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*Review*

# Wind Energy Contribution to the Sustainable Development Goals: Case Study on London Array

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**Abstract:** Clean and safe energy sources are essential for the long-term growth of society. Wind energy is rapidly expanding and contributes to many countries' efforts to decrease greenhouse gas emissions. In terms of sustainable development goals (SDGs), renewable energy development promotes energy security while also facilitating community development and environmental conservation on a global scale. In this context, the current article aims to investigate wind energy's role within the SDGs. Furthermore, the present study highlights the role of the London Array wind farm in achieving the SDGs. Indeed, deploying clean and economical energy sources in place of conventional fossil fuel power plants provides vital insights into environmental impacts. The London Array operation is saving approximately 1 million tons of carbon dioxide ($CO_2$) equivalent. Furthermore, the London Array contributes to the achievement of multiple SDGs, including SDG 8: decent employment and economic growth; SDG 9: industry, innovation, and infrastructure; SDG 11: sustainable cities and communities; and SDG 15: life on land. To enhance the London Array's contribution to the SDGs, a total of 77 indicators (key performance indicators) were proposed and compared to the current measurements that have been carried out. The results showed that the London Array used most of the suggested indicators without classifying them from the SDGs' perspective. The proposed indicators will help cut operation costs, mitigate climate change and environmental damage, improve employee engagement and morale, reduce learning gaps, set goals and plans, and use resources efficiently.

**Keywords:** renewable energy; wind energy; climate change; sustainable development goals; indicators



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## 1. Introduction

Currently, the global energy demand surpasses the available generation capacity. As a result, future energy requirements must be effectively and economically fulfilled. The use of renewable energy sources should be prioritized in the implementation of energy solutions. At the moment, renewable energy's contribution to primary energy on a global scale is insufficient to fulfil primary energy and power demand [1]. Many developing nations appear to be attempting to enhance their energy sectors. However, bringing new inventions to reality appears to be difficult [2]. There is always the issue of sustainability when it comes to energy resources. Resources must offer enough energy to suit our demands, such as heating homes, powering cities, and driving automobiles. However, it is equally critical to evaluate how these resources will be used in the long run. Renewable resources will never be depleted. Renewable resources also generate clean energy, which means reduced pollution and greenhouse gas emissions, both of which contribute to climate change [3,4]. Renewable energy sources are natural resources that can be transformed into clean, usable energy, such as biomass, geothermal resources, solar, hydropower, ocean, and wind. Table 1 summarizes the benefits and drawbacks of various renewable energy sources.

**Table 1.** Renewable energy sources comparison.

| Source | Advantages | Disadvantages |
| --- | --- | --- |
| Solar | • More predictable energy output<br>• Can be installed on the roof<br>• No noise | • Variable source and power output<br>• High initial costs<br>• Land requirement for large-scale projects |
| Wind | • Can produce energy during the day and night<br>• Releases less carbon dioxide ($CO_2$) emissions<br>• Produces more energy (high efficiency) | • Environmental impact<br>• Noise pollution<br>• Variable source and power output |
| Geothermal | • Requires small spaces<br>• No noise<br>• Long-lasting power plants<br>• Does not require frequent maintenance | • Location restrictions<br>• Environmental side effects<br>• High costs |
| Biomass | • High availability<br>• Reduces waste<br>• Being carbon neutral | • Requires space<br>• Low efficiency<br>• Requires water |
| Tidal | • Environmentally friendly<br>• High energy density<br>• Low operation and maintenance costs | • Limited locations<br>• Variable intensity of tides<br>• High construction costs |
| Hydropower | • Safe<br>• Low emissions<br>• Can operate all day (reliable) | • Expensive to construct<br>• Limited locations and reserves<br>• Environmental side effects |

The United Nations developed the Sustainable Development Goals (SDGs) to create a more sustainable future for all. The goals were established in 2015, and extensive implementation is scheduled to be achieved by 2030 [5]. The SDGs' framework, as displayed in Figure 1, allows for the tracking of implementation and progress towards the Agenda 2030 [6].


**Figure 1.** The United Nations Sustainable Development Goals (SDGs). (Open Access, https://www.un.org/development/desa/disabilities/envision2030.html, accessed on 1 November 2022).

In terms of the SDGs, renewable energy development enables energy security in transportation [7], the environment [8], construction [9], mechanical work, industry, economy [10,11], and the internet of things (IoT) [12,13]. Renewable energies such as solar [14], wind [15], hydro [16], tidal [17], geothermal [18], biomass [19], and green hydrogen [20] assist supply energy needs while also facilitating community development and environmental protection on a worldwide scale. In recent decades, clean energy has been advocated as a viable solution to the energy dilemma while avoiding negative climatic and environmental implications [21,22]. Compared to other renewable energy sources, wind power generation has an advantage because of its modern technology, dependable infrastructure, and cheap overall cost [23]. Wind energy is likely to play a larger part in the UK's energy supply in future years. The trends in the world's wind energy capacity are shown in Figure 2.

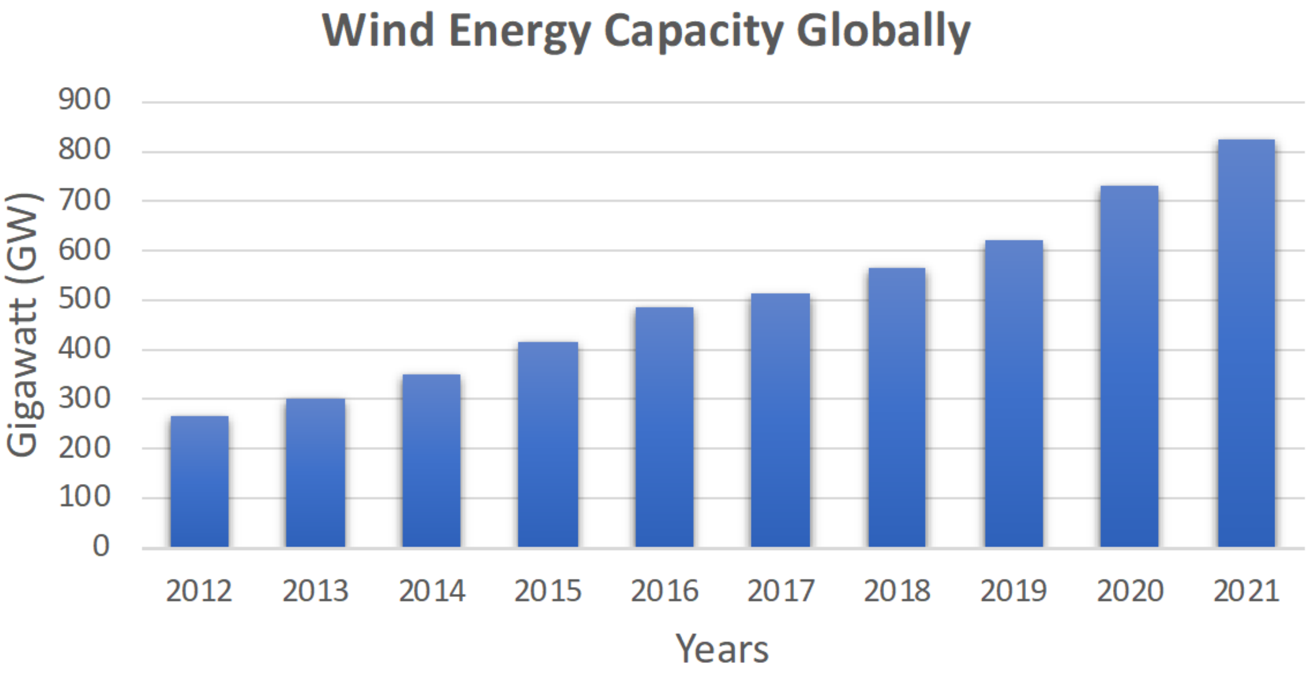


**Figure 2.** Wind energy capacity globally, data extracted from IRENA 2022 (https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Apr/IRENA_RE_Capacity_Statistics_2022.pdf, accessed on 20 January 2022).

This study investigates the significance of increasing wind energy production to meet the SDGs. The role that wind energy, which is abundant worldwide, plays in contributing to the achievement of each of the 17 SDGs is the subject of specific research. In order to illustrate the significance of wind power to the various SDGs, a case study was conducted using the London Array. Then, in order to ensure that wind energy fully meets the requirements of the SDGs, we proposed a total of 77 indicators. This study provides an exciting opportunity to advance our knowledge of the relationship between wind energy and the SDGs.

## 2. Wind Energy

Wind energy is an essential component of renewable energy, it also offers several advantages, including being cost-effective, reliable, and environmentally friendly. It is now used to produce electricity [24]. Wind energy consumption is crucial to investigate because of wind's enormous potential. Furthermore, wind turbine technology has advanced significantly in recent years. Turbines' efficiency and reliability have increased, allowing them to produce more power. Moreover, wind turbines are also relatively safe to operate and have much lower environmental impacts than other power plants [25,26]. Such an increase in efficiency will reduce the used areas, meaning that more land might be used for purposes other than turbines, such as farming or forestry [27,28].

Wind power has been utilized for various applications, such as milling grains, pumping water, and sawing wood, for many years [29,30]. The drawback of wind energy is that it can sometimes be intermittent and cannot power a whole city or country. Denmark, for instance, cannot rely only on wind power since there is too much demand during the winter months when the winds are weak [31]. An experiment was carried out in the country to determine the power density of wind turbines at various heights, and the findings revealed that as the height increased, so did the wind velocity, which increased the power density ($W/m^2$) received from the wind blade. The horizontal axial wind turbine was chosen because it required less wind speed to begin generating power. Masdar city was classified as a bad wind zone with high turbulence intensity, reaching 19.82% at a height of 10 m [32].

Mankind has been harnessing the wind's energy for various reasons, such as sailing ships, grinding grain, using windmills, and recently, generating electricity [29,33]. Wind energy may be harnessed using two distinct types of wind turbines, depending on the direction of the revolving shaft. Wind turbine efficiency is the electrical power obtained by the wind turbine over the available power in the wind. According to Albert Betz, obtaining more than 59.3% efficiency (theoretical efficiency) is unattainable, and the actual efficiency ranges between 25 and 45% [34]. A wind farm can include a few to hundreds of wind turbines spread across a broad region. Wind farms might be built onshore or offshore [35]. Wind farms do not pollute the air or water since no fuel is burnt [36,37]. As a result, wind energy will enhance energy security while simultaneously helping to reduce carbon dioxide emissions. The generator is coupled to a shaft on which the wind blades are rotating. A gearbox connects the slow-rotating turbine shaft to the fast-rotating generator shaft; these gears raise the turbine shaft's rotational speed from 30–60 rpm to 1200–1500 rpm in the generator shaft, resulting in the spinning of copper coils inside a generator-housed magnet. This magnet excites the wire's electrons, creating electricity. The number of copper coils and the speed at which the shaft spins in the magnetic field determine how much power is produced [38].

To achieve sustainability, it is critical to employ renewable energy sources, such as wind energy, which can be harnessed without causing harm to future generations. Wind energy is clean and environmentally friendly since it emits no carbon dioxide or other greenhouse gases into the atmosphere [39]. Wind power is a sustainable and environmentally friendly form of electricity generation since it does not pollute or harm the environment while producing electricity. Wind power also contributes towards a higher quality of life by supplying us with clean air, clean water, and protection from natural disasters, such as hurricanes and floods (associated with global warming) [40,41]. There are several challenges associated with using wind energy, such as the need for more land to operate a wind farm and the difficulty in locating a place with enough wind to provide the optimal efficiency and power [42,43]. Most onshore wind farms are typically located in rural areas, distant from cities that demand power, which necessitates the construction of transmission lines to transport the electricity from the wind farm to the city, eventually increasing the cost. Other disadvantages include the influence on nearby animals; there have been multiple occasions where birds and bats have died due to accidents with spinning turbine blades and turbine obstructions in their flight routes [44].

It is important to note that continuing research is being conducted to discover a solution to the mentioned limitations and any potential major obstacles [45,46].

- Environmental impacts

Several studies have found wind energy to be one of the cleanest, infinitely sustainable, and ecologically beneficial of all the renewable technologies available today. It is considered the most compatible energy source for humans and animals [47,48]. Despite this, several experts have detected small environmental repercussions, notably on animals. Wind farms require a huge amount of land with enough wind to function efficiently, which will undoubtedly impact the area's environment; nevertheless, the ground beneath each turbine may still be utilized for animal grazing or cultivation [40,49]. Furthermore, wind farms directly impact the lives of birds and bats. Birds are among the most common global victims of wind turbine accidents [50]. It is critical to investigate the effects of wind turbine use and wind farms; however, when weighed against the beneficial impact, wind energy has done more benefit than harm to the environment [51]. Wind energy will reduce or eliminate the usage of the fossil fuels that are producing harmful $CO_2$, $NO_x$, and $SO_x$ emissions that are the reason behind acid rain and global warming, which eventually cause the greenhouse gas effect, a rise in sea level, and fluctuating weather conditions [52,53].

- Social impact

The primary concerns for every country's growth are social issues. One of the most significant social benefits of wind power expansion is the creation of job opportunities; the rapid growth that the wind energy sector has shown in recent years is promising; according to the Office of Energy Efficiency and Renewable Energy, the field of wind energy employed over 100,000 people in the United States in 2016 [54]. Furthermore, wind farms can meet citizens' demands, allowing them to carry out their activities without fear of blackouts [55].

- Economic impact

In addition to job opportunities, the wind energy industry supplies residents with low-cost power. It is regarded as one of the most affordable energy sources, with prices for the most competitive projects as low as USD 0.030/kWh [56]. A wind farm may be considered an addition to tourism in regions where tourism is a significant component of the local economy for individuals interested in technology.

## 3. Sustainable Development Goals

The SDGs are a set of 17 goals established by the United Nations to end poverty and hunger, achieve gender equality and empower women, ensure healthy lives and promote well-being for all ages, reduce inequality within and among countries, ensure sustainable consumption and production patterns, and slow or stop climate change and its consequences [57]. The United Nations established the SDGs, also known as the Global Goals, in 2015 as a call to action to eradicate poverty, protect the environment, and promote peace and prosperity for all by 2030 [58]. The Brundtland Commission issued the Brundtland Commission Report in 1987, which defined sustainable development as "development that fulfills existing requirements without harming future generations." The four components of sustainable development are society, environment, culture, and economics [59]. An integrated approach to sustainability takes into account environmental, social, and economic considerations, as well as the desire for a higher quality of life in the future. For example, affluent civilizations may offer food, resources, and clean air to their citizens by maintaining a healthy environment. Sustainability is commonly thought of as an end goal, but sustainable development is the method by which it is attained. All 17 SDGs are interrelated, reflecting the reality that the actions of one zone affect the outcomes in other zones, requiring adjustments to social, financial, and ecological sustainability. Nations have agreed to coordinate advancements for those who are most hampered.

The SDGs also aim to dispense with destitution, starvation, and sexual orientation separation against females. Nowadays, the joined together Countries Office of Financial and Social Issues (UNDESA) Division for Maintainable Advancement Objectives (DSDG) gives substantive support and capacity-building for the SDGs and related topical issues, such as water, vitality, climate, seas, urbanization, transportation, science and innovation, the Worldwide Economic Advancement Report (GSDR). The DSDG plays a critical part in assessing the UN system-wide execution of the 2030 plan and in promotion and outreach activities related to the SDGs. To make the 2030 plan a reality, the far-reaching proprietorship of the SDGs must translate into a solid commitment to execute the worldwide objectives by all partners.

### 3.1. Renewable Energy and SDGs

The SDGs provide a solid foundation for international collaboration in achieving a sustainable future for the planet. Without access to energy services, it is hard to live a dignified life. Not only technology is capable of producing and supplying low-cost, sustainable energy [60,61]. It is not only a goal in its own right but also a means to attain other goals, and the implementation of renewable energy ensures that no one is left behind. With the correct financing mechanism, energy systems can be deployed independently to produce local value [62]. Renewables are easy to install and manage due to their modularity, flexibility, and ease of installation. Every individual or community has the potential to become an energy producer, contributing to the growth of new industries, fostering innovation and environmentally responsible industrialization, and opening up prospects for employment. Renewable energies can reduce the inequalities between urban and rural populations [63]. Renewable energy makes it possible to pay attention to the requirements of women and children, who typically suffer the most from a lack of essential services in their homes. Cooking with renewable power can help preserve our forests and wildlife. Additionally, utilizing renewable energy results in lower levels of air pollution and emissions of greenhouse gases; therefore, it is one of the most important methods" might be better for combating climate change [64,65].

The same is true for life on land as it is for life in the water: renewables can alleviate the effects of ocean acidification and maintain marine ecosystems [66]. Because geopolitical tensions and military confrontations are linked to access to fossil fuel resources and infrastructure in many regions of the world, a world powered by renewable energy is a more peaceful, secure, and equitable environment for everybody [67]. It is regarded as one of the purest and most environmentally friendly energy sources, which aids in achieving sustainable development goals; similar to nuclear power plants, it also does not create any waste. It is also one of the least expensive renewable energy sources accessible to consumers.

### 3.2. Wind Energy Role in Achieving the Sustainable Development Goals (SDGs)

The United Nations SDGs aim to expand the share of renewable energy in the global electricity mix to at least 70% by 2030. Wind energy does not contribute to the pollution of the environment, does not run out, and lessens the need for fossil fuels, which are the primary contributors to the greenhouse effect [47,68]. Wind energy has many benefits, such as reducing carbon emissions and creating jobs, but it also has some challenges, such as the potential to harm wildlife if not properly managed. Wind energy also helps to minimize energy imports while providing income and local jobs. Wind energy generation and good usage contribute to sustainable development [15,69]. Figure 3 shows the wind's advantages and disadvantages in terms of the SDGs. The benefits of wind energy are as follows: it is a renewable energy source; it is inexhaustible; it cuts down on the usage of fossil fuels; it cuts down on energy imports; it creates wealth and local employment opportunities. Figure 4 summarizes the contributions of wind to the three pillars of sustainable development.

Wind energy emits no toxic elements or poisons into the atmosphere, which might be exceedingly destructive to both the environment and humans. Air pollution has been related to several health issues, including cancer, cardiovascular disease, and respiratory diseases such as asthma. Wind energy operates in the same way as windmills do, by harnessing the power of the wind to turn a blade. However, offshore usage has its own set of challenges [70]. Achieving this will help us prevent climate change and other environmental issues that are caused by pollution. Table 2 summarizes the contributions of wind energy to the SDGs.

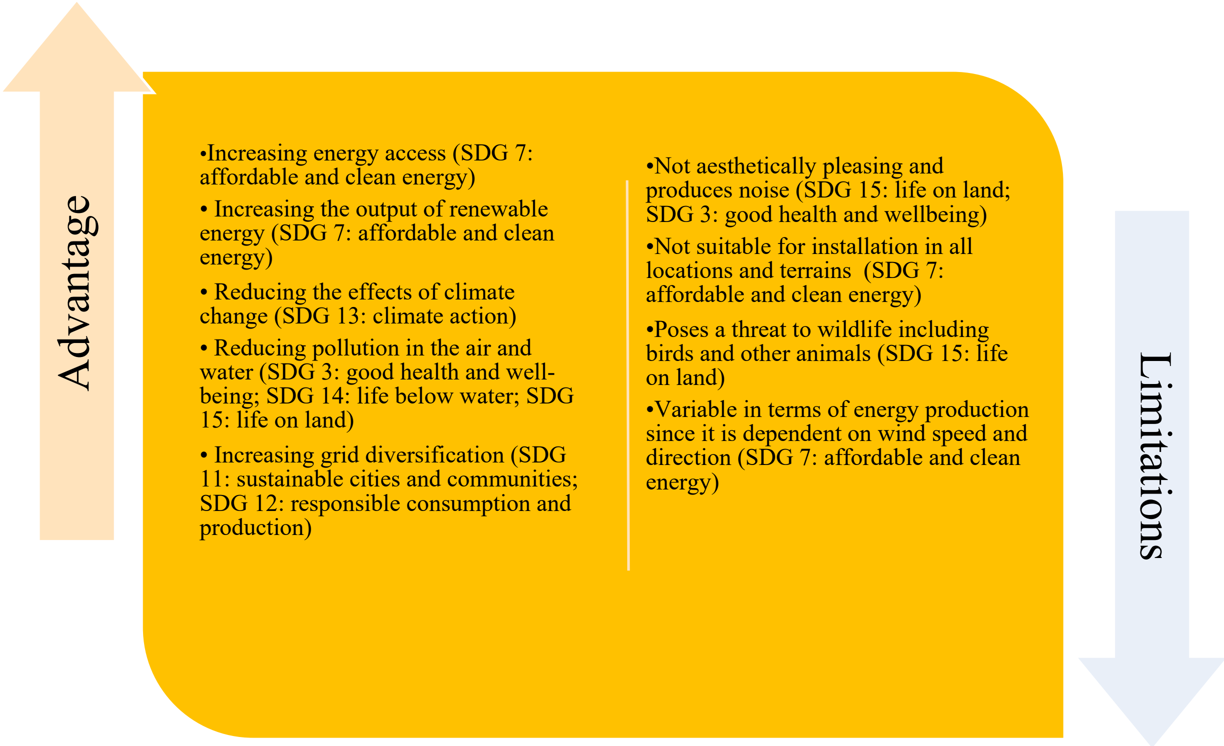


**Figure 3.** Advantages and disadvantages of wind in the context of the SDGs.

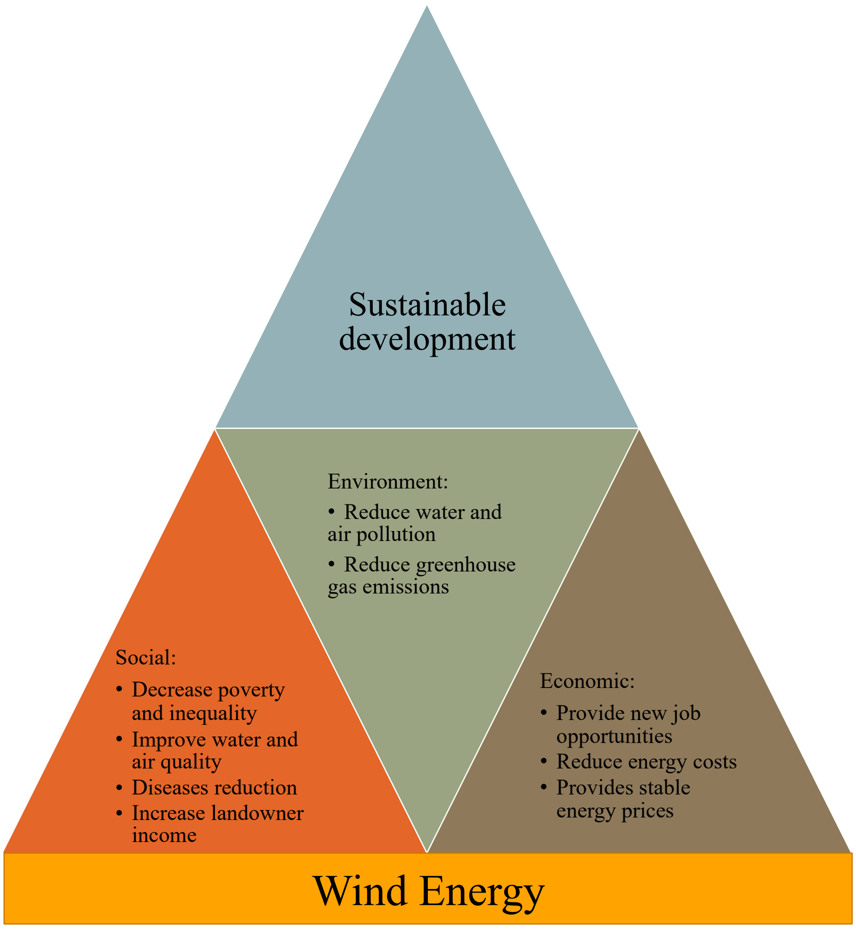


**Figure 4.** Contributions of wind energy in terms of social, economic, and environmental aspects.

**Table 2.** Summary of the contributions of wind energy to the SDGs.

| SDG | Wind Farms' Contribution to the SDGs |
|---|---|
| SDG 1: No poverty | • Increases access to energy and creates more jobs. |
| SDG 3: Good health and wellbeing | • Has the potential to contribute to the improvement of public health by lowering levels of air pollution and emissions of greenhouse gases, both of which have been linked to a variety of adverse health effects. |
| SDG 6: Clean water and sanitation | • Requires no water consumption, unlike conventional technologies. |
| SDG 7: Affordable and clean energy | • A clean, renewable source of energy that does not produce greenhouse gas emissions. As a result, it contributes to the goal of increasing the use of clean energy sources, which is to increase the use of clean energy sources. |
| SDG 8: Decent work and economic growth | • Creates new jobs and improves economic growth. |
| SDG 9: Industry, innovation, and infrastructure | • Improves energy security and reduces the overall carbon footprint of the industry. |
| SDG 11: Sustainable cities and communities | • Reduces reliance on traditional power plants, resulting in less pollution. |
| SDG 12: Responsible consumption and production | • Reduces air and water pollution by supplying cleaner and safer energy. |
| SDG 13: Climate action | • Reduces GHG emissions by supplying a low-emission energy source.<br>• Prevents climate change. |
| SDG 14: Life below water | • Avoids the negative effects on ecosystems of conventional resources. |
| SDG 15: Life on land | • Utilizes unused areas and regions for sustainable energy production. |

Several indicators can be utilized to determine whether or not wind energy is sustainable. Some examples include [22,71]:

- Impact on the environment: Wind energy has several impacts on the environment, including habitat destruction, noise pollution, and aesthetic degradation. The number of birds and bats that are killed by wind turbines, the distance between turbines and homes or other sensitive receptors, and the amount of greenhouse gases emitted during the manufacture and transportation of wind energy components are some of the indicators that can be used to evaluate these factors.
- Economic viability: The economic viability of wind energy can be evaluated by taking into consideration a number of factors, including the cost of the energy that is produced, the amount of subsidies that are required, and the return on investment.
- Acceptability to society: The level of community involvement in wind energy projects, public attitudes toward wind energy, and the potential for conflict with other land uses are some of the factors that can be used to evaluate the acceptability of wind energy to society.

- Maturity in terms of technology: The technological maturity of wind energy can be evaluated by considering a number of factors, including the dependability of wind turbines, the effectiveness of energy production, and the possibility of further technological advancements in the near future.

*3.3. Case Study: London Array Wind Farm*

The London Array was initially designed in four phases and is located 20 km between the counties of Kent and Essex, with the cable path heading southwest towards Cleve Hill in north Kent [72]. It has 175 turbines generating 630 megawatts (MW) of power. The first phase of this project comprised 175 wind turbines capable of powering half a million UK households and reducing damaging carbon dioxide emissions by around 900,000 tons per year. Construction began on March 2011 and was completed in 2013 [73]. Due to concerns about the impact on marine birds, a second phase of the project involving building 166 more turbines (raising the total output to 1000 MW) was denied planning clearance in 2014 [74]. The project was funded in part by E.ON (UK), DONG (Denmark), Masdar (Abu Dhabi), and La Caisse (Canada). Figure 5 shows the London Array project's contribution to sustainable development. Moreover, the London Array can be considered one of Europe's largest wind farms in terms of power generation.

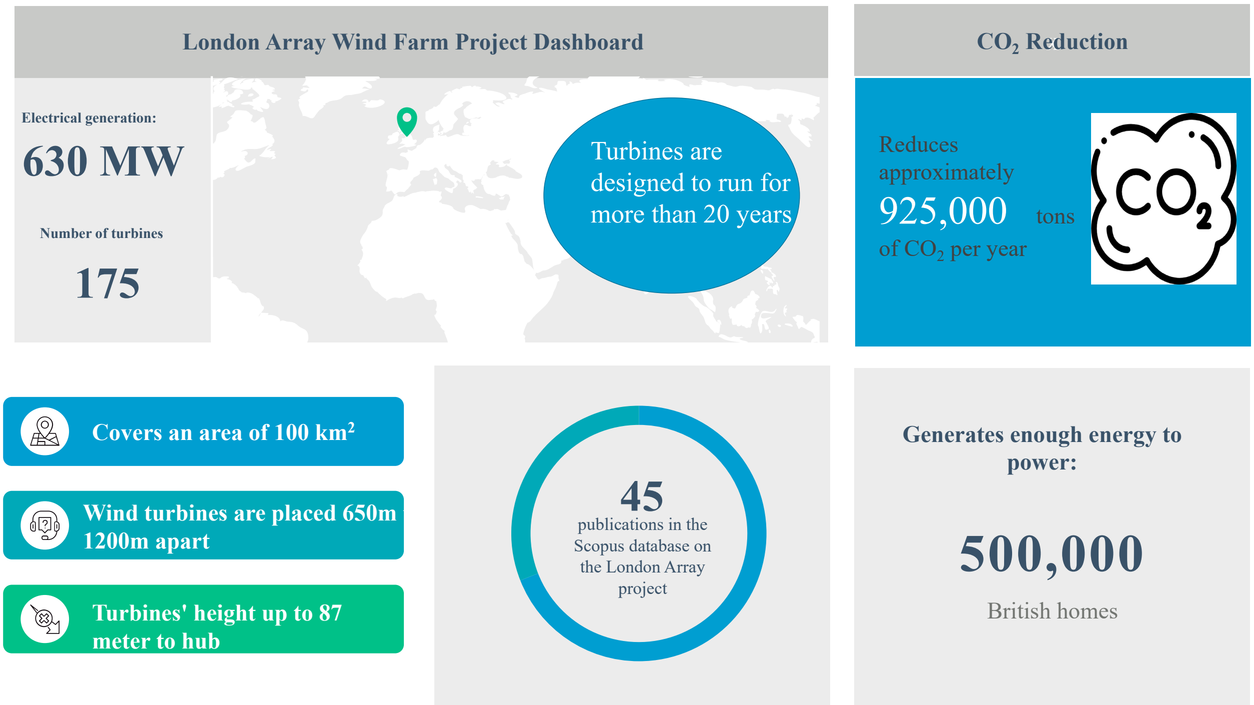


**Figure 5.** London Array project contributions to sustainable development.

Advantages of the London Array project:

- No waste or pollution generated from the plant.
- Relatively inexpensive to create.
- Renewable.
- Significant energy produced.
- Reduce carbon emissions by a huge amount in terms of carbon tons.
- Assists the UK in attaining the EU's 15% renewable energy goal by 2020.
- Local work prospects during the plant's development and life cycle.

Disadvantages of the London Array project:

- A massive number of turbines are required to generate a considerable amount of electricity.
- The unpredictable output of the wind turbines, which are affected by wind speed.

- Disruption to marine life.
- Disruption to seabird existence in that location.
- Disturbance to local fishing grounds.

In terms of the London Array's sustainability, they were able to effectively combat the negative impacts by collaborating with a variety of stakeholders and a variety of connected agencies, including the Maritime and Coastguard Agency. In addition, they have implemented every conceivable preventative precaution to lessen the severity of negative effects. Numerous environmental impact assessments (EIA) were conducted before any building commenced, as with any new development, but notably with the planning requirements for a renewable energy plant [75]. When creating a renewable energy plant, it is critical to evaluate its influence on habitats, migration habits, feeding places, breeding grounds, and ecosystem health, as well as other potential implications [49]. Based on the EIA report provided by London Array, available at https://londonarray.com/wp-content/uploads/2020/07/Non-technical-summary.pdf (accessed on 2 January 2023), in terms of the physical environment, it was anticipated that the construction, operation, or decommissioning of the facility would not have any significant effects on the surrounding physical environment.

In terms of the biological environment, wind farms provide a considerable risk to birds due to the possibility of accidents involving wind turbines. There is also concern that wind turbines would shift populations or lead birds to avoid the farms entirely due to the perceived risk [50]. Larger wind turbines and quicker rotor speeds, which are more prevalent in offshore turbines, increase the chance of collision. The displacement of birds from the surrounding region as a result of visual intrusion or noise from wind farms can result in significant habitat loss. Birds may also alter their migratory or local flyways to avoid the wind farm, resulting in increased energy expenditure and the disruption of feeding and roosting habits and breeding regions [76]. Some of the implications are favorable, such as the elimination of emissions caused by alternative energy sources. However, certain repercussions are extremely damaging, such as probable rotor blade migration impedance or breeding ground displacement due to onshore substation building [77].

The economic benefits of the wind project, such as the creation of jobs during the construction and operation of the facility, as well as the contribution of the wind project to the local economy through taxes and other economic activity, are included in the definition of the social impact that London Array has. It is possible that the wind farm will have a beneficial societal impact as a result of the provision of clean, renewable energy. This has assisted in the reduction of emissions of greenhouse gases and the amelioration of the effects of climate change.

In terms of its community involvement, London Array has been participating in activities such as donating money to local charities and organizations, organizing events for the community, and collaborating with local educational institutions, such as schools and universities, to advance educational opportunities and professional growth. A social effect has also been caused by the London Array employment and diversity policies. These practices include its attempts to recruit and retain a diverse staff and its efforts to promote equal opportunities and inclusion in the workplace.

In terms of supporting the SDGs, the London Array offshore wind farm can be seen as contributing to several of these. The following are some of the ways that London Array has contributed:

- SDG 1: No poverty. The building and ongoing operation of the London Array wind farm has created employment and other economic possibilities, both of which can contribute to the regional economy's expansion and growth. In addition, the project has offered financing for community projects via its community fund, which has funded efforts such as education about renewable energy and energy efficiency upgrades for local homes. Moreover, the project has provided funding for community projects. These activities may enhance the economic and social well-being of disadvantaged communities, which can contribute to decreasing poverty in such places.

- SDG 3: Good health and well-being. London Array may assist in minimizing the effects of climate change on human health by lowering the emissions of greenhouse gases. Human health is susceptible to being negatively impacted by climate change in various ways, including increasing temperatures, severe weather events, and other effects. In addition, the decrease in air pollution that results from using wind energy may have a beneficial effect on human health. This is especially true for more susceptible groups, such as children, the elderly, and those who already have one or more preexisting health concern.
- SDG 7: Affordable and clean energy. London Array generates electricity from a renewable energy source, wind, which is considered to be more sustainable and less polluting than fossil fuels such as coal and oil. By providing clean electricity, the London Array helps to reduce greenhouse gas emissions and combat climate change, which is a key target of this goal.
- SDG 8: Decent work and economic growth. According to London Array's website, the wind farm has supported the creation of over 3000 jobs, with over 60% of the work going to UK-based companies.
- SDG 9: Industry, innovation, and infrastructure: The London Array is a large-scale infrastructure project that requires significant investment and innovation in designing and constructing the wind turbines and offshore substation. The project has also supported the development of the offshore wind industry in the United Kingdom.

Overall, London Array's focus on research and development demonstrates its commitment to improving offshore wind energy's efficiency and sustainability and advancing the state of knowledge in this field.

- SDG 13: Climate action. As a large offshore wind farm, the London Array is expected to offset approximately 1.9 million tons of carbon dioxide emissions per year, making it a significant contributor to climate action.
- SDG 14: Life below water. London Array generates electricity from a renewable energy source, wind, which is considered to be more sustainable and less polluting than fossil fuels such as coal and oil. By reducing greenhouse gas emissions, London Array can help mitigate climate change's impacts on the oceans, which is a major threat to marine life. In addition, London Array has supported offshore wind energy development, which may help reduce the demand for fossil fuels and potentially reduce the negative impacts of offshore oil and gas development on marine ecosystems.
- SDG 15: Life on land: London Array can help mitigate the effects of climate change on land-based ecosystems and biodiversity by reducing the emissions of greenhouse gases. These ecosystems and species are in danger because of rising temperatures, extreme weather events, and other effects of climate change. In addition, London Array has contributed to the development of offshore wind energy, which may help to reduce the demand for fossil fuels and may help to reduce the negative impacts of the extraction and use of fossil fuels on land-based ecosystems.

Figure 6 provides a summary of how London Array will be able to contribute to the achievement of the SDGs. The purpose of Figure 6 is to provide a visual summary of the potential impact that the London Array project could have on the SDGs, highlighting the ways in which the project is aligned with global efforts to create a sustainable and equitable future. It is possible for stakeholders to gain a better understanding of the potential benefits of the project and how the project contributes to the larger goals of sustainable development if this information is presented in a manner that is both clear and concise.

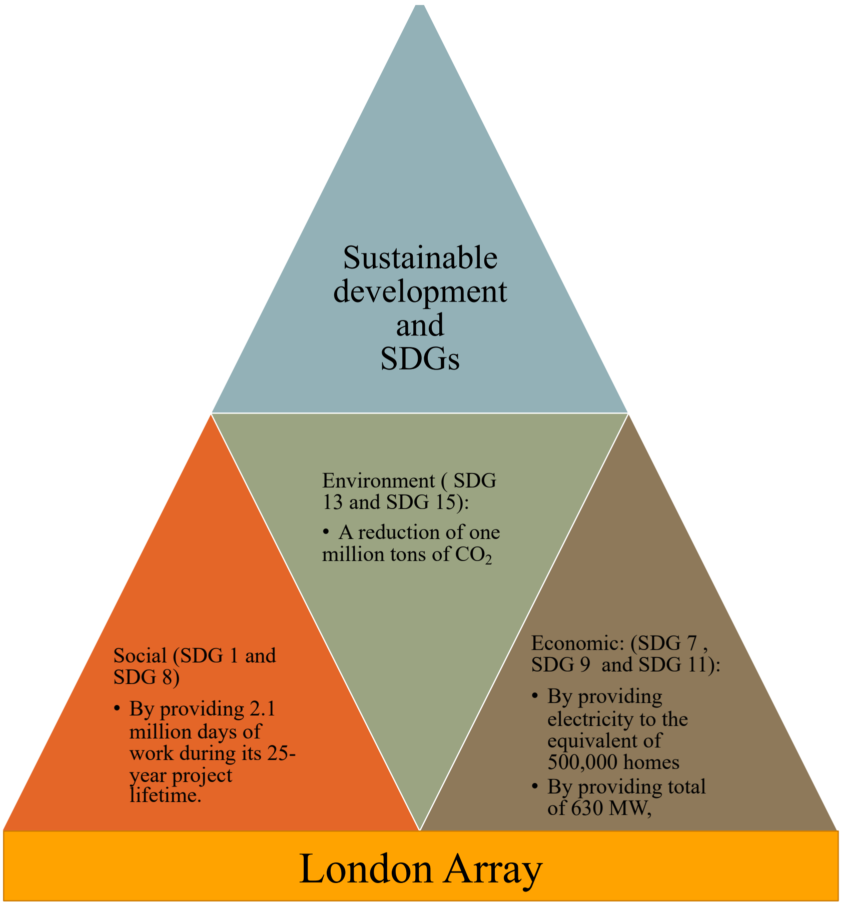


**Figure 6.** London Array's contribution to the SDGs.

### *3.4. Sustainability Indicators*

Businesses are essential to achieving the SDGs because they are the primary drivers of economic growth and possess the resources and influence necessary to have a constructive effect on society and the environment. Linking business to the SDGs can have a number of benefits, including [53,78–80]:

- Improving the reputation of the company and the image of its brand. Businesses can show their commitment to social and environmental responsibility, as well as attract consumers and stakeholders that place a value on sustainability, by aligning their business practices with the SDGs.
- Companies that address the risks and opportunities presented by sustainability are better prepared to withstand economic and social challenges such as natural disasters, resource constraints, and shifting consumer preferences. These companies have taken steps to reduce risks and increase their resilience.
- SDGs provide a framework that businesses can use to identify and address unmet needs in areas such as healthcare, education, and renewable energy, which can lead to the development of new products and services. One of the benefits of the SDGs is that they create new business opportunities.

In summary, by aligning with the SDGs, organizations and individuals can ensure that their work is not only having a positive impact on the local community but also contributing to the global effort to create a more sustainable and equitable world for all.

Key performance indicators are critical (key) measures of progress towards an anticipated objective. KPIs help center attention on what matters most, offer an analytical foundation for decision-making, and give a focus on strategic and operational development. KPIs are the go-to tool for every expert since they serve as measures for developing plans, monitoring performance, and establishing objectives [81]. They facilitate decision-making by emphasizing goals and providing a framework for examination. KPIs are one foundation that helps firms go on the right path. KPIs have long been used in management [82–84]. One of the reasons KPIs are so popular is because of all the advantages that come with employing them. In this paper, a total of 77 indicators, shown in Table 3, were developed based on the study presented above and several other published publications [78,85–87]. The benefit of these indicators is to verify that the wind project contributes to the achievement of the SDGs by providing a balanced approach to each of the SDGs. In addition to the primary advantages that the suggested indicators provide, there are several further advantages, which may be summed up in Figure 7 [78,83–85].

**Table 3.** Wind SDGs indicators and sustainability guideline.

| | |
|---|---|
| SDG 1: No poverty | |
| 1. | Sum paid in taxes. |
| 2. | Total workers' income. |
| 3. | Sum of employee salary. |
| 4. | Training program offered. |
| 5. | Paying reasonable costs, particularly micro, small, and medium-sized businesses. |
| 6. | Reducing low-income residents' utility expenditures. |
| SDG 2: Zero hunger | |
| 7. | Type of land occupied. |
| 8. | Policy on catastrophe risk management available. |
| 9. | Assisting smallholders by lowering utility prices. |
| SDG 3: Good health and well-being | |
| 10. | Ensuring that employees receive full healthcare benefits. |
| 11. | Calculating the possibility of human toxicity, particulate matter, and photochemical ozone formation. |
| 12. | Ensuring that a policy on workplace health and safety is available. |
| 13. | Decreasing the number of accidents that occur as a result of project completion. |
| 14. | Ensuring that noise is controlled and reduced. |
| SDG 4: Quality education | |
| 15. | Offering a program to measure employees' skill levels. |
| 16. | Ensuring zero tolerance of child labor. |
| SDG 5: Gender equality | |
| 17. | Proportion of women hired and recruited. |
| 18. | Total money paid to women. |
| 19. | Percentage of women in positions of leadership. |
| SDG 6: Clean water and sanitation | |
| 20. | Impact on water quality. |
| 21. | Calculating the potential for eutrophication and ecotoxicity in freshwater aquatic systems. |
| 22. | Improving the efficiency of water usage. |
| SDG 7 Affordable and clean energy | |
| 23. | Making an energy balance analysis. |
| 24. | Measuring the capacity factor. |
| 25. | Decreases in energy usage. |
| 26. | Total energy generated overall by the plant. |
| 27. | Total amount invested on energy programs. |
| 28. | Measuring production outcome. |
| 29. | Increasing the amount of energy stored. |
| 30. | Measuring availability time. |
| SDG 8: Decent work and economic growth | |
| 31. | Increasing gross domestic product through decreasing the cost of energy, a resource required by all kinds of industry. |
| 32. | Reducing operating costs by recycling industrial effluent. |
| 33. | Research and development expenditures for clean technologies. |
| 34. | Total number of new jobs. |
| 35. | Maximizing the use of resources. |
| 36. | Costs of capital and electricity. |
| 37. | Total amount spent on research and development. |
| 38. | Integration of employee rights policies. |
| 39. | Total amount paid to the community as compensation for resources used in the project. |
| 40. | Purchasing all products and services locally. |

**Table 3.** *Cont.*

| |
|---|
| SDG 9: Industry, innovation, and infrastructure |
| 41. Evaluating social, economic, and environmental effects.<br>42. Using the circular business model.<br>43. Tracking and reporting on the effects of climate change.<br>44. Overall value added.<br>45. Encouraging industrialization that is inclusive and sustainable.<br>46. Refitting factories with clean technology that uses few resources.<br>47. Lowering the amount of $CO_2$ released per unit of value added.<br>48. Lessening the carbon footprint of materials. |
| SDG 10: Reduced inequalities |
| 49. Sharing training programs for underrepresented groups.<br>50. Total fee differences across various working classes.<br>51. Total pay disparities across several occupational groupings.<br>52. Diversity and inclusion level. |
| SDG 11: Sustainable cities and communities |
| 53. Energy circulation to lessen the effects of urbanization on the environment.<br>54. Sustainability strategies for resources.<br>55. Plans for preparing for disasters are offered to vulnerable groups.<br>56. Ensuring that sustainability regulations are followed. |
| SDG 12: Responsible consumption and production |
| 57. Enhancing the system for recycling waste products.<br>58. Total amount of essential resources and materials.<br>59. Total amount of waste generated.<br>60. Keeping track of pollution, such as greenhouse gas emissions and methane emissions. |
| SDG 13: Climate action |
| 61. Recording and reporting of all forms of pollution.<br>62. The total amount of research focused on climate change.<br>63. Putting a number on the ecotoxicity of maritime environments. |
| SDG 14: Life below water |
| 64. Reducing marine pollution.<br>65. Sustainably managing marine ecosystems.<br>66. Addressing ocean acidification.<br>67. Eliminating harmful fisheries subsidies.<br>68. Increasing research and development in marine technology. |
| SDG 15: Life on land |
| 69. Biodiversity effect quantification<br>70. Using the life cycle analysis to measure environmental effects.<br>71. Brownfield and previously developed land projects.<br>72. Contributing to research and landscaping. |
| SDG 16: Peace, justice, and strong institution |
| 73. Engagement of project stakeholders.<br>74. Disclosure of project regulations and compliance. |
| SDG 17: Partnerships for the goals |
| 75. Integration of the SDGs into business strategies.<br>76. Cooperation between the various government organizations.<br>77. Collaboration with a variety of different groups. |

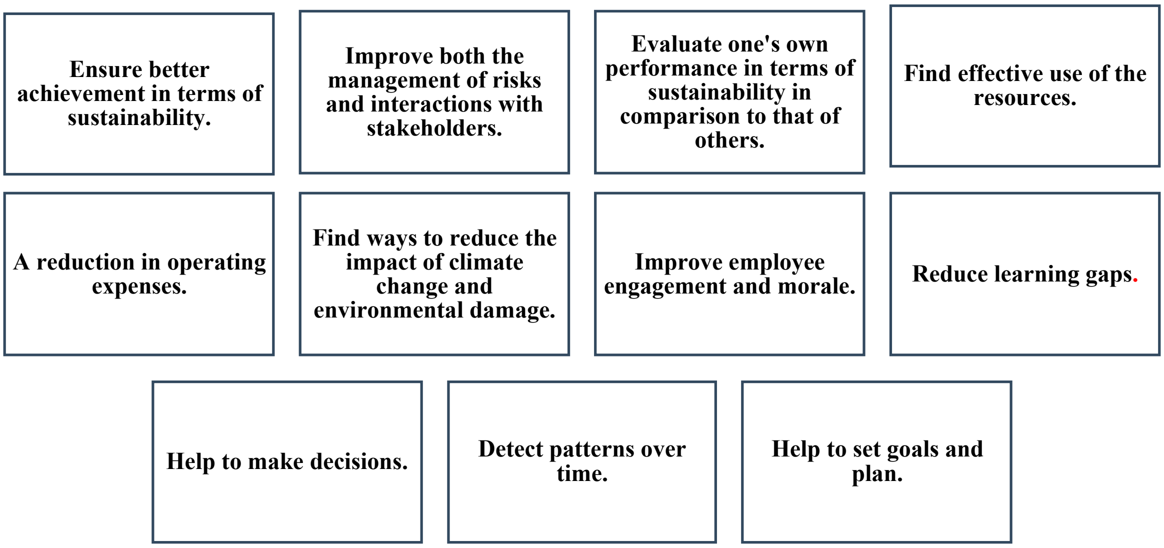


**Figure 7.** Benefits of adopting the KPIs.

The indicators provided in Table 3 are used to measure the progress that various wind energy projects and initiatives are making towards achieving the SDGs. For example, under SDG 1: No poverty, indicators such as the sum of taxes paid, the total number of workers, employee salaries, and the total training program offered provide information on the economic status of individuals and businesses, and the efforts made to reduce poverty. Similarly, under SDG 2: Zero hunger, indicators such as the type of land occupied and the availability of a policy on catastrophe risk management provide information on food security and the efforts to mitigate the impact of natural disasters. While under SDG 3: Good health and wellbeing, indicators such as employee health benefits, a workplace health and safety policy, and control of noise provide information on the health and safety of workers. Moreover, under SDG 4: Quality education, indicators such as a skills measurement program and a zero tolerance policy for child labor provide information on the education and wellbeing of children. Similarly, under SDG 5: Gender equality, indicators such as the proportion of women hired, the money paid to women, and the percentage of women in leadership positions provide information on gender equality in the workplace. Additionally, the indicators listed under the other SDGs, such as 'Clean water and sanitation', 'Affordable and clean energy', 'Decent work and economic growth', and so on, provide information on various aspects of sustainability, including environmental protection, economic growth, and social equality. Overall, Table 3 provides a comprehensive overview of the various indicators used to measure the progress towards achieving the SDGs, and highlights the importance of considering multiple aspects of sustainability in wind energy-related projects.

The London Array was a large-scale offshore wind farm that was constructed in the waters off the coast of Kent in the UK. Based on EIA and EMMP, the following is a list of some of the KPIs that were utilized during the process of developing the London Array:

- Capacity factor: This is a measure of the efficiency of the wind turbines and was an important KPI for the London Array project because it determined the overall energy output of the wind farm. The capacity factor can be calculated by dividing the total energy output of the wind farm by the total number of wind turbines.
- Accessibility: This metric quantifies the proportion of time that the wind turbines were online and able to produce electricity. In order to achieve the highest possible energy output from the London Array, it was essential to guarantee high availability.
- Maintenance expenses: The London Array required regular maintenance to ensure its continued operation and shorten the amount of time it was offline. As one of the KPIs for the project, the costs of maintenance were closely monitored.

- Production costs: The cost of making electricity was an important KPI because it had a direct effect on the project's ability to make money. The goal was to maintain a high level of production efficiency while minimizing the costs of production.
- Impact on the environment: The London Array was developed to have as little of an effect as possible on the local wildlife and the surrounding environment. The environmental impact of the project was measured and monitored with the help of KPIs.
- Health and safety: It was of the utmost importance that the health and safety of the workers involved in the construction and maintenance of the wind farm be kept in the highest regard. KPIs were utilized in the process of monitoring and ensuring the workers' safety.
- Timeline for the project: The London Array was a big, complicated job, and the timeline for finishing it was carefully monitored and managed. KPIs were utilized in order to monitor progress and guarantee that the project would be finished on schedule.

These KPIs were utilized frequently throughout the development of the London Array wind farm project, and their contribution to the overall success of the project cannot be overstated.

As mentioned above, based on the available information and data, London Array has used most of the above KPIs, to measure and track the performance and efficiency of their business and the overall operation of the wind farm. Some examples of KPIs, with their value, if publicly available, that were used in the London Array include:

- SDG 7: Affordable and clean energy:
    - Capacity factor: The ratio of the actual electricity generated by the wind farm to the theoretical maximum output if the wind turbines were operating at full capacity all the time. The capacity factor of the London Array is equal to 38.3%, (from https://energynumbers.info/uk-offshore-wind-capacity-factors, accessed on 2 January 2023).
    - Availability: The percentage of time that the wind turbines are able to generate electricity, taking into account planned and unplanned maintenance, equipment failures, and other factors that could cause the turbines to be offline
    - Production: The total amount of electricity generated by the wind farm over a specific period of time, such as a month or a year. The nameplate capacity of the London Array is equal to 630 MW and the annual net output is 3100 GWh, (from https://londonarray.com/, accessed on 2 January 2023).
- SDG 8: Decent work and economic growth
    - Revenue: The income generated by the sale of electricity. London Array's estimated annual revenue is currently $8.2M per year, (from https://growjo.com/company/London_Array, accessed on 2 January 2023).
- SDG 13: Climate action and SDG 15: Life on land
    - Carbon emissions avoided: The reduction in greenhouse gas emissions that is achieved by generating electricity from the wind farm instead of fossil fuel sources. The total carbon emission avoided was 925,000 tons of $CO_2$.

Moreover, London Array have conducted an environmental impact assessment (EIA) and an ecological mitigation and management plan (EMMP), both available from https://londonarray.com, accessed on 2 January 2023. The EIA considered the potential impacts of the project on the environment, including the impact on birds, marine mammals, and fish, as well as the potential visual impact of the wind turbines. Measures were put in place to mitigate any negative impacts, such as the installation of radar systems to help detect and avoid bird and bat collisions. The London Array was also designed to operate in a way that minimizes any potential negative impacts on the local community and the surrounding environment. An EMMP is a plan that outlines the measures that will be taken to minimize the potential negative impacts of a project on the environment and to protect and enhance the ecological value of an area. An EMMP is typically developed as part of the EIA process for a project, and it outlines the measures that will be taken to avoid, minimize, and compensate for any negative impacts on the environment. It is not unusual for wind projects such as the London Array to have an EMMP in place to ensure that the project is designed and maintained in a manner that minimizes the negative effects it has on the environment. Table 4 shows the KPIs that were covered in the EIA and EMMP from our proposed KPIs. Table 4 also contains a list of the various KPIs that are associated with the SDGs and that can be tracked in order to evaluate the impact of a project. Each SDG has a corresponding set of KPIs that were used to assess the extent to which the London Array project was able to help in achieving that SDG. It is important to highlight that additional KPIs could have been addressed, but they are not currently being announced publicly, as is the case with the majority of the companies. This is mostly due to concerns about maintaining secrecy.

**Table 4.** KPIs covered in the EIA and EMMP from the above proposed KPIs.

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| SDG 3: Good health and wellbeing<br>1. Calculating the possibility for human toxicity, particulate matter, and photochemical ozone formation.<br>2. Ensuring that a policy on workplace health and safety is available.<br>3. Decreasing the number of accidents that occur as a result of project completion.<br>4. Ensuring that noise is controlled and reduced. |
| SDG 6: Clean water and sanitation<br>5. Impact on water quality.<br>6. Calculating the potential for eutrophication and ecotoxicity in freshwater aquatic systems.<br>7. Improving the efficiency of water usage. |
| SDG 7: Affordable and clean energy<br>8. Making an energy balance analysis.<br>9. Measuring the capacity factor.<br>10. Decreases in energy usage.<br>11. Total energy generated overall by the plant.<br>12. Total amount invested on energy programs.<br>13. Measuring the production outcome.<br>14. Increasing the amount of energy stored.<br>15. Measuring the availability time. |
| SDG 8: Decent work and economic growth<br>16. Total number of new jobs.<br>17. Maximizing the use of resources.<br>18. Costs of capital and electricity.<br>19. Total amount spent on research and development.<br>20. Integration of employee rights policies. |
| SDG 9: Industry, innovation, and infrastructure<br>21. Evaluating the social, economic, and environmental effects.<br>22. Using the circular business model.<br>23. Tracking and reporting on the effects on climate change.<br>24. Overall value added.<br>25. Lowering the amount of $CO_2$ released per unit of value added.<br>26. Lessening the carbon footprint of materials. |
| SDG 11: Sustainable cities and communities<br>27. Energy circulation to lessen the effects of urbanization on the environment.<br>28. Sustainability strategies of resources.<br>29. Plans for preparing for disasters offered to vulnerable groups.<br>30. Resource and sustainability regulations. |

**Table 4.** *Cont.*

| |
|---|
| SDG 12: Responsible consumption and production |
| 31. Enhancing the system for recycling waste products.<br>32. Total amount of essential resources and materials.<br>33. Total amount of waste generated.<br>34. Keeping track of pollution, such as greenhouse gas emissions and methane emissions. |
| SDG 13: Climate action |
| 35. Recording and reporting of all forms of pollution.<br>36. Total amount of research that is focused on climate change.<br>37. Putting a number on the ecotoxicity of maritime environments. |
| SDG 14: Life below water |
| 38. Reducing marine pollution.<br>39. Sustainably managing marine ecosystems.<br>40. Addressing the acidification of the ocean.<br>41. Eliminating harmful fisheries subsidies.<br>42. Increasing research and development in marine technology. |
| SDG 15: Life on land |
| 43. Biodiversity effect quantification.<br>44. Using the life cycle analysis to measure environmental effects.<br>45. Brownfield and previously developed land projects.<br>46. Contribution to research and landscaping. |

## 4. Conclusions

The SDGs depend on the transition to clean, renewable energy, therefore wind energy companies must connect with the SDGs. Wind energy companies can show their commitment to sustainability and social responsibility and help achieve the SDGs by linking their business to them. This could boost the company's reputation and brand image and open new business opportunities due to the rising demand for renewable energy. Wind power can support most SDGs. In our case study of London Array, the main benefits were a 925,000-ton reduction in greenhouse gas emissions (Goal 13: Climate action and Goal 15: Life on land), the creation of new jobs (Goal 1: No poverty and Goal 8: Decent work and economic growth), an increase in GDP by 0.8% (Goal 8), and a 630-MW increase in electrical power (Goal 7: Affordable and clean energy, Goal 11: Sustainable development, and Goal 12: Responsible consumption and production). The London Array, one of the world's most successful offshore wind farms, was the world's first. Large-scale wind farms such as the London Array help to achieve long-term goals. The London Array helps reduce greenhouse gas emissions and generate renewable electricity. The London Array, a large-scale renewable energy project, provides clean electricity, reduces greenhouse gas emissions, and boosts regional economic and social development. This research discusses wind energy projects and energy sector strategies to achieve the SDGs. Wind energy is aiding the SDGs in terms of scientific and economic development. Only publicly available data and the SDGs were used to assess London Array's contribution.

This study shows how wind energy can help achieve the SDGs. This research can also be used to analyze how different renewable energy projects contribute to the SDGs and reduce SDG trade-offs. Future research may use different indicators to measure wind energy's impact on the SDGs. During EIA preparation, the SDGs can be considered and a clear link between the different elements and results can be shown.

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