Supergen

Offshore Renewable Energy

Delivering Net Zero: the Role of Offshore Renewable Energy

A COP28 Briefing note prepared by the Supergen Offshore Renewable Energy Hub

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Contents

Acknowledgements

This COP28 Briefing Note has been written by the Supergen Offshore Renewable Energy (ORE) Hub as the trusted voice of the wider UK offshore renewable energy community. The Supergen ORE Hub is a £16.5 Million Engineering and Physical Sciences Research Council (EPSRC) programme, 2018 – 2027, which brings together academia, industry, policy makers and the general public to support and accelerate the development of offshore wind, wave and tidal technology for the benefit of society.

The Hub is led by the University of Plymouth and includes Co-Directors from the Universities of Aberdeen, Edinburgh, Exeter, Hull, Manchester, Oxford, Southampton, Strathclyde, and Warwick.

The Supergen ORE Hub is one of three Supergen Hubs and two Supergen Networks+ created by the EPSRC to deliver strategic and coordinated research on Sustainable Power Generation and supply.

Authors

Professor Deborah Greaves OBE
Professor of Ocean Engineering, Director of the Supergen ORE Hub, School of Engineering, Computing and Mathematics, University of Plymouth

Jiaxin Chen
Research Fellow, University of Plymouth

Professor Dave White
Professor of Infrastructure Geotechnics, University of Southampton

Professor James Gilbert
Professor of Engineering, University of Hull

Professor Henry Jeffrey
Policy and Innovation Group, University of Edinburgh

Professor Xiaowei Zhao
Professor of Control Engineering, University of Warwick

Professor Richard Willden
Professor of Engineering Science, University of Oxford

Professor Timothy Stallard
Professor of Offshore & Renewable Energy Engineering, University of Manchester

Professor Byron Byrne
Professor of Engineering Science and Ørsted / Royal Academy of Engineering Research Chair in Advanced Geotechnical Design, University of Oxford

Professor Beth Scott
Professor in Marine Ecology, University of Aberdeen

Professor Feargal Brennan
James Blythe Professor of Offshore Engineering at the University of Strathclyde

Professor Philipp Thies
Professor Renewable Energy - Offshore Reliability, University of Exeter

Lee Richards
Manager of the Supergen ORE Hub, University of Plymouth

Kirsty Henderson
Communications and Engagement Officer, University of Plymouth

Rosie Mascall
Communications and Engagement Officer, University of Plymouth

Executive Summary

In the context of COP28, this report, prepared by the Supergen Offshore Renewable Energy (ORE) Hub, presents a briefing analysis of the role of Offshore Renewable Energy in achieving Net Zero emissions and mitigating the global climate emergency. This report provides a status update and highlights strategic elements of the roadmap to Net Zero and beyond. We also highlight the contributions of the Supergen ORE Hub and we identify key actions for research, innovation, and policy enhancement. This briefing is written for policymakers, researchers, and industry stakeholders, particularly in the UK. We call for faster collaborative action, continuing innovation, and a deep commitment in our professional activity and our wider advocacy, to meet the UK's ambitious climate objectives and mitigate climate change.

Global and UK Context: In 2022, the Earth experienced one of its warmest years, escalating the urgency for effective decarbonization strategies. The UK, in response, has made significant progress, particularly in offshore wind energy, with renewable sources accounting for 41.5% of our electricity generation in 2022. This shift is part of a broader strategy to meet the ambitious Net Zero targets by 2050, in line with global efforts and national policies, including the 2022 British Energy Security Strategy (BESS). The UK's adherence to the Sixth Carbon Budget, as recommended by the Committee for Climate Change (CCC), involves reducing per capita emissions and tracking progress against milestones on a pathway towards Net Zero by 2050. Despite reductions in greenhouse gas emissions, challenges remain, including fluctuations related to the COVID-19 pandemic, the war in Ukraine and the associated challenges with energy supply. The UK's leadership in climate change mitigation is evident in its successful reduction of offshore wind costs and increased capacity. However, the report identifies a need for further policy reforms, increased investment in climate financing and stronger international collaboration to maintain this leadership.

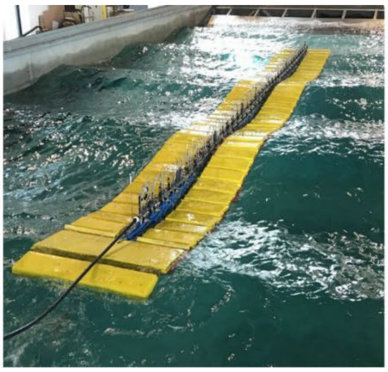
Offshore Renewable Energy's Expanding Role: With the UK's electricity demand expected to double by 2050, offshore renewable energy, particularly offshore wind, is poised to play a crucial role. The report outlines the need for scaling up investment and infrastructure to support this expansion, ensuring that renewable energy sources like wind, wave, and tidal power can together meet their projected share of this demand. Wind energy is already the lowest cost source of new-build electricity generation, as well as being renewable and of low environmental impact. However, our analysis shows that the current rate of UK ORE capacity growth needs to increase by a factor of 5-10, and be sustained until 2050, if we are to develop the ORE capacity required by Net Zero. This represents a massive opportunity for UK business and society, with a vast opportunity for new skilled jobs across many employment sectors and regions of the UK, which will also support the levelling up agenda. To meet this opportunity requires the skills shortage to be addressed and the growth of a newly-skilled workforce in the ORE sector is vital. The report highlights the necessity of comprehensive education and training programmes to meet the industry's growing demands.

Supergen ORE Hub Role: The Supergen ORE Hub, supported by the UKRI EPSRC, is at the forefront of driving innovation and maximizing the societal value of offshore wind, wave, and tidal energy. Post-COP26, the Hub has significantly influenced the shaping of policies and research trajectories to support the UK's Net Zero agenda.

> We have stressed the importance of pioneering new areas such as grid integration and hydrogen-wind energy synergy, and in nurturing new complementary offshore renewable energy technologies.

The Hub’s research landscape, encompassing eight key areas from resource characterization to marine planning, is pivotal in addressing the ORE sector's challenges and seizing opportunities. Meanwhile, our >200-strong network of early career researchers is being equipped as a new generation of experts and advocates capable of advancing ORE technology and policy to 2050 and beyond.

Challenges and Future Directions: Despite progress, the ORE sector faces challenges in meeting capacity targets, managing environmental impacts, and ensuring supply chain resilience. The report calls for immediate action in these areas, underlining the importance of a holistic approach to ORE development. We highlight evidence from other regions and industry sectors to demonstrate that the rapid acceleration we need in ORE can be unlocked, but urgent and bold action is required to fully unlock this potential. All of these actions must be supported by long term stable policy and regulation from government, to attract corresponding levels of commitment from all stakeholders, from investors and developers to researchers, educators, future sector workers and publics.



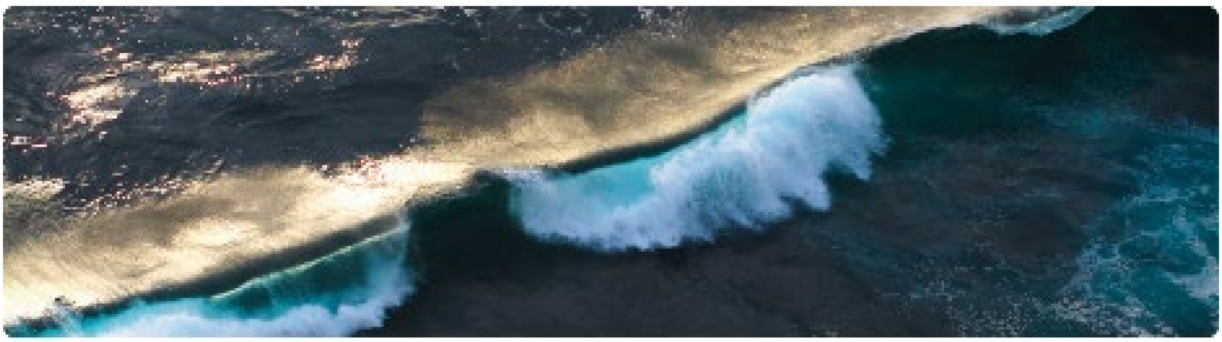
1.0 Context – COP28 and Offshore Renewable Energy

1.1 Introduction

In 2022, the Earth was 1.15°C (± 0.13°C) warmer than the pre-industrial (1850 – 1900) average, which made 2022 one of the six warmest years on record, and the warmest year on record for the UK [1]. Meanwhile, global greenhouse gas (GHG) emissions do not yet show a clear reducing trend, beyond fluctuations associated with the COVID-19 pandemic. Measures to reduce global GHG emissions to Net Zero and below while satisfying the growing demand for energy therefore remains an increasingly urgent challenge for humanity.

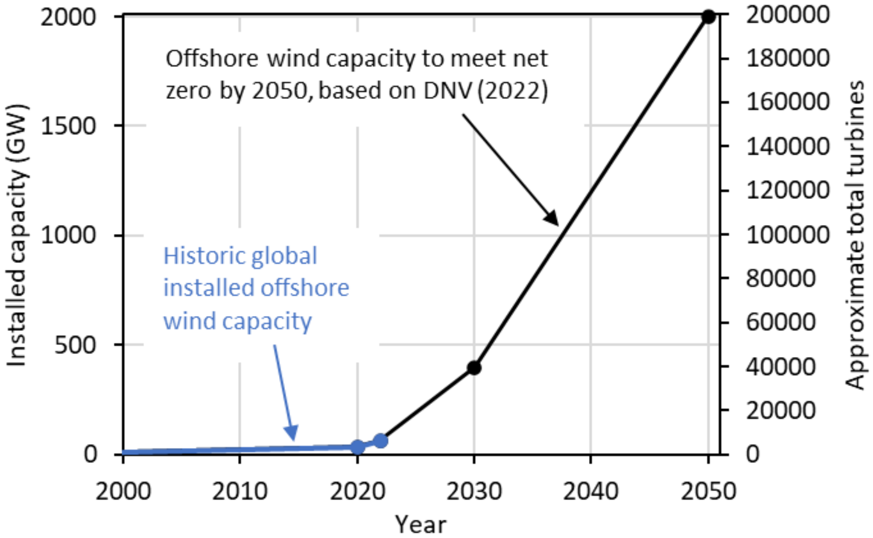
The impacts and risks of climate change due to GHG emissions are becoming increasingly complex and difficult to manage [2], reinforcing the strong need for more effective decarbonisation actions. Geopolitical events since the UK-hosted COP26 have fundamentally influenced decarbonisation pathways and Russia's invasion of Ukraine has increased the urgency for Europe to reduce its reliance on imported oil and gas supplies. The European Commission has implemented the REPowerEU Plan [3] since 2022 to help the EU save energy, produce clean energy and diversify energy supplies. The US has introduced the Inflation Reduction Act with much bigger incentives for low carbon Investments and China has also upped the pace of renewable energy deployment. Globally, these measures are accelerating the decarbonisation of the electricity supply by phasing out unabated fossil fuel generation through a significantly increased capacity for renewable generation.

From the UK perspective, much progress has been made. In 1990, renewables generated just 1% of the UK's electricity supply. Twenty years later in 2010, this had risen to over 6% [2] and in 2022 accounted for 41.5% of the electricity generated in the UK [4]. This transition has mostly been driven by an increase in offshore wind generation and a significant decrease in coal use [2]. The UK Government has committed in the British Energy Security Strategy (BESS) [5] to generating 95% of the country's electricity from low-carbon sources by 2030 and to fully decarbonise the grid by 2035. As the UK's favoured renewable electricity generation technology, offshore wind is supported by policies for the coming decade as part of the Offshore Wind Sector Deal [2].



Since COP26, the targets for renewable energy capacity to help achieve Net Zero by 2050 have progressively increased, as illustrated in Figure 1. An agreement between the UK and the North Seas Energy Cooperation (NSEC) recently committed to achieving a minimum of 260GW of offshore wind in Europe by 2050 [6] and BEIS [4] increased the already ambitious target for UK offshore wind to 50 GW by 2030, much greater than the current installed capacity of approximately 14 GW [7]. For 2050, different scenarios modelled by the Climate Change Committee (CCC) and the ORE Catapult indicate installed capacities ranging from base cases of ~100 GW to beyond 400 GW if the potential export of green hydrogen is included. For comparison, the global trajectory to meet Net Zero, as forecast by DNV [7], involves nine-fold growth of wind power generation from 2,000 TWh in 2022 to 18,300 TWh in 2050, based on an installed offshore wind capacity of 2000 GW by 2050 [8].

a)



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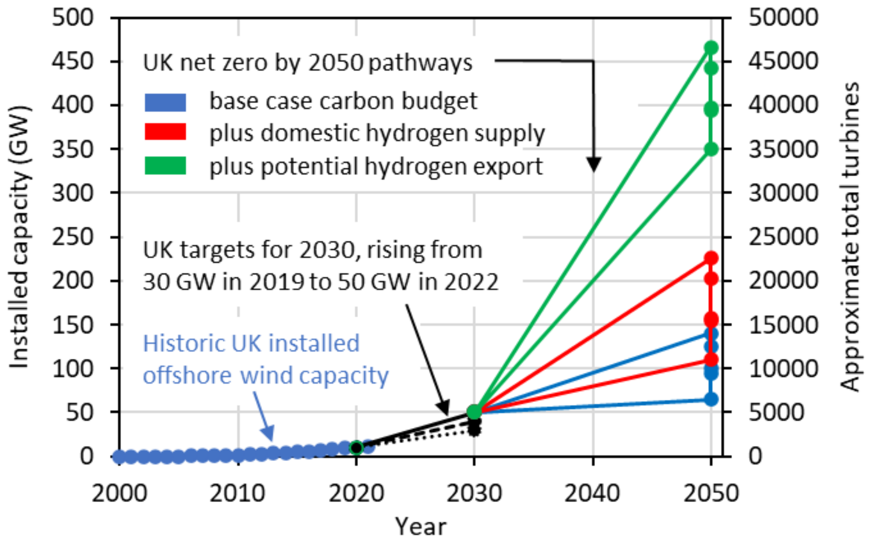


Figure 1 Global trajectory (a) and UK pathways (b) to Net Zero (after [8], [9]).

Approximate total turbines are based on 10 MW/turbine. Since turbine size is increasing, this axis currently underestimates the total, but will in future overestimate it.

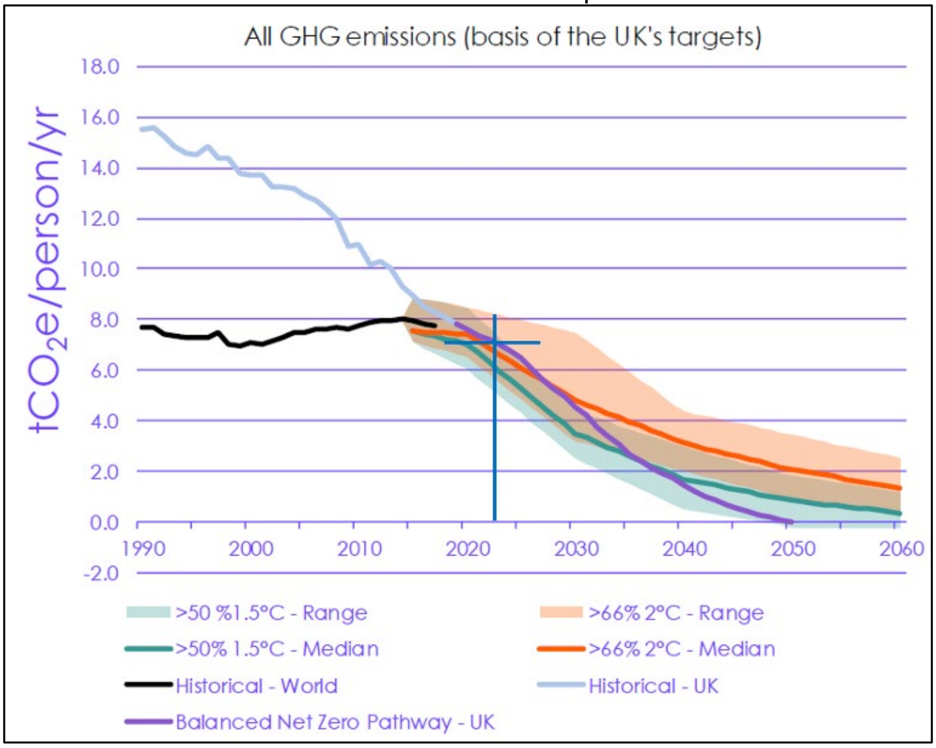
The Supergen Offshore Renewable Energy (ORE) Hub, funded by the UK Engineering and Physical Sciences Research Council (EPSRC) – a part of UK Research and Innovation (UKRI) – is at the forefront of providing research leadership that bridges academia, industry, policy makers, and public stakeholders. We aim to drive innovation and maximize the societal value of offshore wind, wave, and tidal energy. In 2021, the Supergen ORE Hub contributed briefing notes for COP26, underscoring the critical role of ORE in achieving Net Zero. In July 2023, the Hub received a substantial boost, with a £7.5 million grant from the EPSRC, extending the Hub for a further 4 years, aimed at enhancing the impact of existing and future ORE technologies and systems, and propelling the UK towards its Net Zero targets. This report serves as an updated assessment of ORE's evolving role.

The UK's ORE development path links to several main themes of COP28 beyond the ORE industry, encompassing also other industry sectors, social aspects and a range of natural ecosystems. Apart from the deployment and the status of ORE in energy transition (Energy, Industry / Just Transition / Indigenous Peoples scheme), ORE also has broader impact including on ecosystems, lifecycle sustainability (Natural, Land Use, and Ocean scheme), as well as the social impact on future generations (Youth, Children, Education and Skills scheme).

1.2 Tracking Progress against the UK's Sixth Carbon Budget

The CCC [10] has recommended a Balanced Pathway for the UK to achieve Net Zero in 2050 based on the Sixth Carbon Budget, published in 2020. The Balanced Pathway sets the UK emissions limit over the period 2033-37 at 965 $MtCO_2e$, reducing the UK's annual per capita emissions to under 3 tCO_2e per person per year. The year 2023 is the midpoint between the Sixth and the Seventh Carbon Budgets. We are now at the blue vertical line in Figure 2a, at around 7 tCO_2e per capita per year "emissions allowance". To put this value in context, a comparison can be made with the carbon emissions per person travelling in economy class on a return flight from London to Dubai to attend COP28. These are estimated to be approximately 2 tCO_2e [11]. A single return flight to Dubai therefore represents more than a quarter of a UK citizen's personal 2023 "emissions allowance". The CCC reports on data that tracks the UK's progress towards Net Zero [12]. From Figure 2b, UK greenhouse gas emissions were 450 $MtCO_2e$ in 2022, which is 46% below 1990 levels. Since 2021 this is a relatively small 0.8% increase in emissions but remains 9% below pre-pandemic (2019) levels. However, there is no sign yet of decreasing emissions beyond the fluctuations related to the COVID-19 pandemic [12].

(a)



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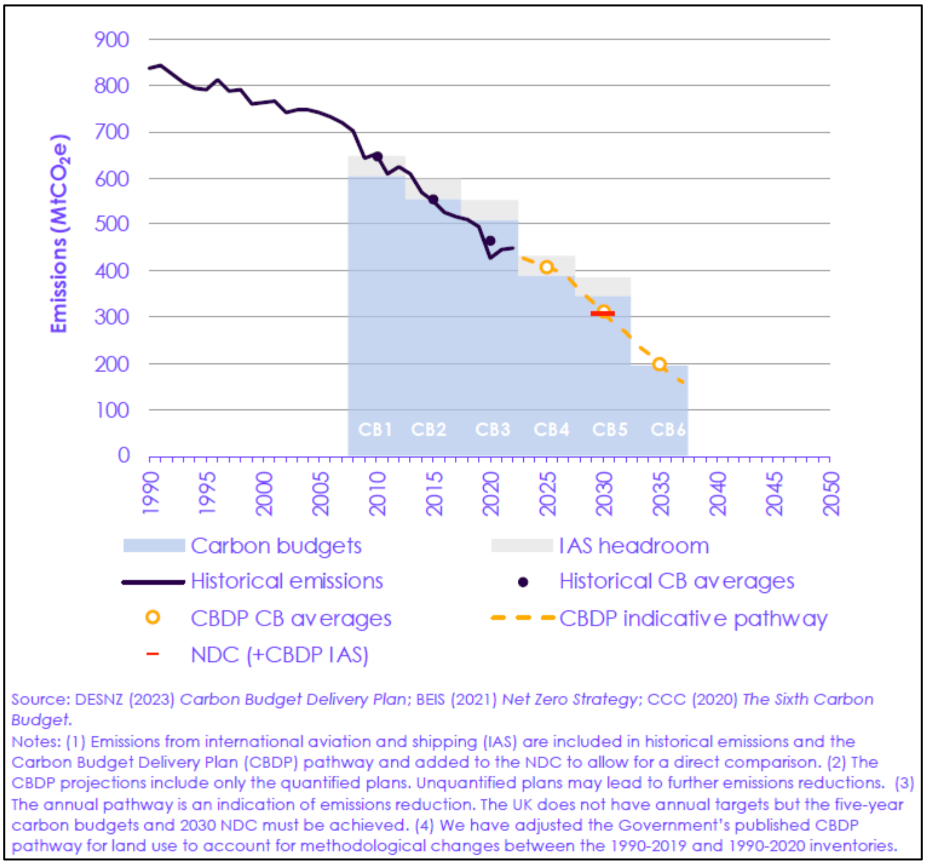


Figure 2: The track of *The Sixth Carbon Budget and the UK's pathway to Net Zero. (a) All GHG emissions per* capita *per year* on the basis of the UK's targets. *(b) The progress of* the UK's pathway to Net Zero.

1.3 Actions Required for the UK to Maintain Leadership in Climate Change Actions

The UK-hosted COP26, built on the UK's long record of global leadership on climate change action. A key milestone in this progress was the 22nd report of the Royal Commission on Environmental Pollution - "Energy and Climate Change" – published in June 2000, which ultimately led to the 2008 Climate Change Act. This Act commits the UK Government by law to reduce greenhouse gas emissions to Net Zero by 2050. The UK Government has committed to decarbonising the electricity supply by 2035, subject to ensuring security of supply, along with ambitious targets for building new renewable and nuclear plants. In the Carbon Budget Delivery Plan announced in March 2022 [13], the UK Government expressed increased confidence in hitting the present Carbon Budget over the next four years. However, no overarching plan or strategy for delivering a decarbonised and reliable electricity system is entirely resilient [12].

Key examples from the UK's track record and future action points:

Mitigation

The cost of offshore wind in the UK has fallen from £150/MWh to £48/MWh over the last decade and is now cheaper than gas generation [11]. As a result, total operational capacity in the UK now stands at 13.7GW, accounting for 45% of the European offshore wind total and 24% of the global offshore wind total [12]. The UK has a mature market, supply chain, workforce, infrastructure and academic support for offshore renewables [12]. As a result, the average carbon intensity of UK electricity reduced from 529 gCO2e/kWh in 2013 to 182 gCO2e/kWh in 2022 [13], February 2022 became the greenest ever month with 126 gCO2e/kWh and 26 December 2022 matched the lowest carbon intensity record with 39 gCO2e/kWh [13].

Adaptation

The UK Government's third Climate Change Risk Assessment (CCRA3) [14] identified sixty-one risks cutting across multiple sectors of society, and a wide range of potential costly impacts of climate change, including on health and productivity, affecting households, businesses and public services. The technical report [15] also highlighted that adaptation is regarded as a core economic priority, as well as mitigating risk to life. For example, unless further action is taken, under a 2°C by 2100 warming scenario, annual economic losses from flooding to non-residential properties across the UK are expected to increase by 27% by 2050 and 40% by 2080. At 4°C this increases to 44% and 75% respectively.

Finance

Meeting climate financing needs in the UK demands a substantial investment program, estimated at approximately £50 billion annually from 2030 to 2050. While spearheaded by the government, the program will largely rely on funding and execution by private companies and individuals [8]. Future emission reductions will require the population and the private sector to be actively involved, with a just transition where fairness must be embedded throughout policies to secure public support as well as private investment. The International Climate Finance (ICF) Strategy has outlined the Government's priorities and principles for delivering the £11.6 billion of ICF they have pledged to spend between 2021 and 2026 [10].

Collaboration

The UK has been a strong contributor to international climate finance, recently doubling its commitment to £11.6 billion in aggregate over 2021/22 – 2025/26 [8], along with other UK contributions to technology development, policy and capacity building. Engaging academia, young people, investors, civil society, and business will be vital to delivering Net Zero.

More recently, in the build-up to COP28, the UK Government has presented a weaker stance on climate change action, contrasting to the UK's historic global leadership position. Recent Government announcements and policy changes have increased the risk of not meeting the Sixth Carbon Budget targets for 2033-2037). For example:

- Following the Prime Minister's announcement on 20th September 2023 to delay the phase-out period for fossil fuel vehicles from 2030 to 2035 [14], the Government has set out the percentage of new vehicles that must have zero tailpipe emissions each year up to 2030. This reduced Government ambition for the EV transition undermines the confidence of consumers, supply chains and investment relating to EVs.
- The new Rosebank North Sea oil field has been approved by the UK Government amid an environmental backlash and against the advice of the CCC, while future licenses for oil and gas projects in the North Sea are now set to be awarded annually [14]. The oil and gas produced by Rosebank will create 200 MtCO2e when burned for energy over the operating life (i.e., almost half of the current UK annual emissions), yet the oil will be primarily sold on the global market, making a negligible contribution to energy security or consumer energy prices.
- Plans for a new coal mine in Cumbria were approved in 2022 [15]. This will increase UK emissions by 0.4 MtCO2e/year, and has been licensed to 2049, beyond the period when UK steelmaking is expected to require coal, based on the Sixth Carbon Budget [16].
- The Offshore Wind Allocation Round 5 (AR5) [17] offering Contracts for Difference (CfDs) for new lease areas failed to attract any bids for offshore wind projects. This was blamed on the Government's choice of maximum power price being set too low [18].

However, there are positive signs. In the AR5, despite the missing bids for offshore wind projects, 11 Tidal Stream projects were awarded contracts. On November 16, 2023, the UK government declared an increase in the administrative maximum strike prices for the upcoming sixth CfD Allocation Round (AR6), scheduled to commence in March 2024. The revised maximum price for offshore wind projects has seen a significant hike of 66%, escalating from £44/MWh to £73/MWh. Additionally, the cap for floating offshore wind projects has been raised by 52%, moving from £116/MWh to £176/MWh in anticipation of AR6 next year. This adjustment is seen as a substantial encouragement for the offshore wind sector.

Despite the good news on the AR6 announcement, there is still an urgent need to re-establish strong British leadership on climate change to inspire global action, meet the domestic requirements of the Sixth Carbon Budget and to unlock the economic potential of a green industrial revolution. Significant policy leaps are needed to achieve this [12], taking a stable and consistent approach through which global consensus can build.

As a backdrop to the recent events highlighted above, it is useful to summarise the current cost and impact of ORE relative to other energy sources.

Energy Cost

In the comparison with other energy sources, offshore wind ORE is lower cost than gas and nuclear. Hinkley Point C nuclear power station has a strike price of £92.50/MWh. Tidal stream ORE, like nuclear, offers predictable baseload power. With reliable policy support, the cost of wave and tidal stream ORE is likely to follow the same cost reduction trajectory as seen in offshore wind. The cost of tidal stream is predicted to halve by 2035, reaching the same level as nuclear [18].

Carbon Emissions

Offshore wind power provided to the UK electricity grid replaces fossil fuel-based energy. During 2022, the UK's 13.7 GW of offshore wind capacity delivered 45 TWh of electricity, eliminating 17 MtCO2e of emissions [19]. Scaled to a 30-year operating life of a single 2 GW wind farm, this corresponds to a lifetime saving of 77 MtCO2e by each farm.

Acceleration of the rollout of offshore wind allows the emissions from fossil fuels to be abated sooner. If the UK's growth to a target of 200 GW by 2050 can be accelerated by one year, a total of 236 MtCO2e will be saved.

Climate Change and Public Health

Carbon emissions cause climate change, which endangers life. The excess deaths caused by carbon emissions can be estimated from integrated climate impact models. It has been estimated that 4,400 tCO2e emitted now will cause 1 excess death this century [20].

This Mortality Cost of Carbon (MCC) can be used to indicate the scale of the global mortality impact from carbon emissions linked to ORE and other energy sources.

- The 77 MtCO2e saved by a 2 GW wind farm eliminates 17,000 excess deaths
- Growing UK's offshore wind to 200 GW a year quicker would eliminate 53,000 excess deaths.
- The 200 MtCO2e of emissions from the Rosebank field scales to 45,000 excess deaths.
- The total 2022 UK GHG emissions of 417 MtCO2e scales to 94,000 excess deaths.
- The COVID-19 pandemic has caused ~200,000 excess deaths in the UK.

2.0 What is Offshore Renewable Energy's role in Net Zero?

2.1 Introduction

UK electricity demand is expected to double from current levels by 2050, reflecting the electrification of sectors across the economy [19]. The CCC Net Zero Balanced Pathway [10] represents a decisive transition to Net Zero, with over 60% of the necessary reduction achieved in the next 15 years and the fastest rate of decarbonisation occurring in the early 2030s. Based on the current energy mix of the UK grid, a 2 GW wind farm based on the UK's energy grid will eliminate 77 MtCO2e over a 30-year operating life (based on the emissions displacement analysis used in [20]. Therefore, the key challenge in the next decade is to scale up investment, markets and supply chains to enable all new energy investments to be zero carbon by the early 2030s.

2.2 Increasing Variable Renewables to 80% of UK Generation by 2050

Under the Balanced Pathway, variable renewables reach 60% of generation by 2030, 70% by 2035, and 80% by 2050. This generation allows new electricity demands to be met with minimal emissions and at low cost. Offshore wind is the backbone of the system, providing 265 TWh of generation in 2035 and 430 TWh in 2050, from an installed capacity of 95 GW (under an alternative Widespread Innovation Pathway, the CCC forecast a capacity as high as 140 GW). These forecasts require deploying 3-5 GW of new offshore wind capacity each year, as well as repowering of older sites as they reach the end of their (25-30 year) operating lives.

In 2022, the mean turbine capacity for initiated projects reached 9MW, marking a nearly fivefold growth from the size of the initial commercial offshore turbines set up two decades ago. The UK's turbine fleet is maturing, with several of the older locations nearing their 20th year of operation, marking a significant transition for the UK.

> As we relentlessly pursue new developments to meet the UK's 2050 net zero goal, it is equally crucial to extend the operational life of existing installations to continue low-carbon energy production off the UK's coasts [20].

The expanding deployment of offshore wind will enter new geographical regions, which reduces the dependence on local wind conditions, contributing to a more stable supply. However, this expansion requires the use of sites further from shore in deeper waters and of new coastal regions where ports and grid connections necessitate development. In particular, the scale of anticipated floating offshore wind platforms and required industrial production requires port infrastructure investments [36].

The Supergen ORE Hub has modelled the potential new sites for offshore wind in UK waters (see Figure 3). Our work integrated metocean, geoscience, ecological and anthropogenic features and constraints with the engineering requirements. This allowed us to quantify the current ocean 'crowdedness', which leads to a suitability ranking of new sea regions. Future offshore wind sites that are equally or less crowded compared to current leases are highlighted in blue on Figure 3, and have been filtered into continuous sea areas capable of hosting a 2 GW offshore wind farm. This analysis highlights the need to eliminate the water depth barrier through floating OW technology, open up new sea regions such as the Celtic Sea, and the associated port and grid infrastructure. To meet the Widespread Innovation pathway of 140

GW of offshore wind requires 7% of this space to be filled, while the higher forecasts that include hydrogen generation for export require up to 44% of this space to be developed. ORE development on these scales will require enhanced marine spatial planning, as well as new frameworks that include cumulative effects from the base of the marine food chain for managing and monitoring impacts on ecosystems and other ocean stakeholders [21].

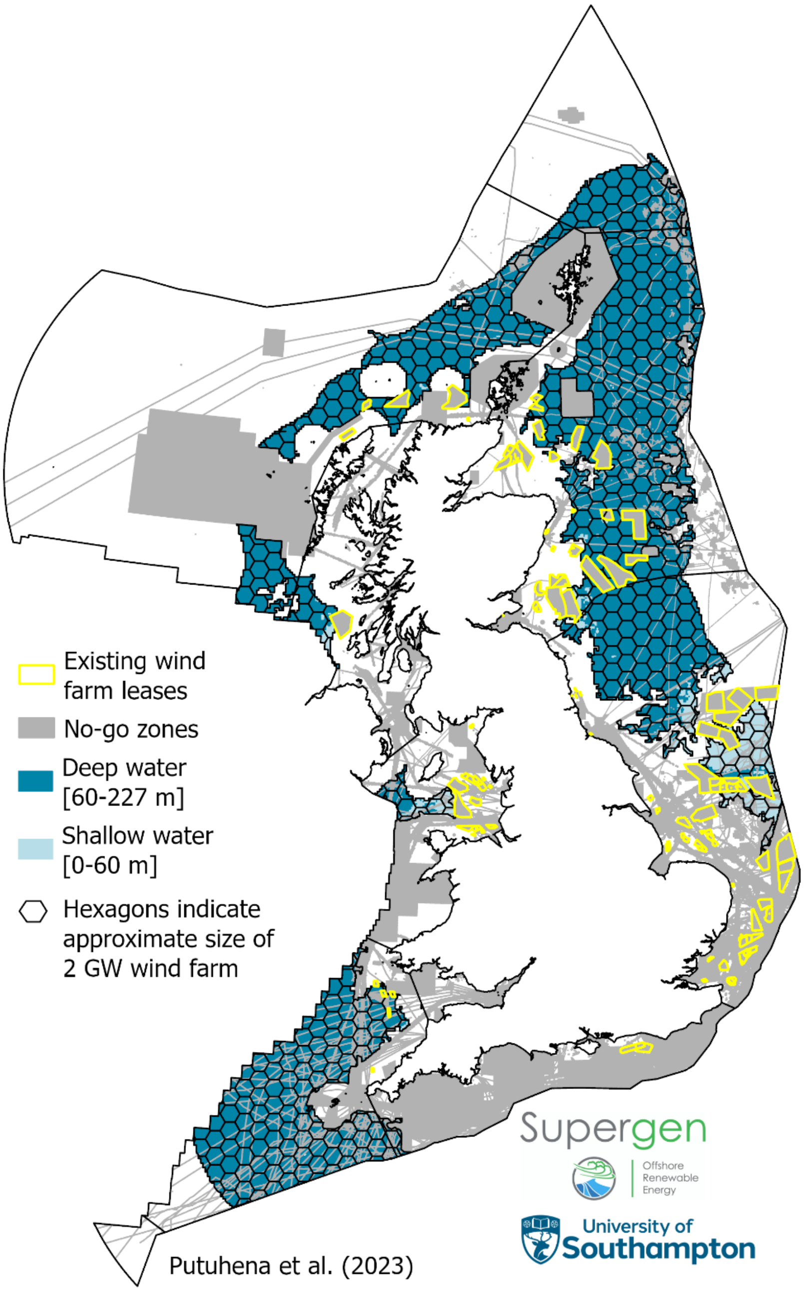


Figure 3 ORE Supergen Hub analysis of potential new sites for offshore wind in UK waters [22].

2.3 A Flexible Future Electricity System

Some flexible low-carbon generation (e.g., gas or bioenergy with carbon capture and storage (CCS), or hydrogen) will be required, and green hydrogen produced from renewable electricity can offer a flexible form of dispatchable generation similar to unabated gas.

A more flexible electricity system will help balance out the variability in renewable generation, addressing both demand (e.g., demand-side responsiveness, and use of surplus renewable power to produce hydrogen) and supply (e.g., use of electricity storage). In addition, tidal and wave technologies provide predictable power into a variable renewables-driven system and have scope for upscaling.

Storage. With an increasing share of variable renewables, storage can capture surplus energy when demand is low and provide backup generation when demand is particularly high.

- **Use of surplus electricity.** The Balanced Pathway has an important role for electrolysers to produce hydrogen at low cost from surplus generation. In the Balanced Pathway, 25% of hydrogen supply comes from electrolysis in 2035, increasing to 45% by 2050.
- **Interconnectors.** Interconnectors between the UK and neighbouring countries allow the sale of surplus energy to neighbouring markets and provide access to resources in other countries. However, until the power systems in the rest of Europe become fully decarbonised, there is uncertainty around the carbon intensity of imported electricity.

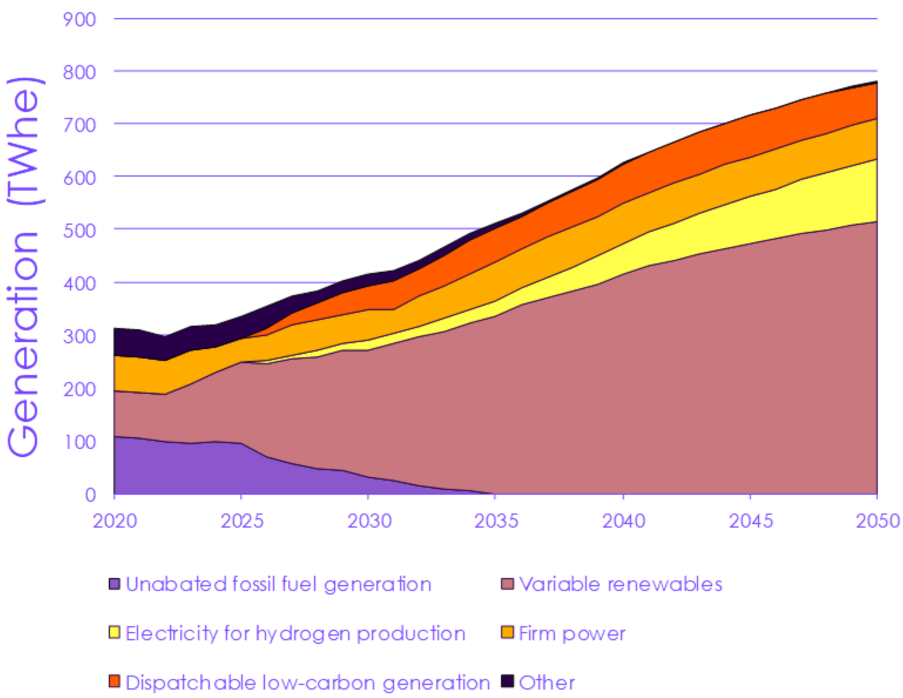


Figure 4 Illustrative UK electricity generation mix for the Balanced Net Zero Pathway (2020-50) [10].

- **Industrial opportunities and Just Transition.** The investment required to expand renewable generation, and to develop new markets in CCS and hydrogen, will help create new opportunities for firms, exports, and jobs. New ORE, hydrogen and CCS industries could also help support the Government's 'levelling up' agenda through investment in regional economies, and by providing new jobs.

- **Exports.** There is a significant opportunity for the UK to export engineering expertise, components, and services to the rapidly growing EU and global market for offshore wind and other offshore renewables. There is also potential for the UK to be a net exporter of zero carbon energy, given our extensive ORE resources.

Rapid Offshore Renewable Energy (ORE) expansion is essential to the UK for (i) Net Zero and climate change mitigation, (ii) energy security, (iii) green growth and jobs.

Net zero and climate change mitigation

Given that the UK's first offshore wind farm was commissioned in 2000 and a total of 13.9 GW installed capacity was achieved by the end of 2022 [24], ORE would need to be deployed 6 times faster than the current rate to reach 50 GW by 2030 and 140 GW by 2050. If we are to meet the UK plans for Net Zero, Energy Security and Just Transition, there needs to be a significant ramp up in underpinning research and in skills and training – it cannot be business as usual.

Energy security

ORE growth will mitigate the effects of the cost-of-living crisis and geopolitical instability. ORE can minimise consumer energy costs, but many research and engineering challenges need addressing to realise the scale and rate of deployment required. A fourfold reduction in project consenting time is targeted, requiring a whole system approach with interdisciplinary collaboration underpinned by an integrated research and innovation ecosystem.

Green growth and jobs

The UK's ORE industry growth underpins new high-skilled jobs, often in areas of the UK in most need of investment, supporting the levelling up agenda. With a local and abundant resource, rapid expansion of ORE for Net Zero could help to achieve a Just Transition with economic and social benefits, keeping the UK as a world leader in deployment and technology for ORE.

2.4 Education and Skills

To meet the rapid growth required in ORE, the sector's ability to attract skilled workers and researchers for existing projects and the development of future technologies will be crucial.

The *Net Zero Energy Workforce Report* by National Grid [23] estimates that in 2018 there were 114,500 jobs in renewable energy (one third of them in the wind industry), out of 144,000 people directly employed in the energy sector. The report by Renewable Energy View [24] suggests that the economic potential of the UK renewable energy sector can support more than 210,000 jobs by 2035. Furthermore, it is estimated that the industry needs to recruit 400,000 jobs between 2020 and 2050 to achieve Net Zero in the UK, [23].

The skills shortage is recognized in the UK Government's Energy White Paper as a major challenge to power the Net Zero future [19]. Their proposed approach involves seven key domains: channelling funds into research and development, establishing dedicated doctoral institutions, introducing transition programs for graduates, expanding community-based training initiatives, preserving the existing expertise from the oil and gas sector, fostering partnerships within industry, and implementing proven strategies from existing agencies [25].

A core component of the Supergen ORE Hub is supporting a network of Early Career Researchers (ECRs) across the ORE Academic sector. This network aims to connect ECRs with more senior researchers and others working in ORE, in the UK and internationally, to create a diverse and supportive community that nurtures the next generation of ORE research leaders.

In July 2023, the Supergen ORE Impact Hub was awarded an additional £7.5 million by the EPSRC together with £4 million from key partners, to accelerate the impact of current and future ORE devices and systems and to drive the UK towards its Net Zero commitments. Through its Flexible Fund, the Hub plans to invest at least £2.8 million in new and emerging research across the UK, in addition to creating additional opportunities for ECRs.

The Supergen ORE Hub also seeks to embody best practice in terms of supporting Equality Diversity and Inclusion (EDI) and to capture and disseminate the benefits that this can bring. This is aligned with UK Government policies such as the Wind Sector Deal EDI target of one third of the workforce being female by 2030. Through partnership with other organisations, we seek to influence the wider ORE industry and promote offshore renewables as a supportive and rewarding career. Our activities span all career stages – from the promotion of ORE as a green STEM career to school children, to collaborations with SMEs and larger companies seeking to enter the ORE supply chain.

As the ORE sector rapidly matures, there is an opportunity to shape its development and embed better EDI practices for the long term. Through these initiatives, the Supergen ORE Hub aims to safeguard and enhance the sustainability of the ORE workforce to meet future needs.

3.0 Current Status of Offshore Renewables

3.1 Current Status: Offshore wind

In 2022, UK offshore wind capacity accounted for 24% of global capacity, second only to China. The UK remains ambitious to make offshore wind a central part of decarbonising the energy system to achieve Net Zero:

- In 2022, 2.7 GW of new offshore wind was installed in the UK [26], and offshore wind provided a record 12% of the UK's energy generation [27].
- In 2020, the Offshore Transmission Network Review (OTNR) was initiated by the Government to ensure the optimal delivery of transmission connections for offshore wind generation aiming to meet the 50GW offshore target by 2030. This initiative takes into account environmental impacts, costs to consumers, the interests of local communities, and the feasibility of implementation.
- After COP26, the Crown Estate Scotland announced the ScotWind Offshore Wind Leasing Round. Initially, 17 projects were selected in April 2021 with three additional projects joined in October 2022 to boost Scotland's Net Zero aspirations [28]. Fourteen of the 20 projects will utilise floating wind turbines.
- The Crown Estate increased its target to 4.5 GW Floating Offshore Wind (FLOW) projects in the Celtic Sea by 2030 [29], able to provide power to more than 4 million homes.
- In the CfD AR4 published by the Department of Business, Energy and Industrial Strategy on 7 July 2022, the TwinHub Floating Offshore Wind (FLOW) Farm project secured support for a 32 MW development at the WaveHub site [30].
- The cost of new offshore wind has fallen by over 50% since 2015 making it one of the lowest cost options for new power in the UK [31].
- The fifth CfD Allocation Round (AR5) [17] failed to receive any bids for offshore wind projects, attributed to the set maximum power price being considered too low [18].
- In contrast, the UK government's announcement on November 16, 2023, regarding the sixth CfD Allocation Round (AR6) revealed substantial increases in administrative maximum strike prices. Specifically, there was a 66% increase for offshore wind projects and a 52% increase for floating offshore wind projects. This change is perceived as a significant encouragement for the offshore wind sector.

3.2 Current Status: Wave and Tidal

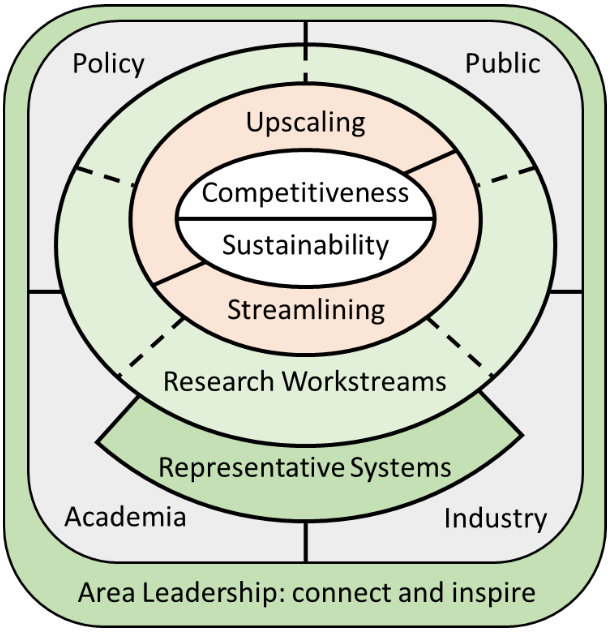
The UK holds 35% of Europe's wave resource and 50% of its tidal resource. Up to 20% of UK energy demand could be met by marine energy. The UK has the global lead in wave and tidal energy development, and leads hybrid Wind + Wave energy innovation, generating economic benefits.

- According to energy system modelling, the UK has large potential to deploy marine energy technologies, with 6.4GW of wave and 6.2GW of tidal stream deployments possible for the UK by 2050 if the 2030 Strategic Energy Technology Implementation Plan (SET Plan) targets for cost reduction can be reached [32].
- There are currently four tidal stream energy sources in the UK producing 10.5MW of power [33].
- Research shows that the resultant value from these marine energy deployments would be up to £8.9bn Gross Value Added [32].
- System benefits of wave and tidal energy can increase the value of other renewable energy investments [32].
- Research shows that the reliability estimates for tidal energy installations are similar to offshore wind at a comparable stage of operating hours [34].
- Historically ocean energy technologies have struggled to gain a CfD through the competitive auction process as they compete in the same CfD 'pot' as offshore wind.
- The Tidal Stream Industry Energiser Project [35], known as TIGER, partly funded by the European Regional Development Fund through the Interreg France (Channel) England Programme from 2019 to 2023, has ambitiously targeted to install up to 8 MW of additional energy capacity to achieve an accelerated cost reduction pathway.
- Following the Government's announcement in 2021 that there would be a separate £20 million ring-fenced fund available solely for the tidal stream sector. AR4 was a major milestone, with four CfD contracts being awarded to tidal energy projects with a total capacity of 40.82MW at a strike price of £178.54/MWh.
- In the recent AR5, 11 Tidal Stream projects were awarded contracts with sizes ranging from 1.5 MW to 11.8 MW over Scottish and Welsh waters at a strike price of £198 /MWh.
- For the recent CfD AR6, the administrative maximum strike prices were established at £261 /MWh for Tidal Stream [36]. These represent increases of 29% compared to the strike prices set in the previous CfD AR5 [17].
- To accelerate wave energy development, UKRI invested £8 million in the conceptual design of instrumental and computational technologies to enable UK leadership in next-generation wave energy infrastructure [37].
- Small scale, high market value wave energy deployments used to power offshore installations and small island states are providing valuable development and experience for future scale up [38].
- In the recent CfD AR6, the administrative maximum strike prices were established at £257 /MWh for Wave energy projects [36], a 4.9% increase compared with the administrative maximum strike price in CfD AR5 [17].

4.0 The Role of ORE Research and the Supergen ORE Hub

With an increased focus on delivering and enabling impact, the Supergen ORE Hub will drive faster ORE expansion via four high level objectives, and its engagement across academic, industry, policy and public stakeholders:

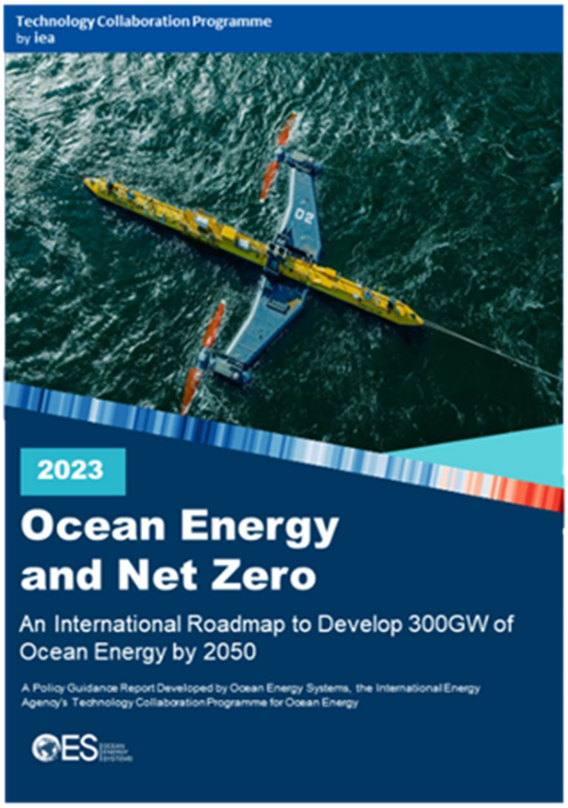
- **Streamlining** ORE projects, by accelerating planning, consenting and build out timescales
- **Upscaling** the scale and efficiency of ORE devices and systems, and the ORE workforce
- **Competitiveness**: maximising ORE local content and economic viability in the energy mix, to maximise UK benefits of the drive to Net Zero
- **Sustainability:** ensuring positive environmental and societal benefits from ORE



Our work is delivered through research workstreams that include the development of representative ORE systems to bridge between academia and industry, as well as our leadership across the ORE area, to connect and inspire.

ORE Research	Supergen ORE Hub
• Offshore Wind deployment needs to accelerate in the 2020s backed by new research to overcome challenges. • Accelerate Innovation – Research working with industry and government to reduce costs and speed up project development. • Consider and investigate a range of constraints, including seabed availability, wildlife and cumulative impacts. • Develop new technologies – floating offshore wind, wave and tidal. • Build social value and long-term sustainability into project developments. • Consistent and stable innovation policy with a pipeline of projects for investment.	• Enhancing the impact of existing and future ORE technologies and systems and propelling the UK towards its Net Zero targets. • Increase collaboration through Internationalisation. • Take a whole system approach to ORE research, including cumulative ecological impacts and identify synergies between offshore wind, wave and tidal. • Develop links with other research Hubs: energy storage, energy networks, robotics, health & safety and resilience. • Develop People Skills and infrastructure, supporting researchers of the future. • Champion a Just transition through a culture promoting Equality, Diversity and Inclusion.

4.1 Supergen ORE Hub Policy Guidance



Between 2021 and 2023, the Supergen ORE Hub has also led the production of a series of policy guidance reports, intended to help prospective policy makers form clear, consistent and coordinated policy frameworks that help to accelerate the development of the ocean energy sector.

This series of reports and the modelling and analysis that underpin them have also helped to inform the production of the upcoming global ocean energy roadmap, published by Ocean Energy Systems, the International Energy Agency's technology collaboration programme for ocean energy, entitled "Ocean Energy and Net Zero: An International Roadmap to develop 300GW of Ocean Energy by 2050" [38]. This report provides a roadmap to achieving the deployment of 300GW of ocean energy by 2050 and outlines clearly the different policy support mechanisms that will be required, as well as supply chain and infrastructure development and updating of regulatory and legislative frameworks. This report also includes a comprehensive list of policy actions that are aligned with the high-level results delivered in the Supergen ORE Hub series of reports.

5.0 Supergen ORE Hub Research Landscape

The Supergen ORE Hub Research Landscape summarises the research needs in ORE identified by the community through a series of consultation workshops involving stakeholders from academia, industry, policy and NGOs. It is accessible through the interactive web-based landscape tool (available to access here), which brings together and helps communicate UK-based offshore wind, wave, and tidal energy research. The Research Landscape enables industry, government, and researchers to share opportunities and challenges across eight research themes. The Supergen ORE Hub, through its core research programme and flexible funding calls, is taking a strategic approach to tackling these challenges.

Theme A: Resource and Environment Characterisation	Better measurement techniques for forecasting and resource characterisation
	Improved modelling tools for resource and loading assessment
	Resource and environmental characterisation in physical modelling facilities
	Long-term sediment transport measurement and modelling
Theme B: Fluid- Structure-Seabed Interaction	Realistic fluid-structure-seabed design tools that work together, not in isolation.
	Novel device concepts – rethinking the mechanism of energy extraction
	Moorings, anchors and foundations
	Multi-purpose hybrid systems for ORE and ocean resources
	Design of reliable cabling systems
Theme C: Materials and Manufacturing	Structural Integrity in the Marine Environment (corrosion, fatigue, coatings)
	Serial (volume) manufacturing of complex structural systems
	Design for safe and cost-effective installation methods
	New materials and coatings
	Recycling/reuse of composites
Theme D: Sensing, Control and Electromechanics	Control of ORE farms
	Smart sensor system use
	Drive train design
	Power Electronic Conversion
Theme E: Survivability, Reliability and Design	Higher and more consistent reliability through risk-based design
	Extending limits to operation or performance by mitigating extreme actions
	Innovative sub-systems to provide higher and more consistent reliability and better performance.
	Sustainable whole-life design methods
	Design tools for arrays
	Whole systems approach to operate large scale ORE
Theme F: Operations, Management, Maintenance and Safety	Analysis of remote sensing and condition monitoring data.
	Use of autonomous systems for inspection.
	Data and digital cyber security.
	Increased use of automation to reduce risk in installation and operation (O&M).
Theme G: Environmental and Ecosystem Aspects	Fit-for-purpose approaches to environmental monitoring
	Development of population level environmental impact models
	Ecosystem Modelling
Theme H: Marine Planning Governance	Communication: Ocean literacy and public perception of ORE
	Interaction with other marine users
	Development of market mechanisms for ORE
	Reducing uncertainty of both technology and social costs of ORE

6.0 ORE Challenges and Recommendations

The challenges within the Offshore Renewable Energy (ORE) sector are diverse and require targeted strategies. These challenges can be categorised into streamlining, upscaling, competitiveness, and sustainability of ORE, which are also the key high-level objectives of the Supergen ORE Hub. A further overarching challenge is the skills shortage and public education within these themes.

Streamlining Processes and Policies

- **Meeting Capacity Targets:** A primary concern is the urgency to reach offshore wind capacities of 50 GW by 2030 and 140 GW by 2050 to meet climate commitments.
- **Policy Reform for Rapid Deployment:** Offshore wind is crucial for achieving Net Zero; hence, policies must be revised promptly to streamline the commissioning of wind farms.
- **Leasing and Consenting Acceleration:** There is a need to hasten leasing and consenting to mitigate start up delays in ORE project deployment. The UK government's new Environmental Outcomes Report (EOR) proposes a reform that streamlines environmental assessment [39]. This reform simplifies environmental assessments, focusing on key environmental issues with robust data, potentially speeding up project approvals and aligning with the sector's need for efficient process management.

Upscaling Infrastructure and Integration

- **Holistic Network Delivery:** The Pathway to 2030 Holistic Network Design outlines the requirements for connecting 23GW of offshore wind, a delivery that poses a significant challenge.
- **Offshore wind design tools improvement:** It is important to accelerate the development and validation of design tools for turbines and farms to underpin investment decisions and enable effective marine spatial planning.
- **Grid Integration Research:** There is an immediate need for breakthroughs in understanding the dynamics of larger wind turbines and their integration into power grids.
- **Hydrogen-Wind Energy Convergence:** The synergy between hydrogen production and wind energy conversion calls for accelerated scaling within the industry.
- **Educational Initiatives and Skills Development:** The skills shortage and gap through educational programs and training in expertise needed for ORE technologies should be highlighted.

Enhancing Competitiveness

- **Global Best Practices:** Experiences from countries like China illustrate that expedited ORE deployment is technically achievable, providing a blueprint for others.
- **Cost Competitiveness:** To meet the ambitious wave and tidal installation capacity goals, tidal and wave energy technologies face an urgent imperative to reduce costs, in line with the SET Plan [40] targets, to become viable competitors in the renewables sector and realise their potential in wider system benefits.

- **Public Education and Engagement:** Enhancing public understanding of ORE benefits to gain community support and foster a receptive environment for renewable projects is of great value in supporting the energy transition.
- **Resource limitations:** The escalating global deployment of offshore renewables is creating a competitive environment, with different countries vying for limited resources. These include financial investment, installation vessels, manufacturing capabilities and, ultimately, a share of the growing market.

Fostering Sustainability

- **Conscious Site and Environmental Management:** The rapid deployment of ORE must be balanced with careful consideration of seabed use, wildlife conservation and broader ecosystem implications as well as other sea-users such as shipping and fishing.
- **Supply Chain Resilience:** Accelerating ORE deployment necessitates a robust supply chain capable of sustaining profitability amid swift growth and market volatility.
- **Circular Economy:** drive down the carbon footprint of ORE infrastructure and operations and design in marine net gain to ensure benefits are realised by communities and are sustainable over time.

References

[1] World Meteorological Organisation, 'State of the Global Climate in 2022'. Accessed: Oct. 23, 2023. [Online]. Available: https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate

[2] P. Johnstone, K. S. Rogge, P. Kivimaa, C. F. Fratini, E. Primmer, and A. Stirling, 'Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom', *Energy Res. Soc. Sci.*, vol. 59, p. 101287, Jan. 2020, doi: 10.1016/j.erss.2019.101287.

[3] European Commission, 'REPowerEU'. Accessed: Nov. 17, 2023. [Online]. Available: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

[4] BEIS, 'UK ENERGY IN BRIEF 2023', 2023. [Online]. Available: https://www.gov.uk/government/statistics/uk-energy-in-brief-2023

[5] HM Government, 'British energy security strategy', GOV.UK. Accessed: Oct. 25, 2023. [Online]. Available: https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy

[6] NSEC, 'Joint Statement on the North Seas Energy Cooperation - 12 Sept 2022'. 2022.

[7] BEIS, 'UK signs agreement on offshore renewable energy cooperation', GOV.UK. Accessed: Oct. 24, 2023. [Online]. Available: https://www.gov.uk/government/news/uk-signs-agreement-on-offshore-renewable-energy-cooperation

[8] DNV, 'Energy Transition Outlook: A global and regional forecast to 2050', 2023.

[9] B. Cerfontaine, D. White, K. Kwa, S. Gourvenec, J. Knappett, and M. Brown, 'Anchor geotechnics for floating offshore wind: Current technologies and future innovations', *Ocean Eng.*, vol. 279, p. 114327, Jul. 2023, doi: 10.1016/j.oceaneng.2023.114327.

[10] CCC, 'The Six Carbon Budget', 2020. [Online]. Available: https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf

[11] Flight Free USA, 'Explore The Climate Impact of Flying', FLIGHT EMISSIONS CALCULATOR. Accessed: Nov. 13, 2023. [Online]. Available: https://flightfree.org/flight-emissions-calculator

[12] CCC, 'Progress in reducing UK emissions - 2023 Report to Parliament', 2023.

[13] HM Government, '2030 Strategic framework for international climate and nature action', 2023. Accessed: Oct. 26, 2023. [Online]. Available: https://www.gov.uk/government/publications/2030-strategic-framework-for-international-climate-and-nature-action

[14] UK energy security, 'Hundreds of new North Sea oil and gas licences to boost British energy independence and grow the economy', GOV.UK. Accessed: Nov. 09, 2023. [Online]. Available: https://www.gov.uk/government/news/hundreds-of-new-north-sea-oil-and-gas-licences-to-boost-british-energy-independence-and-grow-the-economy-31-july-2023

[15] C. Madeleine, 'What impact will planned new UK coal mine have on carbon emissions?', New Scientist. Accessed: Nov. 09, 2023. [Online]. Available: https://www.newscientist.com/article/2350696-what-impact-will-planned-new-uk-coal-mine-have-on-carbon-emissions/

[16] CCC, 'Letter: Deep Coal Mning in the UK', 2021.

[17] BEIS, 'Contracts for Difference Allocation Round 5 results'. [Online]. Available: https://www.gov.uk/government/publications/contracts-for-difference-cfd-allocation-round-5-results

[18] Offshore Magazine, 'Investors shun UK offshore wind auction', Offshore. Accessed: Nov. 09, 2023. [Online]. Available: https://www.offshore-mag.com/renewable-energy/article/14298700/investors-shun-uk-offshore-wind-auction

[19] BEIS, 'Energy White Paper: Powering our Net Zero Future', 2020, [Online]. Available: https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

[20] The Crown Estate, 'Offshore Wind Report', 2022. [Online]. Available: https://www.thecrownestate.co.uk/media/4378/final-published_11720_owoperationalreport_2022_tp_250423.pdf

[21] M. Declerck, N. Trifonova, J. Hartley, and B. E. Scott, 'Cumulative effects of offshore renewables: From pragmatic policies to holistic marine spatial planning tools', *Environ. Impact Assess. Rev.*, vol. 101, p. 107153, Jul. 2023, doi: 10.1016/j.eiar.2023.107153.

[22] H. Putuhena, D. White, S. Gourvenec, and F. Sturt, 'Finding space for offshore wind to support net zero: A methodology to assess spatial constraints and future scenarios, illustrated by a UK case study', *Renew. Sustain. Energy Rev.*, vol. 182, p. 113358, Aug. 2023, doi: 10.1016/j.rser.2023.113358.

[23] National Grid, 'National Grid Net Zero Energy Workforce Report'. 2020. [Online]. Available: https://www.nationalgrid.com/document/126256/download

[24] REA, 'REVIEW23, THE REA'S ANNUAL STATE OF THE INDUSTRY REPORT', 2023. Accessed: Oct. 26, 2023. [Online]. Available: https://www.r-e-a.net/wp-content/uploads/2023/10/REview23-FINAL.pdf

[25] Mike Barnes, 'Skills shortage: The biggest challenge to offshore wind in 2021'. Accessed: Oct. 26, 2023. [Online]. Available: https://blog.policy.manchester.ac.uk/posts/2021/03/skills-shortage-the-biggest-challenge-to-offshore-wind-in-2021/

[26] L. Waters, 'Digest of UK Energy Statistics (DUKES) - Renewable sources of energy', Jul. 2023. Accessed: Aug. 27, 2023. [Online]. Available: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

[27] ORE Catapult, 'ReEnergise Summer 2023', 2023. [Online]. Available: https://ore.catapult.org.uk/wp-content/uploads/2023/06/ReEnergise-Summer-2023.pdf

[28] Crown Estate Scotland, 'Briefing: ScotWind Leasing for offshore wind'. 2022.

[29] The Crown Estate, 'The Crown Estate refines plans for Celtic Sea floating wind | 2023 - The Crown Estate refines plans for Celtic Sea floating wind'. Accessed: Oct. 23, 2023. [Online]. Available: https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2023-the-crown-estate-refines-plans-for-celtic-sea-floating-wind/

[30] BEIS, 'Contracts for Difference Allocation Round 4 results'. [Online]. Available: https://www.gov.uk/government/publications/contracts-for-difference-cfd-allocation-round-4-results

[31] E. Simon, 'Analysis: Record-low price for UK offshore wind is nine times cheaper than gas', Carbon Brief. Accessed: Oct. 25, 2023. [Online]. Available: https://www.carbonbrief.org/analysis-record-low-price-for-uk-offshore-wind-is-four-times-cheaper-than-gas/

[32] Policy and Innovation Group, University of Edinburgh, 'What are the UK power system benefits from deployments of wave and tidal stream generation?', Supergen ORE Hub, 2023. [Online]. Available: https://supergen-ore.net/uploads/Supergen-ORE-Power-System-Benefits-Study-2023.pdf

[33] R. Hakimian, 'How tidal power could become a vital part of the UK's energy security', New Civil Engineer. Accessed: Oct. 26, 2023. [Online]. Available: https://www.newcivilengineer.com/latest/how-tidal-power-could-become-a-vital-part-of-the-uks-energy-security-12-01-2023/

[34] S. Walker and P. R. Thies, ‘A review of component and system reliability in tidal turbine deployments’, *Renew. Sustain. Energy Rev.*, vol. 151, p. 111495, Nov. 2021, doi: 10.1016/j.rser.2021.111495.

[35] Interreg France (Channel) England Programme, ‘TIGER: Tidal Stream Industry Energiser project’, TIGER: Tidal Stream Industry Energiser. Accessed: Nov. 20, 2023. [Online]. Available: https://interregtiger.com/

[36] DESNZ, ‘Contracts for Difference (CfD): Allocation Round 6’. Accessed: Nov. 16, 2023. [Online]. Available: https://www.gov.uk/government/collections/contracts-for-difference-cfd-allocation-round-6

[37] UKRI, ‘Infrastructure Fund projects’. Accessed: Nov. 20, 2023. [Online]. Available: https://www.ukri.org/what-we-do/creating-world-class-research-and-innovation-infrastructure/funded-infrastructure-projects/

[38] Ocean Energy Systems, ‘Ocean Energy and Net Zero: An International Roadmap to develop 300GW of Ocean Energy by 2050’, Supergen ORE Hub, 2023.

[39] DLUHC, ‘Environmental Outcomes Report: a new approach to environmental assessment’, GOV.UK. Accessed: Nov. 20, 2023. [Online]. Available: https://www.gov.uk/government/consultations/environmental-outcomes-reports-a-new-approach-to-environmental-assessment/environmental-outcomes-report-a-new-approach-to-environmental-assessment#what-an-environmental-outcomes-report-will-cover

[40] SETIS, ‘SET Plan Ocean Energy Implementation Pla Ocean energy’. European Commission, 2017. Accessed: Nov. 20, 2023. [Online]. Available: https://setis.ec.europa.eu/implementing-actions/ocean-energy_en

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