Journal of Sustainability Science and Management
Volume 17 Number 8, August 2022: 232-246
eISSN: 2672-7226

SUPPORTING SUSTAINABILITY THROUGH THE USE OF OFFSHORE WIND ENERGY: THE CASE OF UNITED KINGDOM

VLATKA BILAS[1], SANJA FRANC[1]* AND LANA TRIFUNIĆ[2]

[1]*J.F. Kennedy Square 6, 10000 Zagreb, Croatia.* [2]*Horvaćanska 174, 10000 Zagreb, Croatia.*

**Corresponding author: sfranc@efzg.hr*
Submitted final draft: 24 May 2022 *Accepted: 19 June 2022* http://doi.org/10.46754/jssm.2022.08.014

Abstract: To meet the goal of sustainability and transition to a green economy, renewable energy sources have to be used. Although many countries have declared their transition to a smart, green and sustainable economy, there is still modest evidence of achieving climate change goals, Sustainable Development Goals and other related societal and environmental goals. This paper aims to give an overview of the current global and regional trends, and the strategic frameworks on the use of wind energy to clarify its potential, especially offshore wind energy, using the example of the United Kingdom as one of the global leaders in this area. For several decades, the United Kingdom has implemented various regulations and mechanisms to improve climate action and the transition to a green economy. It offers specific Contract for Difference schemes to offshore wind producers, under which they are entitled to a specially defined purchase price of electricity produced for 15 years. Thus, the United Kingdom is one of the global leaders in offshore wind energy generation. Initiatives, strategic frameworks and regulations in the United Kingdom can serve as guidelines for other countries in developing their own strategic framework.

Keywords: Sustainability, renewable energy sources, wind farm, regulation.

Introduction

In the current advanced climate change environment, caused primarily by the intense use of non-renewable energy sources such as fossil fuels, wind energy has great potential to meet energy needs sustainably worldwide. Trends in the use of wind energy at the global level indicate that there is a common goal of developing a centralised low-carbon economy based on renewable energy sources, with a special focus on technologies such as wind farms (Kättlitz *et al.,* 2021). In the wind energy industry, onshore (land) and offshore wind power plants (farms) produce energy using wind turbines, which are devices that capture wind energy and convert it into electricity. Wind energy is thus transformed into electricity by wind turbines (Liščić *et al.,* 2014).

There are significant differences between onshore and offshore wind farms. For example, offshore wind projects can begin and develop slower than onshore wind projects. In addition, the environmental impact assessment for offshore wind farms is more complex than for onshore wind farms (Wilson, 2020). Also, wind turbines must avoid other offshore infrastructure such as electricity and telecommunications cables and gas pipelines, taking care not to disrupt major waterways (Wilson, 2020).

Floating offshore wind farms enable a high level of wind energy use in deep waters, without restrictions that are otherwise present in the case of fixed offshore wind farms, which has led to an intensification of other related industries such as finished products, semi-finished products and offshore hydrogen, and thus, have multiplicative effects on other industries and the economy and society as a whole. Offshore wind farms are complementary to onshore wind farms in terms of coexistence and in addition, contribute to environmental protection in terms of minimising the impact on birds present in onshore wind farms, eliminating noise effects, and releasing and allowing land use for other purposes. The use of wind turbines is in trend again, fully optimising and maximising their benefits in terms of producing electricity from onshore wind energy. However, all major projects, energy transition and offshore wind projects must be based on scientific research and knowledge, not only to ensure their sustainability but to eliminate the possibility of negative effects on the environment and various ecosystems as well. The overall impact of offshore wind farms on different ecosystems is still not sufficiently known, thus, research and efforts in defining and implementing measures to pursue wind farm projects without damaging the environment are necessary (Draget, 2014). Such integrated assessment could build on findings for evaluation systems for onshore wind farms, such as the study by Kazak *et al.* (2017) who proposed a multi-criteria decision support model that helps to explain the relationship between human activity and the location of power plants.

Evidence shows that innovation is crucial not only for the development of technology but also for its optimisation, cost-effectiveness and cost reduction. For example, in the last seven years, as innovation has intensified and technology has become more affordable, offshore wind prices have fallen by as much as 75% (European Commission, 2021a). In addition, innovation is key to supplying electricity produced in offshore wind farms even to landlocked countries, all with the help of research and development, advances in technology and the development of offshore wind clusters connected to hubs that will interconnect several countries through electricity networks.

The main aim of this paper is to give an overview of current global and regional trends, and the strategic frameworks for the use of wind energy to clarify the potential of wind energy and wind farms using the example of the United Kingdom. For several decades, the United Kingdom has implemented regulations and mechanisms to improve climate action and transition to a green economy. It is considered to be a global leader in this field with ambitious future goals. The scientific contribution of this paper is in terms of a systematic overview of global trends, challenges and perspectives of wind farms as producers of electricity, and a comprehensive analysis of the strategic and regulatory framework on the global and the European Union levels. The case of the United Kingdom was analysed as it has one of the largest global capacities of offshore wind farms and the highest number of successful projects implemented, as well as a quality strategic and regulatory framework. Analysis of the strategic framework and regulation in the United Kingdom resulted in some conclusions that can serve as guidelines for other countries in developing their strategic framework and achieving their national goals.

Trends in the Use of Wind Energy: Literature Review

The seriousness of the global climate situation certainly points to numerous warnings, one of which is sustainability, not only of resources but also of the entire life cycle of renewable energy production. Namely, the experience so far has shown that growth brings with it several consequences. That is why it is crucial to consider the sustainability of energy production from (offshore) wind when considering energy production from renewable sources.

A comprehensive project life cycle assessment covers all segments, from production, through transport and installation to the very end of the project, when an offshore wind farm is either uninstalled or repurposed for other needs in other industries. According to the Global Wind Energy Council (2021), more than 80% of all wind turbines are made of recyclable materials, such as steel, iron, copper, and aluminium. However, wind turbines (namely rotor blades) consist of carbon fibre and/or fibreglass composites, plastic or resin in the range of 11-16% with a life expectancy of up to 25 years and are currently difficult to recycle commercially. These ratios and compositions can be recalculated and adjusted for greater sustainability, and later, simpler and more efficient recycling which is very important to take into account. It is important to take note of the entire life cycle of offshore wind farms and their full sustainability, and this can only be achieved by developing a comprehensive offshore wind sustainability strategy that includes not only environmental impacts but also horizontal issues such as social impact, inclusion and social responsibility in general. In this way, ultimately, wind energy gradually becomes completely circular — wind turbines are recycled for other needs in other sectors, recycled materials are used to produce new wind turbines and new wind turbines are produced in a way that they can be recycled after their life cycle (Wind Europe, 2021).

Unlike fossil fuels, wind energy comes from renewable sources does not consume water and is “clean”, i.e., it does not produce greenhouse gases or air pollutants. Today, the wind energy industry is of paramount importance as an alternative and renewable energy source. For example, the global offshore wind market grew by an average of 22% per year between 2010 and 2020 (Global Wind Energy Council, 2021). In 2016, the installed offshore wind capacity was 14 GW and it increased to just over 35 GW in 2020 (Figure 1), accounting for 5% of the total global wind energy capacity in 2020 (Global Wind Energy Council, 2021). In other words, at the global level, in 2020 alone, 93 new GW of total wind power capacity (onshore and offshore) were installed, of which the onshore wind capacity was approximately 86.9 GW, with the rest (6.1 GW) being the offshore capacity (Renewable Energy Network - REN21 Secretariat, 2021). After Europe, Asia is the second-largest market for electricity produced from offshore wind farms and in 2020, it had a total offshore wind capacity of 7,791 MW with as many as 73 offshore wind projects underway (Musial *et al.,* 2021).

In its estimates, the Global Wind Energy Council (2020) considered that offshore wind energy would contribute to the recovery from the coronavirus (COVID-19) crisis. It is estimated that an additional 235 GW of new offshore wind capacity will be installed during this decade, which will result in a total of 270 GW of offshore wind capacity by 2030 (Global Wind Energy Council, 2021) and according to some calculations, up to 408 GW of capacity by 2050 (Kättlitz *et al.,* 2021). The estimated share of electricity that can be produced by offshore wind farms worldwide by 2050 is around 7% (Schweizer *et al.,* 2016). In addition, according to the European Union’s 2021 Blue Economy Report, the offshore wind industry saw a 15% increase in employment in just one year from 2017 to 2018 (European Commission, 2021a).

In Europe, there is also a trend of wind farm development, both onshore and offshore in the period from 2009 to 2019. According to the latest data, by 2020, Europe had approximately 25 GW (25,073 MW) of installed capacity of offshore wind farms (Musial *et al.,* 2021). Such propulsive results are in line with the EU’s political and strategic framework and

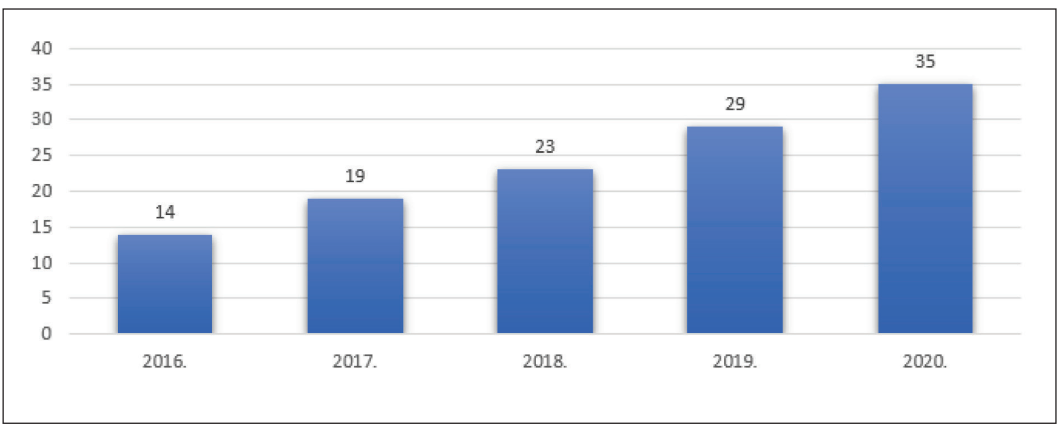

Figure 1: Total installations of offshore wind farms, 2016-2020, global level (GW)
Source: Global Wind Energy Council (2021)

plan to build 300 GW of wind energy by 2050. The vision of EU for offshore wind is for it to become Europe's primary source of electricity (European Commission, 2020) and it plans to achieve this by fulfilling the goals of increasing European capacity from 12 GW to at least 60 GW by 2030 and as already mentioned, an increase to 300 GW of offshore wind energy by 2050 (European Commission, 2020).

The repulsiveness of the wind industry and offshore wind farms is also evident from the global results achieved in 2020, especially given the fact that 2020 was influenced by the crisis caused by the COVID-19 pandemic. For example, orders for wind turbines for offshore wind farms in 2020 were six times higher than in 2019. Trends also show that further development and innovation of wind turbine technologies will improve wind turbine efficiency and resilience, which will ultimately open new market opportunities for offshore wind farms and the global decarbonisation of energy systems in general (Global Wind Energy Council, 2020). However, although research, development, innovation and new technologies often entail high (or at least partially higher) costs, research in the area of offshore wind farms has shown a declining trend in costs. Namely, the latest research from 2020 shows that the levelled cost of energy in offshore wind farms in the period from 2014 to 2019 decreased by 28-49% (Wiser *et al.,* 2021) which is a far larger reduction than earlier forecasts from 2015 when a reduction of 24-30% by 2030 and 35-41% by 2050 was expected. These data indicate that with the maturation of the industry, the decline in costs is accelerating which is especially evident in the last few years. Accordingly, given the growing intensification of the offshore wind industry, the costs of offshore wind exploitation will continue to decrease.

For example, targeted cost reductions can be applied throughout the lifecycle of the offshore wind farm and even the supply chain itself as was the case in the "LEANWIND" project (Leanwind, 2017). Namely, the "lean" principle implies a dynamic process focused on knowledge and the end consumer, continuously eliminating phases and processes that bring waste and striving to create added value (European Commission, 2021). This principle was originally introduced by Toyota in the automobile industry, after which it was implemented by many other industries, although in the area of offshore wind farms, this principle is still a novelty. The key postulates of this cost-reduction principle are: (1) Identification of customer needs, (2) Monitoring, reducing and eliminating processes, and phases that generate waste, (3) Continuous demand for improvement and (4) Further approach to improvements in a holistic, multidisciplinary and comprehensive manner.

The price of energy from renewable sources has decreased (World Economic Forum, 2021) which is an undeniably significant advantage in the efforts toward decarbonisation and mitigating climate changes. If we take the example of solar energy, it was predicted that in the period from 2010 to 2020, annual energy prices will fall by an average of 2.6% but they fell by 15% per year (Way *et al.,* 2021). The previously mentioned technological innovations have also contributed to this, which have also brought significant savings in the field of offshore wind farms. Current trends in practice have shown that technologies become more cost-effective with increased production. In fact, they are potentially entering the "magic" circle — the intensification of industry and widespread use lead to lower prices, resulting in market competitiveness and increased demand, ultimately leading again to a larger and more widespread use that further allows for price reductions, thus, closing this circle (World Economic Forum, 2021). Climate, environmental and other green policies around the world have enabled the increase in demand and the use of sustainable and renewable sources, which ultimately allowed them to join this circle. Namely, while the price of solar energy has fallen by 89% since 2010 and the price of wind energy by 70%, the price of electricity from coal has decreased by only a slight 2% (World Economic Forum, 2021) which certainly contributes significantly to easier green energy and climate transition than previously expected. For this reason, a continuous reduction of offshore wind energy prices is expected.

In addition, the development of offshore wind farms has a significant impact on other related industries, at least through the value chain (International Renewable Energy Agency, 2018). Namely, project planning is crucial for the needs of offshore wind farm development as well as the production of semi-finished and finished products and services that are necessary for the building and operation of offshore wind farms. Then, transport systems are necessary to transport not only the parts needed in the wind farm construction phase but also the later phases of its operation and maintenance. After the installation of the wind farm, the procedure of connection to the electricity network follows and then, the commissioning of the wind farm. The penultimate phase in the lifecycle is the implementation of the project with operational maintenance and ultimately follows either the uninstallation of the offshore wind farm or its conversion to other purposes in other industries. Also, another related element is certainly the services that accompany offshore wind farms throughout their lifecycle, from consulting services, administrative activities, education services, strategic planning, production and project planning, financial services, and research and development (International Renewable Energy Agency, 2018).

Methodology

The main objective of this paper is to identify major trends and challenges in supporting sustainable development with a specific emphasis on renewable energy sources. Thus, the paper analysis global trends in wind energy use and prices provides an overview of the strategic and regulatory framework, and clarifies the potential of wind farms by exploring the case of the United Kingdom as it is globally known for its efforts and initiatives in this area.

Writing this paper was based upon previous research and secondary data. In accordance with the practice of scientific research, methods of analysis, compilation and deduction were applied. Firstly, by reviewing recent and relevant literature in this field, the paper describes global trends and perspectives regarding the use of wind energy as a renewable energy source. Secondly, global and regional regulatory and strategic frameworks and initiatives supporting sustainable development with emphasis on wind energy use are identified and explained, which gives a clearer understanding of the potential and benefits of offshore wind farms. Then, the practical experiences regarding the use of wind energy are explored in the case of the United Kingdom, to identify good practices and useful regulatory schemes for supporting energy production from renewable sources. Systematically, the development and implementation of offshore wind projects are analysed together with regulations and mechanisms that support the transition to a green economy in the United Kingdom. Through deduction, certain recommendations and conclusions were made on the development, management and usage of wind energy with emphasis on the significance of offshore wind energy and the necessity of modifying existing or creating a new regulatory framework, new technologies and practices.

Global and Regional Strategic Framework and Regulations

Globally, the exploitation of offshore wind energy is in line with the Sustainable Development Goals (SDGs), primarily Goal 7: Affordable Clean Energy (United Nations (UN), 2021). The development of offshore wind farms significantly contributes to providing affordable energy from clean sources and thus, contributes to all other goals of sustainable development — the fight against poverty, ensuring the health and well-being of all, water purity, creating good jobs, ensuring economic growth and development, developing industries, innovation and infrastructure, developing sustainable cities and communities, generally responsible consumption and production, combating climate change, the preservation of underwater life, the preservation of life on land, and partnerships to achieve the goals of sustainable development (UN Environment Programme, 2021).

Furthermore, the long-awaited 26th United Nations Climate Change Conference in 2021 resulted in the Glasgow Climate Pact. which aims to resolve all hitherto unresolved elements in the mechanisms for the implementation of the Paris Agreement on Climate Change and the transparency of procedures (UN Climate Change Conference, 2021; Ministry of Economy and Sustainable Development, 2021). The pact stipulates that it is necessary to accelerate and strengthen the goals of achieving climate neutrality by 2030, implement adaptation measures to protect communities and natural habitats, provide financial resources to achieve these goals, and joint efforts and cooperation to accelerate climate mitigation activities at all levels — governments, research sector, business sector and civil society (UN Climate Change Conference, 2021). The construction of offshore wind farms for the production of electricity cleanly and sustainably way from renewable sources is certainly one of the most important and influential tools for meeting the goals of the Glasgow Climate Pact, achieving climate neutrality and mitigating climate change.

Following the postulates of the Paris Agreement on Climate Change, the European Union has been making significant regulatory and strategic efforts for many years to protect and preserve the environment, prevent and neutralise climate change, and improve the overall quality of life and work in the European Union. The EU Energy and Climate Package for 2020 were followed by an even more concrete Climate and Energy Framework until 2030.

In addition, in 2014, the European Commission adopted guidelines for the granting of state aid for environmental protection and energy, which set out in detail the postulates of aid that member states may grant to encourage the development of renewable energy production, including offshore wind farms.

The EU is aware of the domino effect and that the results of its efforts will have far-reaching consequences for the global ecological, climate, economic and social system. The European Union Strategy for the Adriatic-Ionian Region (EUSAIR) was also adopted in September 2014 as a joint strategy of the European Commission and countries of the Adriatic-Ionian Region within the EU (Croatia, Greece, Italy, Slovenia) and outside the integration, Albania, Bosnia and Herzegovina, Montenegro and Serbia (European Union, 2021). The strategy is one of the umbrella strategies for the blue economy and blue growth (i.e., all activities related to the sea) and thus, one of the key strategies for the development of offshore wind farms through three of the four pillars it is based on (Government Office of the Republic of Slovenia for Development and European Cohesion Policy, 2021). Following the 2014 EUSAIR Strategy Action Plan and the 2020 EUSAIR Strategy Action Plan, a new EUSAIR Strategy Implementation Plan for 2021-2027, "EUSAIR Flagships 2021-2027" was adopted at the end of 2020 as well as areas that could be eligible for co-financing in the coming period. The blue economy can contribute to climate and carbon neutrality through the development of electricity from offshore wind farms, which is evident from the fact that offshore wind is recognised and prioritised in the New Approach to Sustainable Blue Economy in the EU which aims to transform the EU blue economy and achieve a sustainable future.

The European Union has also defined the bloc's Long-Term Strategy for Achieving Climate Neutrality until 2050. As part of this strategy, the European Green Plan (European Commission, 2021c) was developed which emphasises that offshore wind is the key element of the transition to a green economy and green energy. Also, in 2021, the Revised Renewable Energy Directive was adopted as part of the package for the implementation of the European Green Plan and its objectives (European Commission, 2021c).

Based on the European Green Plan, in 2021, the EU also introduced a new climate plan "Fit for 55" which aims to accelerate and catalyse the activities and changes necessary to achieve climate neutrality by 2050 (European Council, 2021). Simplification and strengthening of the relevant legislative framework is crucial for the realisation of climate neutrality, as well as the system of monitoring and facilitation through mechanisms that will enable targeted activities of energy production from renewable sources, especially offshore wind farms as the most viable potential.

In addition, the adoption of the European Union Maritime Spatial Planning Directive (2014/8/EU) establishes a framework for the adoption of maritime spatial plans for "coastal" member states which are obliged to adopt their maritime spatial plans by 2021. To this end, the European Platform for Maritime Spatial Planning has been developed to make it easier for EU members to put spatial planning into practice, which will speed up and facilitate the development of offshore wind farms.

The importance of offshore wind for sustainable development and the economy is also recognised in the new Industrial Strategy 2020 as well as in the document Advancing the New Industrial Strategy 2020: Building a Stronger Single Market for Europe's Recovery in 2021. Also, the European Union Strategy for Biodiversity until 2030 recognises offshore wind farms as one of the positive solutions for preserving the environment, biodiversity and natural habitats of marine animals as well as the EU strategy for exploiting the potential of renewable energy at sea for a climate-neutral future (European Commission, 2021d) adopted in 2020 which aims for the implementation of at least 60 GW in capacity of offshore wind farms by 2030 and as much as 300 GW capacity of offshore wind farms by 2050. This ambitious and "strict" political and strategic framework of the EU to achieve climate neutrality applies to all member states, which means that they are obliged to develop their long-term national strategies for economic transformation and sustainable development as well as meeting the Paris Agreement on Climate Change goals and European Climate Regulation.

Results of the Wind Energy Usage Analysis: The Case of the United Kingdom

In 2020, the United Kingdom had the largest share in the capacity of offshore wind farms worldwide (Hassan & Majumder-Russel, 2020). According to Airswift data, United Kingdom has about 35% of the installed capacity of offshore wind farms globally and as many as seven of the 10 largest offshore wind farms in the world. By 2030, electricity produced from offshore wind farms is expected to account for 30-33% of the total electricity in the United Kingdom (UK government, 2019; Crown Estate, 2019). Below are the results and discussion on the development and implementation procedures for some of the most important offshore wind projects in the United Kingdom as well as the regulatory framework for supporting the transition to a green economy.

Development and Implementation of Offshore Wind Projects

At the end of 2020, the United Kingdom set a target of 40 GW of offshore wind capacity by 2030, compared with the original target of 30 GW by 2030. These plans include the realisation of as much as 1 GW of floating offshore wind farms (Hassan & Majumder-Russel, 2020). In addition, the ultimate goal of the United Kingdom is to eliminate greenhouse gas emissions by 2050 which puts the kingdom at the forefront in Europe. Offshore wind development plays a key role in the British government's plans for the Green Energy Revolution, as evidenced by the fact that just 10 years ago, around 40% of the United Kingdom's electricity came from coal while in 2020, that number fell to about 2.4%.

The Hornsea One project, launched in 2020 is the largest global operational offshore wind farm. In addition to the Hornsea One project, there are currently eight other key offshore wind projects in the United Kingdom at different stages of implementation (Table 1).

Over the next five years, an additional 31 offshore wind projects worth US$93

Table 1: Key offshore wind projects in United Kingdom

Name of Project	Short Description of Capacities
Hornsea One project	Uses 174 offshore wind turbines has 1.2 GW capacity powering more than one million households.
Hornsea Two offshore wind farm	Uses 65 Siemens Gamesa 8MW SG 8.0-167 DD turbines which will deliver 20% more annual output than those used for Hornsea One. Expected 1.4 GW capacity realisation in 2022.
Dogger Bank wind farms A, B & C	Realisation of 3.6 GW capacity in three phases, starting in 2023, lasting 35 years. Up to 400 turbines will be installed.
Moray West offshore wind farm	Realisation of 850 MW capacity in 2024/2025. Up to 85 wind turbines will be installed.
Sofia offshore wind farm	Realisation of capacity of 1.4 GW by 2026. Total of 100 turbines will be installed.
East Anglia hub offshore wind complex	Realisation of capacity of 3,100 MW. Expected to start in 2023 and finish in 2026.
Erebus floating offshore wind farm	Realisation of the first demonstration floating of offshore wind farm with a capacity of 96 MW by 2026/2027, lasting 25 years.
Inch Cape offshore wind farm	Realisation of capacity of up to 1 GW. Up to 72 turbines will be installed. Currently in the final phase of realisation.
Seagreen offshore wind farm	Realisation of 1,075 MW capacity by 2022/2023. Uses 114 wind turbines.

billion are planned in the United Kingdom. Of particular importance is the Kincardine Offshore Windfarm, currently the largest global operational floating offshore wind farm with a capacity of 50 MW.

The United Kingdom market is based on clear and stable political support as well as strong inter-industry cooperation (Crown Estate, 2019). The legal authority in charge of energy is the Ministry of Energy, Clean Growth and Climate Change. As the competent authority for offshore wind farms, key support in these activities is provided by the Crown Estate, an institution specialising in real estate and seabed management in England, Wales and Northern Ireland. The Crown Estate is in charge of maintaining the supply and energy infrastructure in the United Kingdom. It manages a diverse portfolio of seabed projects and provides seabed rights for offshore renewable energy in the form of loans and concessions. The institution conducts technical analysis of potential sites as well as analysis of potential marine soil constraints at target sites for offshore wind farms to determine which sites are optimal for offshore wind farm development. This analysis is performed in several steps according to the methodology, consisting of several models: Technical resource analysis model, analysis model according to exclusion criteria, analysis model according to constraint criteria and, analysis model according to the criteria of characteristics i.e., determining the area based on the results of previous analysis (Crown Estate, 2019). Accordingly, United Kingdom is also implementing a centralised approach and a one-stop shop.

From the very beginning of the wind farm trend, sea soil leases are awarded by the Crown Estate for the development and implementation of offshore wind projects through tenders. This bidding model awards the lease of offshore soil i.e., the holders of offshore wind power projects are awarded contracts for the lease of offshore soil with which they exercise long-term exclusive rights to certain parts of the seabed where they have permission to develop and build offshore wind farms and their management network on land. In other words, this form of permit or lease also includes a concession. Offshore wind farms as a part of the Crown Estates' lease model have been carried out periodically since 2000 (Crown Estate, 2019).

As shown in Table 2, the first round of leasing for offshore wind farms was conducted in 2000 to develop demonstration pilot projects to enable potential offshore wind producers to design and build these pilot projects and develop technological, economic and environmental expertise in United Kingdom waters. In this first round, a total of 18 leases were awarded for small offshore wind projects which are smaller in size and capacity. In the second round in 2003, sea soil leases were awarded to offshore wind farms which were the first projects of a commercial nature (Crown Estate, 2019). The third round of leases in 2010 represented a significant transformational growth of the wind energy industry in the United Kingdom and brought major projects — the right to lease sea soil for offshore wind farms for nine zones with a total capacity of more than 32 GW. Some offshore wind projects from this lease round are still in the development phase, and another 24 GW of offshore wind farms from this round remain to be completed. Within this round, in 2013, an additional round of leases for testing and demonstration projects was conducted which was the so-called "extension" of the lease round in 2010, followed by another "extended" round in 2017 which allowed an additional expansion of the project portfolio by 2.8 GW of new offshore wind capacity. These activities carried out within the third round of leases from 2010 to 2018 resulted in offshore wind farms producing 8% of the total estimated electricity production in United Kingdom in 2018 (Crown Estate, 2019).

The fourth round of lease of sea soil began in 2020. It further promotes the development of technology with significant cost reductions, and successful applicants under this tender will be eligible for a lease agreement with the Crown Estate (Orrick, 2021). The tender procedure consists of five phases (Crown Estate, 2021): (1) A pre-qualification questionnaire or assessment of the financial and technical capacity of the bidder, (2) An invitation to Tender Stage 1 for bidders who have passed the first phase of the tender, (3) An invitation to Tender Stage 2 which is a multi-cycle bidding process using the so-called "option fees bid" by eligible bidders to determine and award the fee with the bidding cycle lasting until a capacity of up to 7 GW and a maximum of 8.5 GW is reached, (4) Plan-level habitats regulations assessment (HRA) and (5) Concluding a wind farm lease agreement with selected bidders for the construction and operation of an offshore wind farm for 60 years as well as a Transmission Lease Agreement for the construction and management of the transmission system (Crown Estate, 2019). The novelty and specificity of the fourth lease round is the extension of the lease terms to

Table 2: The Crown Estates' leasing rounds

Lease Round/ Year	Objective
2000	Development of demonstration pilot projects. A total of 18 leases were awarded for wind farms, with a capacity of up to 30 wind turbines and a total capacity of just over 1 GW.
2003	Sea soil leases were awarded to offshore wind farms for commercial purposes. Total capacity of 7 GW.
2010	Sea soil leases for offshore wind farms for nine zones. Total capacity of more than 32 GW. In 2013, additional round of leases for testing the projects and in 2017, new round for expanding the project portfolio by 2.8 GW of new offshore wind capacity.
2020	Promoting the development of technology with significant cost reductions.

60 years which is enough for as many as two complete life cycles of offshore wind farms (Crown Estate, 2019). Currently, the call for the second phase of the tender has been completed, in which six projects have been selected for the next phase, i.e., the assessment of the project's impact on relevant areas (HRA) (Crown Estate, 2021). From the initial phase to the commercial phase, it can take up to 10 years in the United Kingdom (Crown Estate, 2019).

After concluding the lease agreement, the selected bidders must obtain all necessary permits for the successful implementation of the project such as the Development Consent Order required for infrastructure projects of national importance. Infrastructure Projects need several different permits such as planning approval and maritime permit, to shorten the permitting process and speed up the project implementation process (Crown Estate, 2019).

To connect to the electricity grid, the option is either: (1) The owner of the offshore wind farm builds the physical infrastructure of the transmission system which he then transfers to the owner of the offshore transmission system through a tender procedure conducted by an independent energy regulator in the United Kingdom, the Office of Gas and Electricity Markets (Office of Gas and Electricity Markets, 2021) or (2) The physical infrastructure of the transmission system is built from the outset by the owner of the offshore transmission system designated by the office. The result of both options is that the system for transmitting electricity from the offshore wind farm to the power system is ultimately not owned by the offshore wind farm owner but by another entity (Crown Estate, 2019). So far, eight rounds of these tenders have been conducted to build the physical infrastructure of the transmission system. The eighth round was conducted in 2021 and the ninth round is expected as early as 2022 (Office of Gas and Electricity Markets, 2021).

Regulatory Framework for the Transition to a Green Economy

For several decades, United Kingdom has implemented various regulations and mechanisms to improve and facilitate climate action and the transition to a green economy (Table 3). Since 2001, it has implemented a Climate Change Levy relating to electricity, gas, solid fuels and liquefied gases used for lighting, heating and power in the business and public sectors. In addition, since 2001, Climate Change Agreements allow a discount on the environmental energy tax used by business users by as much as 90% in exchange for achieving energy efficiency or carbon-saving targets. There is also a 100% tax exemption for certain energy-intensive metallurgical and mineral industries.

Furthermore, the 2006 Climate Change and Sustainable Energy Act includes various measures to promote national targets for microgeneration, as well as the scheme of Green Certificates for Renewable Electricity and Reporting on Energy Efficiency in Housing.

2008 Climate Change Act provides a long-term framework for improving carbon governance and assisting in the transition to a low-carbon economy. Under this act, the United Kingdom is legally obliged to bring all greenhouse gas emissions to zero by 2050. It also creates five-year "carbon budgets" as a way to achieve the long-term goal. The act has thus established a legally binding target of 100% reduction in greenhouse gas emissions by 2050 which will be achieved by performing within the United Kingdom and abroad.

Furthermore, the Energy Act 2016 established the Oil and Gas Administration which has regulatory powers and regulates the activities of onshore wind farms. Finally, although the United Kingdom left the European Union on 1 February 2020, the transitional period agreed in the EU-UK Withdrawal

Agreement ended on 31 December 2020 and the United Kingdom submitted its National Energy and Climate Plan before the end of 2020.

United Kingdom has been providing specific support for renewable energy sources (including offshore wind farms) since 2002, initially in the form of the so-called Renewables Obligation (Crown Estate, 2019) which stipulated that licensed electricity suppliers have to annually supply a certain share of electricity from renewable energy sources with the share increasing every year, otherwise they are given a fine (Grantham Research Institute, 2021). This renewable energy commitment mechanism was replaced in 2014 by the Contract for Difference scheme which has remained the main support mechanism for offshore wind farms to date (UK government, 2019). Under this mechanism, offshore wind producers are entitled to a specially defined purchase price of electricity produced for a period of 15 years (Crown Estate, 2019; Dalton & Polito, 2021). The stated price of electricity is the difference between the "strike" prices (i.e., electricity prices that reflect the cost of investing in a particular technology) and "reference" prices (i.e., average market prices of electricity in United Kingdom) (UK government, 2019).

These Contracts for Difference are awarded through a tender procedure (Crown Estate, 2019) conducted by the electricity system operator National Grid ESO and the premium under these contracts is paid by the state-owned Low Carbon Contracts Company (LCCC) as the second contractor of a "Contract for Difference" owned by the Department for Business, Energy and Industrial Strategy (UK government, 2019). Under the Contract for Difference, if the reference market price of offshore electricity falls below the "strike" price defined in the contract, then the LCCC pays the electricity producer the resulting price difference (Electricity Market Reform Settlement, 2021). However, when the reference market price of offshore electricity rises above the "strike" price defined in the Contract for Difference, the electricity producer pays the resulting price difference to the LCCC (Electricity Market Reform Settlement, 2021).

In addition to the four mentioned rounds of lease, additional rounds of bidding for grants under the Contracts for Difference were conducted. So far, the following four rounds of bidding have been conducted: (1) The first round of awarding the Contracts for Difference (CfD1) in the period 2014-2015, (2) The second round of awarding the Contracts for Difference in 2017, (3) The third round of awarding the Contracts for Difference (CfD3) in 2019 and (4) The fourth round of awarding the Contracts for Difference (CfD4) has been opened in December 2021 (Department for Business, Energy and Industrial Strategy, 2020).

The summary of the regulatory framework and designated schemes is presented in Table 3.

Looking at the global trends in wind energy use, the development of centralised low-carbon economy based on renewables is generally evident with a particular focus on technologies, such as offshore wind farms.

Table 3: Regulatory frameworks in United Kingdom

Year	Regulation	Instruments and Schemes
2001	Climate Change Agreements	Climate Change Levy
2006	Climate Change and Sustainable Energy Act	Green certificates for renewable electricity and reporting on energy efficiency in housing
2002	Renewables Obligation scheme policy	Renewables Obligation Certificates
2008	Climate Change Act	Carbon budget
2014	Private law contract	Contracts for Difference
2016	Energy Act	Oil and gas administration
2020	National Energy and Climate Plan	Climate Change Levy

The first precondition for the development of offshore wind projects is the existence of a regulated, simplified and agile regulatory framework which then regulates the institutional framework for the implementation of offshore wind projects and therefore, the overall strategy and approach to achieving national objectives. The construction that is the development of an offshore wind farm has a different duration in different countries. In UK, for example, from the initial stage to the commercial stage of an offshore wind farm can take up to 10 years.

There is no single approach to building and operating an offshore wind farm and much depends on the specific conditions at the location. As already mentioned, the pace of innovation in the wind industry has been rapid over the past decade (Crown Estate and the Offshore Renewable Energy Catapult, 2019). Giebel and Hasager (2016) found that wind farm design is a crucial factor for offshore wind energy to be viable. They divide the process of wind farm design into two phases, each managed by different stakeholders. We can agree that for the first initial phase, the institutional framework is crucial. Without effective regulation, a transparent system, well-informed stakeholders, specific consulting guidance and simple procedures, the project cannot be either planned or developed.

Conclusion

Key megatrends in wind power generation have recently come to the fore as a result of accelerated climate change and other sustainability challenges, but also efforts to achieve climate neutrality and preserve the environment. Primarily, there is a growing increase in the size of wind farms, especially offshore wind farms, which have recently developed in proportion to an increasing number of offshore wind turbines, increasing capacity of wind turbines and offshore wind farms, and efforts to optimally position offshore wind farms to interconnect several countries, thus saving space, time, money and costs. Numerous global and European initiatives and strategies focus on sustainable development emphasizing the need to explore new energy sources. Wind energy is recognised as having great potential. What is more, wind energy is the key tool of the European Union with which it can ensure a neutral climate impact and it is expected that wind energy will contribute the most to achieving the goals of using renewable energy sources and climate neutrality by 2050. According to recent data, renewable energy sources have surpassed fossil fuels as the primary and key energy source, meeting a large share of Europe's electricity needs. The first precondition for the development of offshore wind projects is an organised, simplified and solid regulatory framework which then regulates the institutional framework for the implementation of offshore wind projects, and thus, the overall strategy and approach to achieving national goals and implementing necessary activities. The case of United Kingdom has shown that wind energy and the development of wind farms have great potential to contribute to sustainable development. United Kingdom has numerous mechanisms already in place to support wind energy use, primarily focusing on various financial schemes supporting wind energy producers and the achievement of climate change and Sustainable Development Goals. It can be concluded that with increased development of wind energy, its costs will decline and demand will increase.

References

Crown Estate (2019). *Introducing Offshore Wind Leasing Round 4*. London: The Crown Estate.

Crown Estate and the Offshore Renewable Energy Catapult (2019). *Guide to an offshore wind farm, updated and extended*. Swindon: The Blackthorn Centre.

Crown Estate (2021). *Offshore Wind Leasing Round 4 programme update*. Press release. Retrieved from: https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/

offshore-wind-leasing-round-4-programme-update/.

Dalton, L. & Polito, S. (2021). The Renewable Energy Law Review: United Kingdom. *The Law Reviews*. Retrieved from: https://thelawreviews.co.uk/title/the-renewable-energy-law-review/united-kingdom.

Draget, E. (2014). *Environmental Impacts of Offshore Wind Power Production in the North Sea a Literature Overview.* Oslo: World Wide Fund for Nature (WWF).

Electricity Market reform - EMR Settlement Limited (2021). *Contracts for Difference*. Retrieved from: https://www.emrsettlement.co.uk/about-emr/contracts-for-difference/.

European Union (2021). *EU Strategy for the Adriatic and Ionian Region (EUSAIR).* Retrieved from: https://maritime-spatial-planning.ec.europa.eu/practices/eu-strategy-adriatic-and-ionian-region-eusair

European Commission (2020). *Boosting Offshore Renewable Energy for a Climate Neutral Europe*. Press release. Retrieved from: https://ec.europa.eu/commission/presscorner/detail/en/IP_20_2096.

European Commission (2021a). *EU Blue Economy Report.* Luxembourg: Office of the European Union.

European Commission (2021b). *State aid: Commission approves Danish support for Thor offshore wind farm project*. Press release. European Commission: Brussels.

European Commission (2021c). *The European Green Deal*. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. EU: Brussels.

European Commission (2021d, November 15). *Why the EU supports wind energy research and innovation*. Retrieved from: https://ec.europa.eu/info/research-and-innovation/research-area/energy-research-and-innovation/wind-energy_en.

European Council (2021). *Fit for 55.* Retrieved from: https://www.consilium.europa.eu/en/policies/green-deal/eu-plan-for-a-green-transition/.

Giebel, G., Hasager, C. B. (2016). An Overview of Offshore Wind Farm Design. In Ostachowicz, W., McGugan, M., Schroder-Hinrichs, J.U. & Luczak, M. (Eds.), MARE-WINT. *New Materials and Reliability in Offshore Wind Turbine Technology*, 337-346. Springer.

Global Wind Energy Council (2020). *Global Offshore Wind Report 2020*. Brussels, Belgium: Global Wind Energy Council (GWEC).

Global Wind Energy Council (2021). *Global Offshore Wind Report 2021*. Brussels, Belgium: GWEC.

Government of the UK (2019). *Offshore wind energy revolution to provide a third of all UK electricity by 2030.* Press release. Retrieved from: https://www.gov.uk/government/news/offshore-wind-energy-revolution-to-provide-a-third-of-all-uk-electricity-by-2030.

Government of the UK. Department for Business, Energy & Industrial Strategy (2021). *Contracts for Difference. Policy Paper*. Retrieved from: https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference.

Grantham Research Institute (2021). *Contracts for Difference (Replacing the Renewables Obligation.* Retrieved from: https://climate-laws.org/geographies/united-kingdom/laws/contracts-for-difference-replacing-the-renewables-obligation.

Hassan, D. & Majumder-Russel, M. (2020). Renewable energy law and regulation in United Kingdom. CMS. Retrieved from: https://cms.law/en/int/expert-guides/cms-expert-guide-to-renewable-energy/united-kingdom.

International Renewable Energy Agency (2018). Re*newable Energy Benefits: Leveraging*

Local Capacity for Offshore Wind. Abu Dhabi: IRENA.

Kättlitz, A., Cavarretta, M.C., Buyuk, N., Lebois, O. & Boersma, P. (2021). *TYNDP 2022 Draft Scenario Report*. Brussels, Belgium.

Kazak, J., van Hoof, J. & Szewranskia, S. (2017). Challenges in the wind turbines location process in Central Europe – The use of spatial decision support systems. *Renewable and Sustainable Energy Reviews*, *76*, 425-433.

Leanwind (2017). *Driving Cost Reductions in Offshore Wind*. Retrieved from: https://windeurope.org/wp-content/uploads/files/about-wind/reports/LEANWIND-Driving-cost-reductions-in-offshore.pdf.

Liščić, B., Senjanović, I., Čorić, V., Kozmar, H., Tomić, M. & Hadžić, N. (2014). Offshore Wind Power Plant in the Adriatic Sea: An Opportunity for the Croatian Economy. *Transactions on Maritime Science*, *3*(2), 103–110.

Ministry of Economy and Sustainable Development (2021, November 14). *Završena klimatska konferencija COP26 u Glasgowu* (cro.). Press release. Retrieved from: https://mingor.gov.hr/vijesti/zavrsena-klimatska-konferencija-cop26-u-glasgowu/8492

Musial, W., Spitsen, P., Beiter, P., Marquis, M., Cooperman, A., Hammond, R. & Shields, M. (2021). *Offshore Wind Market Report.* 2021 Edition. Virginia, USA: National Renewable Energy Laboratory (NREL).

Office of Gas and Electricity Markets (Ofgem) (2021). *Offshore Electricity Transmission (OFTO*). Retrieved from: https://www.ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/offshore-electricity-transmission-ofto.

Orrick (2021). *2021 Offshore Wind Energy Update and Outlook*. Retrieved from: https://www.orrick.com/en/Insights/2021/07/2021-Offshore-Wind-Energy-Update-and-Outlook.

Renewable Energy Network - REN21 Secretariat (2021). *Renewable Energy Policy Network for the 21st Century*. REN21: Paris, France.

Schweizer, J. Antonini, A., Govoni, L., Gottardi, G., Archetti, R., Supino, C., Berretta, C., Casadei & C. Ozzi, C. (2016). Investigating the potential and feasibility of an offshore wind farm in the Northern Adriatic Sea. *Applied Energy*, *177*, 449-463.

United Nations (2021, November 16). *SDG 7.* Ensure access to affordable, reliable, sustainable and modern energy for all. Retrieved from: https://sdgs.un.org/goals/goal7.

UN Climate Change Conference (2021, December 5). *What is A COP?* Retrieved from: https://ukcop26.org/uk-presidency/what-is-a-cop/.

United Nations Environment Program - UNEP (2021, October 26). *Why do the Sustainable Development Goals matter*? Retrieved from: https://www.unep.org/explore-topics/sustainable-development-goals/why-do-sustainable-development-goals-matter.

Way, R., Ives, M., Mealy, P., & Farmer, D.J. (2021). *Empirically grounded technology forecasts and the energy transition.* Oxford, UK: Institute for New Economic Thinking at the Oxford Martin School, University of Oxford.

Wilson, A.B. (2020). *Offshore wind energy in Europe.* Brussels: European Parliamentary Research Service.

Wind Europe (2019, 19). *Wind energy in Europe in 2019 - Trends and statistics*. Retrieved from: https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-in-2019-trends-and-statistics/.

Wind Europe (2021, 4). *Mega trends in wind energy technology*. Retrieved from: https://windeurope.org/intelligence-platform/product/mega-trends-in-wind-energy-technology/.

Wiser, R., Rand, J., Seel, J., Beiter, P., Baker, E., Lantz, E., & Gilman, P. (2021). Expert elicitation survey predicts 37% to 49% declines in wind energy costs by 2050. *Nat Energy,* 6, 555–565.

World Economic Forum (2021, December 5). Re*newable energy is cheaper than previously thought, says a new report - and could be a game-changer in the climate change battle.* Retrieved from: https://www.weforum.org/agenda/2021/10/how-cheap-canrenewableenergyget?utm_source=facebook&utm_medium=social_scheduler&utm_term=SDG+13:+Climate+Action&utm_content=18/10/2021+21:30&fbclid=IwAR1n9lAVYcWzFrdGglp0dVRRXCxEjr7cuf2UEH6rZ8scnQ5MK-BhxoDjiA.