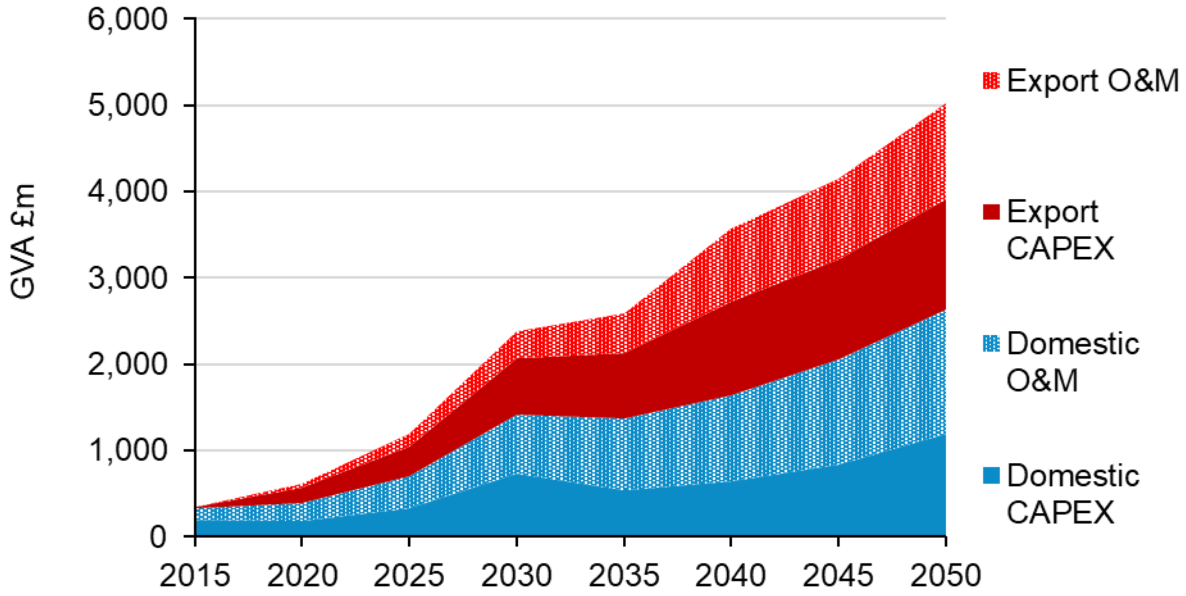
Table 8. **Domestic market shares and innovation impact – offshore wind**

Technology	Domestic market 2050 (£m)	Current market share of related goods and services	2050 outlook with strong learning by research: Market share* (%)	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
Turbines	2,600	29%	49%	1,300	400	High innovation allows the UK to increase its share of CAPEX in the domestic market to 49% by 2030, contributing to the UK capturing 60% of the total domestic offshore wind market in line with the UK's Offshore Wind Sector Deal vision. Given limited data on areas of strength within CAPEX, these shares are assumed equal for **turbines**, **foundations** and **balance of plant**.
Foundations	1,900			900	360	
Balance of plant	540			270	100	
Installation	1,200	29%	40%	490	320	The UK increases its current share of **installation** to 40% by 2030 and maintains this share under high innovation. Vessel operators associated with offshore wind installation compete globally, and the UK does not currently have substantive strengths in this area of offshore wind deployment.
O&M	4,100	75%	80%	3,300	1,500	The UK slightly increases its share of domestic **O&M** and supplies around 80% of the domestic market through 2050.

Note: ** Future market shares are not a forecast, but what UK business opportunities could potentially achieve. The possible market share of the UK, and rationale for the impact of innovation, are based on PRODCOM analysis and additional market research. N/A indicates data is not available.*

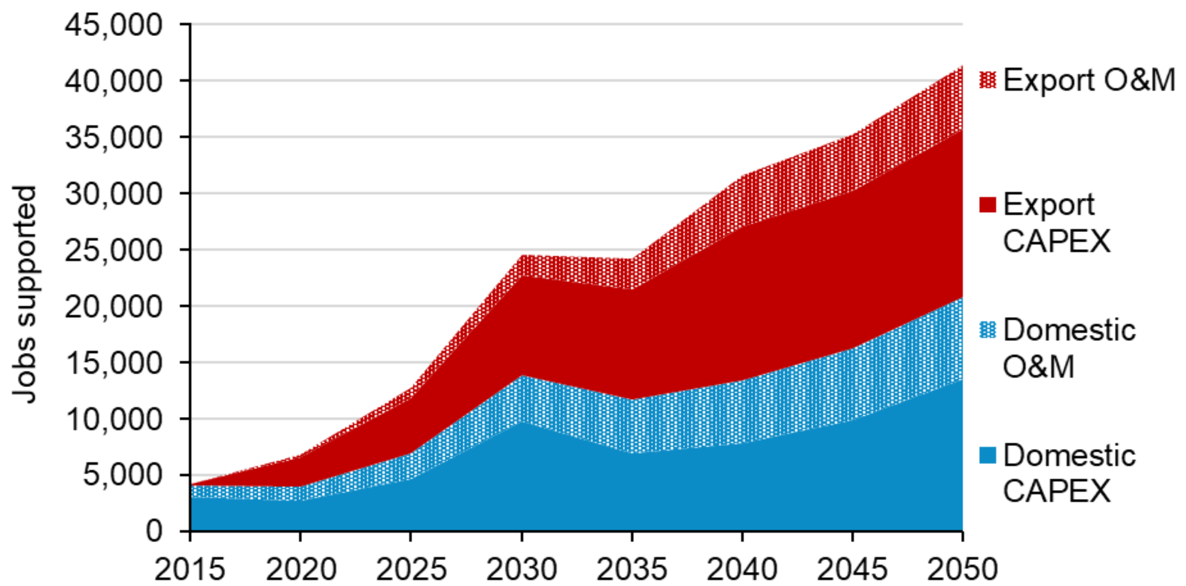
Source: *Vivid Economics*

Figure 5 **GVA from export and domestic markets – offshore wind**



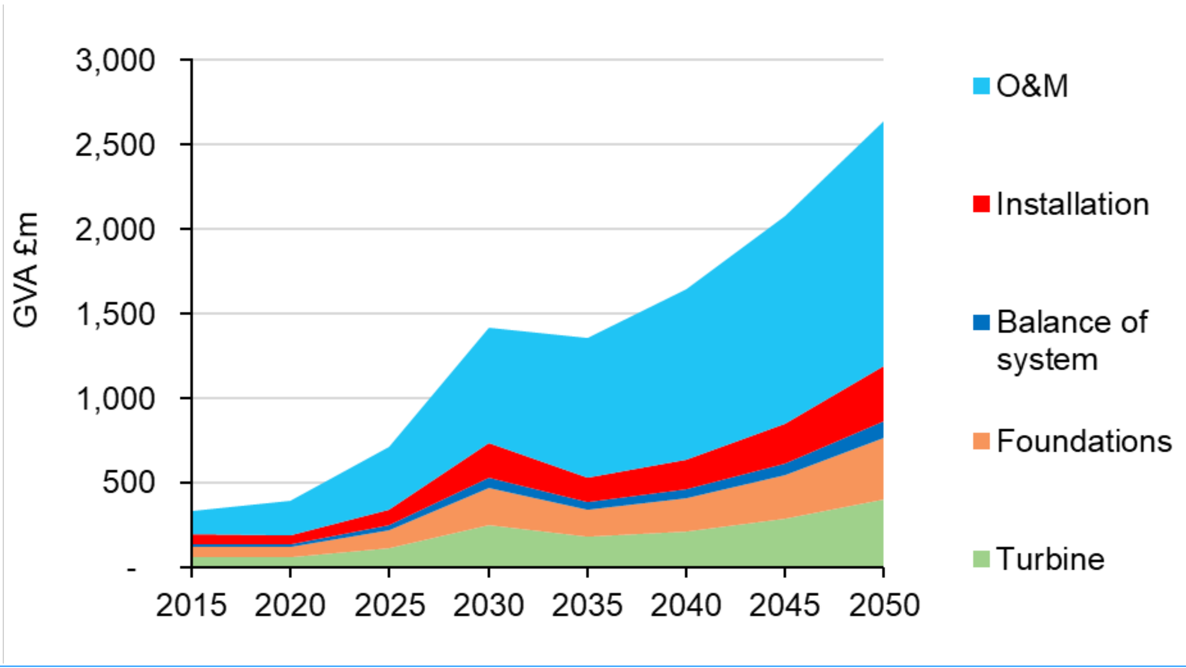
Source: *Vivid Economics*

Figure 6 **Jobs supported from export and domestic markets – offshore wind**



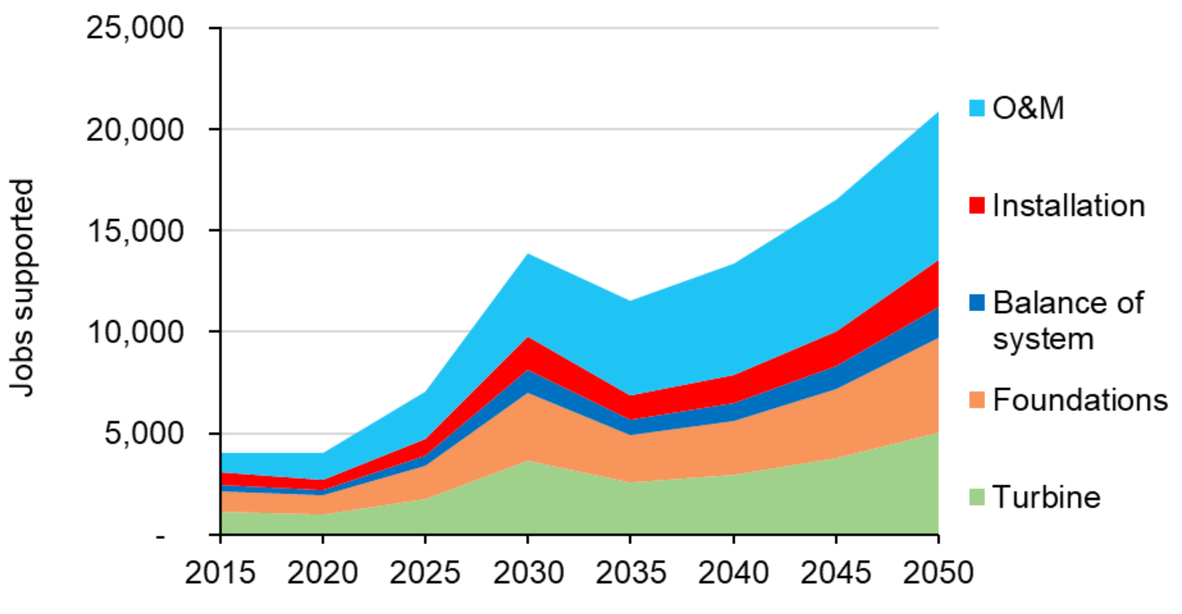
Source: *Vivid Economics*

Figure 7 **GVA from domestic markets by component – offshore wind**



Source: *Vivid Economics*

Figure 8 **Jobs supported from domestic markets by component – offshore wind**



Source: *Vivid Economics*

Business opportunity deep dive: Turbines

Turbines are an established technology and market, but expected growth is driving necessary increases in size and efficiency to make offshore wind cost-effective against other energy technologies. Global sales for turbines are expected to increase to over £18 billion per annum by 2050. Turbines make up nearly 30% of levelised costs, with blades and the drive train providing the largest components by cost within the turbine. As the largest cost component, it provides the largest market opportunity. The trend is towards both lower costs and higher yields, through better control and power conversion, thus requiring significant innovation. They are relatively labour-intensive to produce, requiring a skilled workforce, and along with assembly exports could support almost 7,000 jobs per annum. The UK could grow a significant manufacturing industry, particularly in specialised technical manufacturing, but given the strength of incumbents, innovation support would need to be complemented by strong industrial strategy.

Specialised components, such as blades and drive train parts, are key to increasing yields and could be aligned with the existing UK facilities. There are existing innovation opportunities, such as further development of blades, converters, and gearboxes, which could provide the UK with a significant competitive advantage and likely increase the UK's market share of value associated with turbines. Improved blade design is seen as key to increasing yields and is already a UK strength at the two UK facilities currently producing blades for wind turbines. The UK is also a significant supplier of converters and gearboxes, within the drive train, to the offshore wind industry.[47] Further innovation is required to increase reliability and reduce downtime. Due to their high technical specification and relative ease of transportation they can be exported to both Europe and to the rest of the world. Current UK exports of turbines are minimal, so this represents significant, but feasible, growth. The UK supply chain also delivers smaller specialised parts required in turbines, such as FT Technologies' sensors that are in 70% of offshore wind turbines.[48]

The UK could plausibly ramp up European specialised turbine parts exports over the next decade. This market share in offshore wind exports could be worth over £250 million annually to the UK by 2030 and £0.4 billion per annum by 2050**.** Some key parts, blades and drive train, are relatively established within the UK and

[47] BVG Associates, UK offshore wind supply chain: capabilities and opportunities, 2014, 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
[48] Martin Whitmarsh for OWIC (2019). The UK Offshore Wind Industry: Supply Chain Review https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/publications/supply_chain_review_31.01.20.pdf

the size of the UK market could help drive further expansion of this component in the UK. Reports for the offshore wind industry council[49] and by BVG associates for BEIS[50] suggest this is feasible. Increasing the UK's market share could come through various channels, some unrelated to innovation, such as the opening of an OEM factory in the UK given its large domestic market and the further scaling of existing UK strengths. Producing turbines encourages manufactures of the parts to locate themselves within proximity of the key producer, to create hubs.

Business opportunity deep dive: O&M and decommissioning

Global trade of O&M and decommissioning services is expected to increase to a market size of £53 billion per annum by 2050, with UK delivery of these services adding £1.1 billion per annum to the UK economy. Services present a significant potential opportunity to the UK economy. Decommissioning is included within O&M as it is likely that as turbines age they would be replaced as a large part of O&M, rather than a complete shutdown of a wind farm. The UK already has a base in more technical aspects, particularly in O&M servicing. Due to the location of many of Europe's offshore wind, in or near the North Sea, they could be serviced directly from UK ports, though this would need to be balanced against the time and cost of travel.

O&M services are both a strength of the UK and could add substantial benefit to the UK economy. Like installation, O&M services build on the UK's established base in offshore engineering services and require similar skills and equipment. This is aided by software for offshore marine coordination; a highly technical area of expertise within the UK that has been developed and improved over many years. The highly technical nature, and years of learning by doing, also mean that this an area where it is harder for competitors to move in. Exports could support over 5,600 jobs per annum by 2050. Due to the current stage of development of offshore wind, there is no established base in decommissioning, providing a first-mover market opportunity to provide these services.

[49] ORE Catapult for OWIC (2018) Offshore wind industry prospectus. https://cdn.ymaws.com/www.renewableuk.com/resource/resmgr/publications/catapult_prospectus_final.pdf
[50] 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

Market barriers to innovation within offshore wind

Box 11. **Objective of the market barrier analysis**

Market barriers prevent firms from innovating in areas that could have significant UK system benefits or unlock large business opportunities. Market barriers can either increase the private cost of innovation to levels that prevent innovation or limit the ability of private sector players to capture the benefits of their innovation, reducing the incentive to innovate.

Government support is needed when market barriers are significant, and they cannot be overcome by the private sector or international partners. Table 8 lists the main market barriers in offshore wind, along with an assessment of whether HMG needs to intervene.

Introduction

Grid-connected offshore wind capacity has been on the rise over the last decade, driven by China, Germany, and the UK. The largest operational offshore windfarm in the world, Walney Extension (660 MW), was fully commissioned in the UK. Its capacity will be exceeded by Hornsea Project One, which is currently under construction (planned capacity 1,218MW, completion date 2020).[51] Through initiatives such as the Industrial Strategy, HMG has committed to playing an active role in providing demand visibility, supporting innovation and skills, and providing access to finance to build a competitive supply chain for the offshore wind sector jointly with industry.[52]

Offshore wind is a relatively mature technology, with HMG commitments until 2030 and strike prices below, for example, nuclear power.[53] Compared to other low-carbon technologies, market barriers are therefore less severe. Table 8 lists the main market barriers in offshore wind, along with an assessment of whether the government needs to intervene. For each identified market barrier, an assessment of

[51] IEA (n.d.) Offshore wind Tracking Clean Energy Progress https://www.iea.org/tcep/power/renewables/offshorewind/; 4C Offshore (n.d.) Hornsea Project One Offshore Wind Farm https://www.4coffshore.com/windfarms/hornsea-project-one-united-kingdom-uk81.html
[52] HMG (2013) Offshore Wind Industrial Strategy Business and Government Action Offshore Wind Industrial Strategy Business and Government Action
[53] HMG (2018) Energy Minister Claire Perry hails success story of offshore wind in Newcastle today https://www.gov.uk/government/news/energy-minister-claire-perry-hails-success-story-of-offshore-wind-in-newcastle-today ; HMG (2018) Hinkley Point C https://www.gov.uk/government/collections/hinkley-point-c

the need for government intervention is provided. The assessment categories are low, moderate, severe, and critical:

- **Low** implies that without government intervention, innovation, investment, and deployment will continue at the same levels, driven by a well-functioning industry and international partners.
- **Moderate** implies that without government intervention, innovation, investment, and deployment will occur due to well-functioning industry and international partners, but at a lower scale and at lower speed.
- **Severe** implies that without government intervention, innovation, investment, and deployment are significantly constrained and will only occur in certain market segments or must be adjusted for UK market.
- **Critical** implies that without government intervention, innovation, investment, and deployment will not occur in the UK.

Market barriers for offshore wind

Table 9. **Market barriers**

Market barriers in offshore wind innovation	Need for public support
Skills deficiencies in advanced engineering, logistics, and infrastructure management, driven by increasing technical complexity, limited experience, and fragmented infrastructure provision.	Severe
Lack of visibility over a sufficiently-sized future market, in part driven by unclear UK policy position, reduces innovation across the supply chain, skills development, and entry of new UK players.	Moderate
Test sites, incl. onshore prototype test facilities and offshore demonstration facilities, are lacking due to unaffordable capital costs for private sector and future demand uncertainty.	Moderate
High infrastructure cost, high risks and contract awards based on unit costs deter entry of new players in the UK market. As a result, innovation is largely driven by international competition.	Moderate
Coordination failures due to perceived risks of losing competitive advantage, including data sharing.	Low

Source: Vivid Economics analysis and stakeholder input

Box 12. **Industry workshop feedback**

Industry experts raised several areas that require HMG support:

- Skills requirements exist in advanced engineering and manufacturing. Efficient management of the components in the supply chain, logistics, and infrastructure planning are additional areas that lack skills in the UK, partly due to limited experience in these more complex strategic tasks.
- Although UK policy has strengthened and a pathway to 30GW by 2030 has been provided, there remains some uncertainty over the future market size. According to industry, recent announcements regarding the size and allocation of Contracts for Difference budgets are challenging to reconcile with other HMG statements on market size. There is also a tension in policy direction between steep cost-reduction and local-content requirements.
- High investment costs for test facilities limit industry investment. Test sites for onshore prototype testing and offshore demonstration facilities were mentioned by Industry experts as priority areas to de-risk investments and accelerate innovation.
- Data sharing constraints require little government intervention and collaboration across the sector occurs currently, for example as part joint projects and university partnerships.
- Financial barriers still exist in the sector, but the financial market increasingly addresses these. HMG financing support could be used to support UK skills and to accelerate innovation.

International opportunities for collaboration

- **The growing global market for offshore wind presents opportunities for international cooperation for innovation across the supply chain.** International partnerships can accelerate technology development, demonstrate the UK's innovation capacity, reduce costs, and support new product development.
- **International competition is an important driver for innovation in offshore wind.** Regionally, the UK must compete with Germany and Denmark, who are key global producers and receive significant government support for offshore wind.

Appendix 1: Organisations at expert workshop

- AWS True Power
- MHI Vestas
- Atkins
- Frazer Nash
- Ørsted
- ARUP
- Shell
- DNV-GL
- Senvion
- Siemens Gamesa
- ENBW
- ORE Catapult
- Innogy

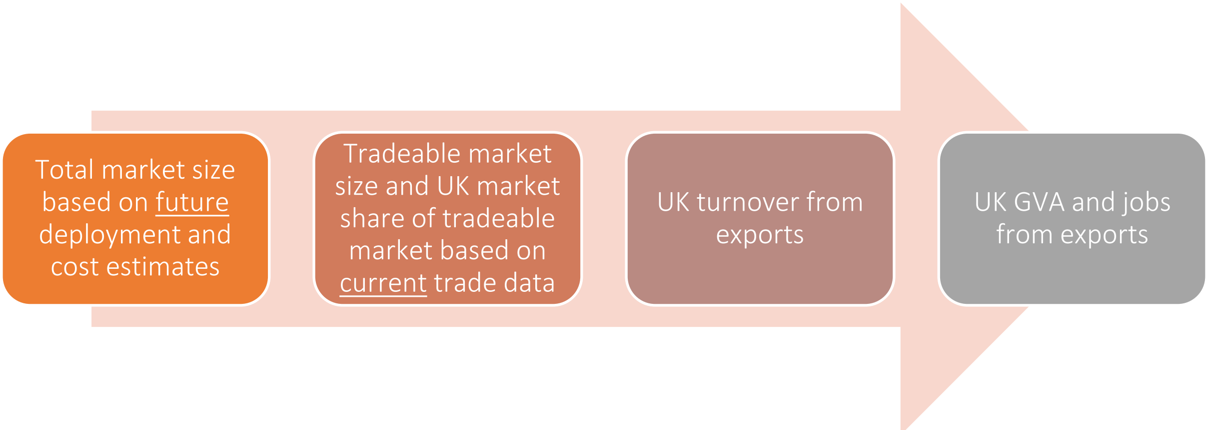
Appendix 2: Business opportunities methodology

Methodology for export business opportunity analysis

In identifying export opportunities for the UK, the EINA process uses a common methodology to ensure comparability of results:

- The **global and regional markets** to 2050 are sized based on deployment forecasts, which come from the IEA when available. For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market.
- The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs created**.

Figure 9 **Methodology for assessing export opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Export business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade data, where available. If the technology is immature or export levels are low, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to reach a market share in the EU and RoW by 2050. The potential future market share is intended as an ambitious, but realistic, scenario. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.
- Market share assumptions are validated at a workshop with expert stakeholders and adjusted based on stakeholder input.

Export business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The EINA methodology does not quantify opportunities associated with installation and operation and maintenance as these are typically performed locally. Exceptions are made if these types of services are specialised, such as in offshore wind.
- The key services to consider are based on desk research and verified through an expert workshop.
- The services considered in the CCUS EINA export analysis are EPCm services, transport and storage services.

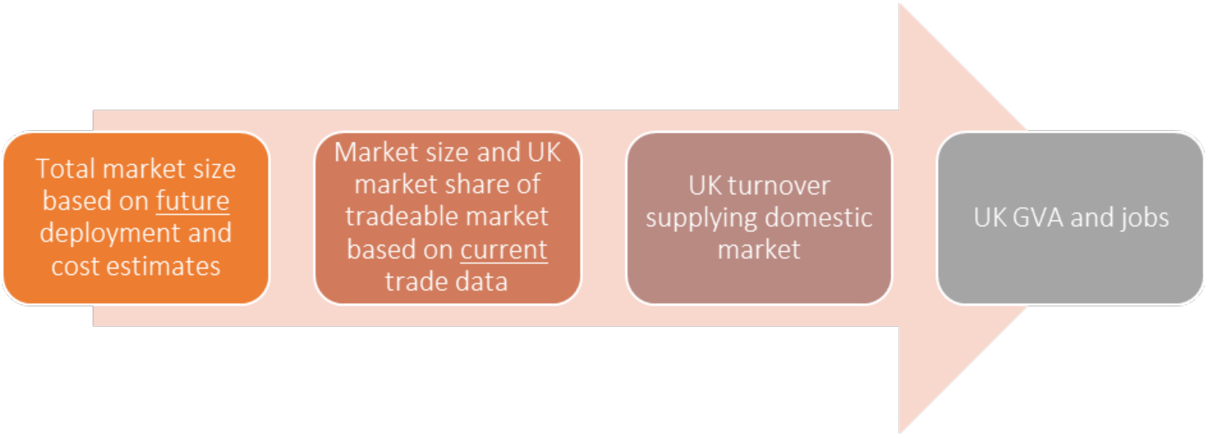
Methodology for domestic business opportunity analysis

To estimate the size of domestic business opportunities for the UK, the EINA methodology, as developed to size export opportunities, is adapted. The domestic analysis leans heavily on insight gleaned from the export analysis, particularly in estimating UK competitiveness and ability to capture market share in its domestic market. To estimate the domestic opportunity, the following methodology is used:

- The **domestic market** to 2050 is sized based on deployment and cost estimates. Deployment estimates are based on ESME modelling used for the EINAs and cost estimates are equal to those from the export work, and based on analysis for each of the EINA sub-themes.[54] For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the UK's market is likely accessible for foreign firms (e.g. electric vehicles), and how much is likely to be exclusively provided by UK companies (e.g. heat pump installation).
- For the traded share of the UK market, the UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- To estimate **UK captured turnover** the traded and non-traded markets are summed.
    - The UK's captured turnover of the UK traded market is estimated by multiplying the tradeable market by the UK's market share.
    - The UK's turnover from the non-traded market is equal to the size of the non-traded market.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs supported**.

[54] For detail on cost estimates used, please refer to the Excel calculators provided for each sub-theme, and the individual sub-theme reports.

Figure 10 **Methodology for assessing domestic business opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Domestic business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade (import) and domestic production data, where available. If the technology is immature, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to potentially increase its market share in its domestic market. This estimate is informed by the previously performed export analysis. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.

Domestic business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The domestic assessment explicitly quantifies services such as O&M and installation, which are typically not traded but can support a large number of

jobs associated with e.g. heat pumps. For these services, the estimate of potential service jobs supported is based on:
    - An estimate of the total turnover and GVA associated with the service
    - A ratio of GVA/jobs (adjusted for productivity increases) in analogous existing service sectors based on ONS data.
- The key services to consider are based on desk research, verified through stakeholder workshops.

Worked example

1. The **global and regional markets** to 2050 are sized based on illustrative deployment forecasts, which come from ESME when available.[55] For example, deployment of nuclear power (37 GW by 2050) is multiplied by O&M costs (~12% of total plant costs) to obtain annual turnover for the nuclear O&M market (~£2.5 billion by 2050).
2. The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market. In the case of nuclear O&M, tradability is 0% being as it is not tradeable. For the domestic analysis, tradability does not directly feed into our model, but is vital to provide insight on the share of the domestic market UK firms will capture.
3. The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below. For example, for nuclear O&M the UK domestic market share is 100% because the component is not tradeable and therefore foreign firms do not capture some of the value.
4. The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**. For nuclear O&M, market turnover (~£2.5 billion) is multiplied by the UK market share (95%) of O&M to obtain UK-captured turnover (~£2.5 billion by 2050).
5. The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by labour productivity figures for that sector to obtain **jobs supported**. For example, appropriate Standard Industrial Classification (SIC) codes are chosen for nuclear O&M. This leads to a GVA / turnover multiplier (49%) that is multiplied by market turnover (~£2.5 billion) to isolate GVA (~£1 billion by 2050), which is then divided by labour productivity (~70,000 GVA / worker by 2050) to isolate jobs supported (~16,000 jobs by 2050).

[55] If deployment information is not available from the IEA, alternative projections from, for example, Bloomberg are used. Please see individual sub-theme reports for further detail.

Appendix 3: Assessment of business opportunities uncertainty

The assessment of business opportunities in the long term, associated with new technologies is uncertain. This assessment does not attempt to forecast what *will* happen. Instead, the business opportunity assessment attempts to provide a realistic and consistent assessment, based on current information, on the business opportunities that *could* be captured by the UK. Whether these opportunities are indeed realised depends on domestic and international developments, political decisions, macro-economic conditions, and numerous other complex variables.

As this assessment is not intended as a full forecast, a formal quantitative sensitivity analysis has not been performed. the below provides a high-level qualitative assessment of the uncertainty associated with the sized opportunity. Note, this is *not* an assessment of how likely the UK is to capture the opportunity, rather it is an assessment of the uncertainty range around the size of the opportunity. The assessment is based on three key factors driving the assessment

1. *The level of future deployment of the technology*. Technologies such as offshore wind are deployed at scale across different energy system modelling scenarios and hence considered relatively certain. In contrast, there is more uncertainty for e.g. hydrogen related technologies. The export analysis is based on 3 IEA scenarios (with numbers provided for the IEA ETP 2 degree scenario). Domestic analysis is based on a single ESME run used across the EINA process.
2. *The potential domestic market share* the UK can capture. This assessment attempts to estimate a plausible market share for the UK across relevant markets. Where this can be based on longstanding trade relationships and industries, this assessment is considered more robust.
3. *Future technology costs and production techniques* are a key driver of the future turnover, gross value added and jobs associated with a technology. For immature technologies for which manufacturing techniques may, for example, become highly automated in future, future costs and jobs supported by the technology may be significantly lower than assessed.

The ratings in the table below are the judgement of Vivid analysts based on the above considerations. The analysts have worked across all sub-themes and the ratings should be considered as a judgement of the uncertainty around the size of the opportunity relative to other sub-themes. As a rough guide, we judge the uncertainty bands around the opportunity estimates as follows:

- **Green**: Size of the opportunity is clear (+/- 20%). Note, this does not imply the UK will indeed capture the opportunity.
- **Amber:** Size of the opportunity is clear, but there are significant uncertainties (+/- 50%).
- **Red:** There are large uncertainties around market structure and whether the technology will be taken up at all in major markets. The opportunity could be a factor 2-3 larger or smaller than presented.

Table 10. **Assessment of uncertainty in business opportunities across sub-themes**

Sub-theme	Uncertainty rating	Comments
Biomass and bioenergy		• **Deployment**: Moderate deployment uncertainty; BECCS can produce negative emissions that have high value to the energy system under a deep decarbonisation pathway; there is moderate uncertainty as to whether BECCS will be used for hydrogen production, as in the ESME modelling, or for power generation. • **UK market share:** Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services and feedstocks. • **Costs and production techniques:** Relatively certain costs with most opportunities associated with labour input rather than immature technologies.
Building fabric		• **Deployment:** Depends on levels of retrofit that greatly exceed those seen to date. • **Market share:** Speculative for traded. However, majority of market untraded, highly likely captured domestically. • **Costs and production techniques:** High share of labour costs (independent of uncertain tech cost).
CCUS		• **Deployment:** Moderate deployment uncertainty; decarbonisation scenarios anticipate rapid uptake of CCUS, though there are few large-scale facilities today. • **Market share:** Moderate market share uncertainty; the UK is likely to be competitive in the storage of CO2 and EPCm services while component market shares are less certain given numerous technology choices and lack of clear competitors. • **Costs and production techniques:** Moderate cost uncertainty; the lack of large-scale facilities today makes estimating future costs difficult.
Heating and cooling		• **Deployment**: Expected to be deployed in most UK buildings by 2050. • **Market share:** some uncertainties, immaturity in markets such as for hydrogen boilers. • **Costs and production techniques:** Relatively certain given relative maturity of boilers and heat pumps. • **Deployment of hydrogen boilers or heat pumps** lead to similar opportunities for UK businesses, while heat networks present a 50 per cent smaller opportunity per household.

Hydrogen and fuel cells		• **Deployment**: Highly uncertain future deployment with a wide-range of 2050 hydrogen demand estimates across scenarios, particularly for export markets. • **UK market share**: Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services. • **Costs and production techniques:** Although deep uncertainty in future hydrogen production costs, for example electrolysis, most domestic costs are associated with labour input rather than equipment.
Industry		• **Deployment**: Relative certainty in deployment as it is based on the 2050 Roadmaps • **UK market share**: Some uncertainty due to poor quality of trade data that may not be representative of technologies within scope. • **Costs and production techniques:** Some uncertainty in costs, particularly for less mature technologies.
Light duty transport		• **Deployment**: Certainty in deployment; low-carbon vehicles will be required in any deep decarbonisation scenario. • **UK market share**: Speculative market share for a relatively immature market; a small number of uncertain future FDI investment decisions generates high uncertainty in overall business opportunities. • **Costs and production techniques:** Highly uncertain future costs, with substantial falls in battery costs a key enabler of BEV uptake.
Nuclear fission		• **Deployment**: Moderate uncertainty in future deployment with some proposed nuclear plants recently cancelled • **UK market share**: Relatively certain market shares based on robust estimates of current nuclear activity; market share growth is dependent on uncertain development of UK reactor IP; however, most business opportunities are associated with untraded activity or areas where the UK has existing strength • **Costs and production techniques:** Uncertain costs for nuclear new build, with dangers of construction overrun; deep uncertainty in costs for immature nuclear technologies, for example SMRs and AMRs.
Offshore wind		• **Deployment**: Offshore wind will be required in any deep decarbonisation scenario, with clear government commitments. • **UK market share**: Expected growth in current market shares given commitments and progress to date. • **Costs and production techniques:** Costs are relatively certain, with clear pathways to 2050.
Tidal stream		• **Deployment**: Global sites for tidal stream are relatively limited, and hence the potential market size well established. • **UK market share**: Although the market is immature, the UK has a an established (and competitive) position. • **Costs and production techniques:** Costs are relatively certain, although the impact of potential scale production is hard to anticipate.
Smart systems		• **Deployment**: High deployment uncertainty given immaturity of smart system market today and evolving business models and regulatory framework. • **UK market share**: Moderate uncertainty given immaturity of the market today and scalable nature of digital smart

		technologies, though there is UK leadership in aggregation services and V2G charging. • **Costs and production techniques**: Moderate uncertainty of cost reductions of batteries and V2G and smart chargers, though costs are expected to continue to fall.

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