ARTIFICIAL INTELLIGENCE AND ROBOTICS ACCELERATING THE DEVELOPMENT OF OFFSHORE WIND ENERGY

BOOK EXECUTIVE SUMMARY

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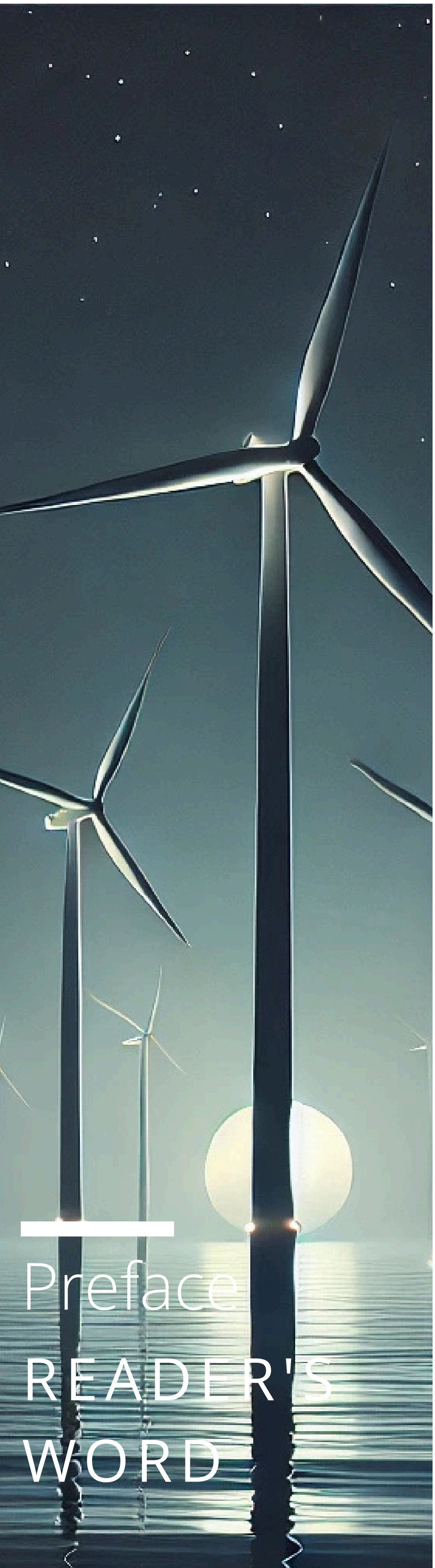

Book Preface

READER'S WORD

ELBIA GANNOUM

The journey towards Energy Transition is a continuous path that relies on clean energy sources capable of scaling their installed capacity in the coming years. Among these existing technologies, offshore wind could be an ally in combating climate change, paving new paths for the industrialization of the low-carbon economy and preventing the world from exceeding the Netzero limits.

The paths to be charted go far beyond the implementation of new clean energy sources such as offshore wind, and involve the use of strategies that must consider technologies like artificial intelligence, robotics, digital twins, and the Internet of things. The use of these technologies will directly contribute to industrial and economic development in the coming years, revolutionizing conventional economic systems with the capacity to ensure a clean, renewable, and socially inclusive future.

The context of offshore wind encompasses a new opportunity to experience the evolution of technologies that together have the potential to reduce impacts on the environment and society. Innovations involving technology can assist in the preservation of species, accuracy in project development, creation of new types of jobs, and the mitigation of social conflicts.

Accelerating the development of offshore wind energy in various regions of the world is a synergy of Industry 4.0 and disruptive innovations that will collaborate with critical factors for this renewable source. Some of these factors include: licensing emissions, transparent regulatory mechanisms, capacity building, document delivery timelines, databases, and encouragement for research, as well as alignment in the use and utilization of maritime regions. These factors are already recognized in various markets and could be subject to improvement with the increasing implementation of robotics and artificial intelligence.

This book explores the different applications of artificial intelligence and robotics for offshore wind, highlighting through existing and theoretical cases how the combination of these applications will assist in the technological maturity of the source and its development in various countries. Additionally, throughout the work, alternatives are presented that could serve as catalysts for offshore wind markets that are in the development phase and need to harvest innovations to accelerate their structuring process.

The scientific, technical, and market connection that comprises the creation of this book aims to encourage and collaborate in the creation of innovations and business models that can assist in combating climate change and achieving the goals set to reduce the exponential rise in temperature in the coming years (Netzero 2050). In this way, we hope that enthusiasts of the theme and readers can envision new paradigms and strategic horizons for offshore wind with the contributions of this book.

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EXECUTIVE SUMMARY TOPICS

INTRODUCTION

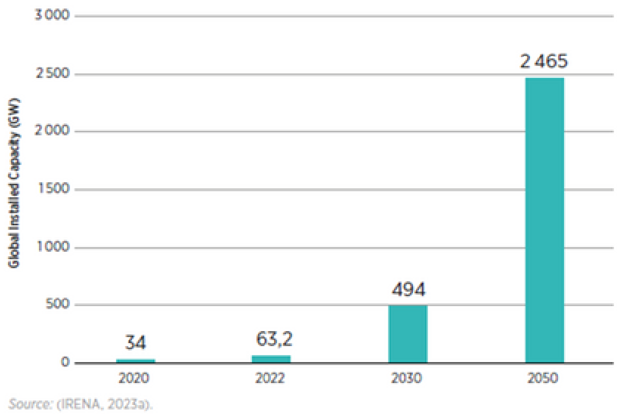
Climate change is a global challenge, manifested by **rising temperatures** and **extreme events** exacerbated by the emission of greenhouse gases. The **Energy Transition** through renewable energies, particularly **offshore wind**, is crucial for reducing **dependence on fossil fuels** and **decarbonising** the electrical sector. This energy source stands out for harnessing constant winds at sea, increasing the capacity for electrical generation.

The use of innovative technologies, such as **Artificial Intelligence (AI)** and **Robotics,** could be a fundamental alliance to **accelerate this transition**, being applicable at all project stages. These tools can optimise the development and operation of offshore wind farms.

The book aims to **present to the offshore wind industry how applications of AI and robotics can assist at various stages of the project lifecycle**. In summary, the work is dedicated to exploring different answers to the following question: **"What are the applications of AI and robotics that can accelerate the offshore wind industry?"**. The consolidation of various applications with the aim of answering this question becomes increasingly relevant given the rising growth of the offshore wind industry, as well as the emergence of new possibilities to explore technology around the world.

The chapters of the project lean towards presenting **strategies to achieve Net Zero goals** and **boost carbon emission reduction** in the energy generation process, focusing on the benefits that AI and Robotics can bring to the offshore wind market and to science. According to data from the Global Wind Energy Council (GWEC) and the International Renewable Energy Agency (IRENA), to reach the 1.5°C carbon neutrality scenario set by Netzero, offshore wind will be a central technology in the discussion. For this, about 500 GW of offshore wind energy installed will be needed by 2030 and 2,465 GW by 2050 (Figure 1).

Figure 1: Projections of offshore wind installed capacity until 2050



Source: IRENA e GWEC (2023) | Enabling Frameworks for Offshore Wind Scale Up

ARTIFICIAL INTELLIGENCE AND WIND SPEED FORECASTING

Wind forecasting is crucial for the safe and efficient operation of offshore wind farms in terms of energy generation planning for projects. **Increased efficiency and optimization of generation, reduction of operational costs, and predictability for energy trading operations** are some of the benefits that project wind forecasting can bring.

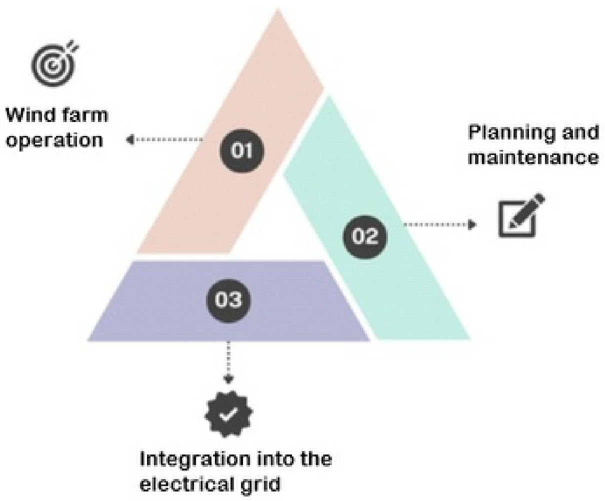
In this context, various **Artificial Intelligence** approaches can be used to analyze the direction, constancy, and speed of the winds, allowing energy generators to operate efficiently.

Deep Learning and Machine Learning techniques have been emerging with distinct approaches for wind speed forecasting. Advanced mathematical models, such as artificial neural networks and nonlinear regression techniques, are commonly used in this field.

Essentially, the various ways of modeling utilize historical meteorological data (e.g., air temperature and humidity) to estimate the wind flow variable over short-term and long-term time horizons, allowing for appropriate planning throughout the operation of offshore wind farms.

TRIAD OF WIND SPEED FORECASTING VIA AI

Figure 2: Triad of wind speed forecasting via AI



Source: Authors

Within the scope of the **operation of wind farms,** structures known as floating LIDARs are responsible for collecting and measuring wind speed and direction from data that is subsequently calibrated. These data are processed and used for wind forecasting in future horizons.

Regarding **planning and maintenance**, the prediction of windless periods can be used to schedule possible maintenance times, whether for the structures or the wind turbines that are part of the offshore wind farm.

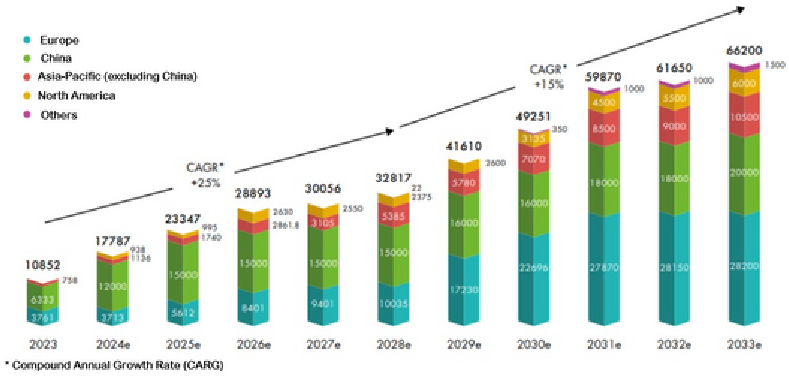
Finally, in terms of **integration into the electrical grids**, forecasting allows for the integration of new projects to be more efficient for integration into transmission lines. In other words, with scheduled shutdowns for possible maintenance on the network.

UNDERWATER ROBOTICS

According to the Global Wind Energy Council (GWEC), global installed offshore wind capacity is expected to reach **75 GW** by the end of 2023. GWEC projects a 25% average annual growth (CAGR) in new installed capacity, with offshore wind expected to reach approximately **380 GW by 2030 to meet the goal of limiting global warming to 1.5°C**.

The advent of **autonomous robotic systems** marks the beginning of a new era in the offshore wind industry, significantly improving o**perational efficiency and safety.**

Figure 3: New offshore wind power installations, global (MW)



Source: GWEC - Market Intelligence (2024)

PRACTICAL APPLICATIONS

In practice, underwater robots have been successfully used in several offshore wind farms. One example is the **"Operations Support and Diving Supervision Center - ROV"** of Oceânica Engenharia.

Oceânica Engenharia has an Operations Support Center that is used to supervise diving and **ROV operations**. With three independent video wall systems consisting of **18 49" monitors, it** is possible to monitor live the more than **1000 cameras** installed on the vessels, ROVs and diving helmets, through the **internet connection of Low Orbit Satellites**, in addition to the positioning of the vessels and offshore platforms. In this way, the most experienced professionals are allocated in a single location with access to all of the company's operations online, ensuring greater **safety, efficiency and management of offshore activities.**

Figure 4: Diving Operations and Supervision Support Center | ROV

Soure: Oceânica Engenharia e Consultoria (2024)

ROBOTICS AND ARTIFICIAL INTELLIGENCE: ALLIES FOR PREDICTIVE MAINTENANCE

To ensure the continued development of offshore wind farms, it is necessary to delve deeper into the engineering complexity involved in **operation and maintenance (O&M)** and inspection, logistics and maintenance factors. Among these factors, predictive maintenance has stood out through technological alternatives that use Artificial Intelligence (AI) and Robotics to **reduce O&M costs and anticipate possible maintenance** required in the various systems involved.

Predictive maintenance is the activity of **continuous monitoring to identify** in **advance the need for possible repairs and maintenance. This type of maintenance** allows imminent failures and signs of deterioration to be anticipated in their early stages, enabling strategic contingency action to carry out maintenance processes. The process involves the collection and analysis of operating data associated with temperature, vibration, pressure and electrical current and **allows corporations to act in advance to avoid possible losses.**

CASE STUDY OF AI AND ROBOTICS FOR PREDICTIVE MAINTENANCE

UAVs (Unmanned Aerial Vehicles) are drones that are being widely used in inspections by trained agents, as in-person inspections are becoming more difficult and time-consuming. Given this problem, the use of drones is on the rise.

UAVs are playing a crucial role in the development of automated predictive maintenance techniques for inspections, monitoring the actual conditions of wind turbines, as well as contributing to the safety, efficiency and cost reduction of O&M services. UAVs can be used to inspect blades, nacelles, towers and all structural components involved in offshore wind farms.

Figure 5: UAV Drone

Source: UST – Unnamed System Technology (2021)

ROBOTICS AND ARTIFICIAL INTELLIGENCE: ALLIES FOR PREDICTIVE MAINTENANCE

CONFIGURATION OF OFFSHORE WIND TURBINES

Optimizing wind turbines in offshore wind projects is an area where Artificial Intelligence (AI) technologies can help to achieve better results. Blade design, real-time blade orientation, operational asset control, and layout optimization are some of the areas where AI linked to these applications can be used.

Blade design is an area that seeks to develop the blades of offshore and onshore wind turbines, aiming at the best use of the resource and the useful life of the equipment. The use of AI linked to blade design seeks to find the best solution that achieves the degree of structural and aerodynamic efficiency of wind turbines. Thus, the best selected design minimizes the weight of the blades on the tower structures and allows the real-time performance of offshore wind turbines to be increased.

Offshore wind energy **asset control** refers to the concept of monitoring turbines that are located offshore. To achieve this goal, it is possible to use smart sensors linked to AI systems that allow, for example, continuous assessment and monitoring of operating conditions. With this supervision, it becomes possible to adjust the blade positioning profile to make better use of the energy resource.

Finally, when it comes to **layout optimization**, AI helps to discover the best locations for wind turbine placement based on various parameters such as the local weather, technical characteristics of the turbines, among many others that may be possible depending on the modeling. One of the well-known programs for this purpose is **Pywake**, which helps in the studies and analysis of data to optimize project layouts, evaluating wake effects and turbine turbulence, for example.

CASOS PRÁTICOS

Case 1 - Clustering for fault monitoring - Grouping common features of wind turbines

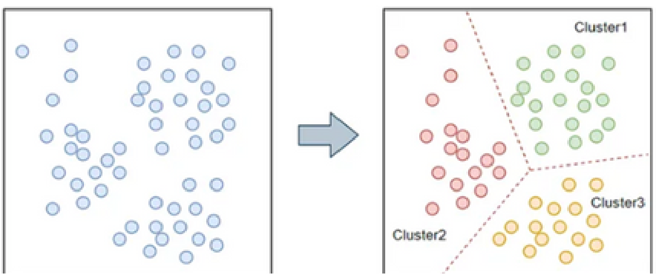


Figure 6: Clustering and Failure Monitoring
Source: *eCloud Valley* (2023)

Case 2 - Optimized layout of an offshore wind farm

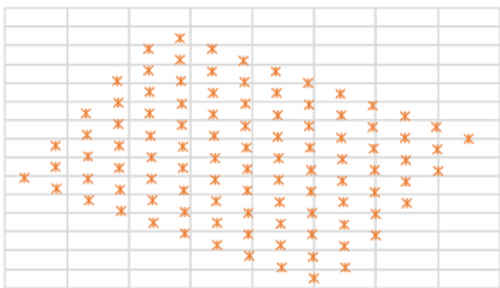
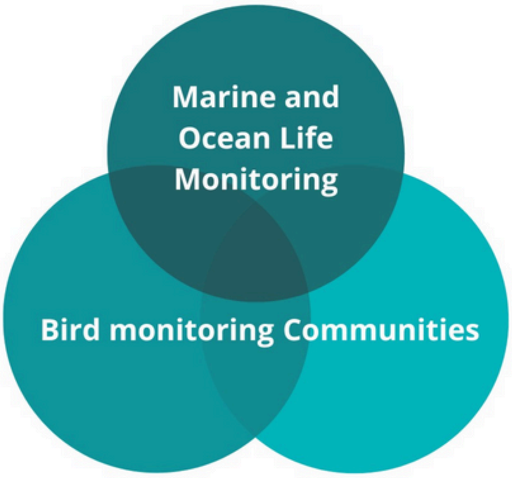


Figure 7: Optimized Layout
Source: *Strathgen*

ARTIFICIAL INTELLIGENCE AND ENVIRONMENTAL MONITORING

It is important to highlight that while offshore wind farms are presented as a solution to scale decarbonization, the alignment between environmental issues and technology must be congruent and transparent in the Energy Transition process. Thus, several industry organizations have promoted the use of Artificial Intelligence (AI) and robotics solutions to ensure the conservation of marine life, birds and ocean conditions that allow the preservation of ecosystems, while offshore wind farms are consolidating themselves in international markets.

Figure 8: Artificial Intelligence in offshore wind farms and ecosystem monitoring



Soure: Authors

Socio-environmental factors can use existing AI technologies to help and accelerate the identification of potential conflicts and opportunities in project development regions. In this sense, this chapter focused on presenting specific cases that involve the use of AI and robotics solutions in the areas of: **(a) Monitoring of marine and oceanic life; (b) Monitoring of birds; (c) Communities** (Figure 8).

BIRD MONITORING CASE

One of the areas in which AI is applied in offshore wind farms is **bird monitoring.** In this area, **deep learning** techniques such as **artificial neural networks** are used to **detect the geographic coordinates of birds in real time**, identify them, and track their movements. These technologies allow developers to take early **action to preserve the birds** throughout the operation of offshore farms.

According to studies by the RPS Group, monitoring seabirds in offshore wind farms is essential to mitigate environmental impacts and reduce the risk of collisions. AI has emerged as a technology to **improve these monitoring systems**, providing more **accurate and efficient analysis** of the data collected..

SMART GRIDS AND THE USE OF AI IN SUPPORTING THE OPERATION OF WIND FARMS

The growth of installed capacity in wind energy has broadened the scope of the energy transition on a global scale. However, the different characteristics of onshore and offshore winds present a challenge in maintaining the stability of the electrical system. In this context, the use of Artificial Intelligence (AI) **emerges as a solution to optimize network operations, allowing for more efficient management of this natural variation.** With this, it becomes possible to balance energy supply and demand. This chapter explores AI technologies applied in the operation of wind farms, enhancing the management of electrical grids.

WHAT ARE SMART GRIDS AND HOW DO ENERGY UTILITIES BENEFIT?

Smart Grids are **characterized as a modernized version of traditional electrical grids**. The integration of advanced digital and communication technologies with the grids allows for more efficient management of the transport of electricity from a generation source (e.g., Offshore Wind Energy) to residential areas. This grid is called 'smart' because it **uses sensors, meters, and control and automation systems to monitor the flow of electricity in real time**, ensuring that electricity reaches consumers without significant issues.

WHAT IS THE DIFFERENCE BETWEEN THE TRADITIONAL ELECTRICAL GRID AND THE SMART GRID?

The main difference between traditional systems and smart grids lies in the **capability for two-way information exchange** across the network, **from utility companies to consumers** and vice versa. Some of the key features that distinguish smart grids include:

- **Distribution:** The energy generated by prosumers and renewable energy sources can be variable. Smart grid technologies help to coordinate, store, and distribute energy from these sources in a stable flow.
- **Generation:** Predictive analytic functions in smart systems mean that high-demand pressures can be anticipated and distributed across various plants and substations. Additionally, digital clouds are used for asset management.
- **Sensors:** IoT sensors throughout the network can help detect risks early on, redistributing energy to minimize disruptions and help balance loads.
- **Self-healing and predictive maintenance:** Sensors can also be used to detect mechanical issues and perform simple troubleshooting and repairs.
- **Customer choice:** More energy providers, cooperatives, and microgenerators can join the network.

SENSOR DATA ANALYSIS

The offshore wind industry, increasingly vital to the decarbonization drive, has benefited from advances in remote sensing and data analytics technologies. These developments have made sensor data analysis an **essential component of offshore wind farm management, not only to ensure the efficiency and sustainability of these facilitie**s, but also to ensure operational safety. **Turbines, exposed to extreme environmental conditions, require constant monitoring to ensure their continued safe operation.**

APPLICATIONS OF SENSOR DATA IN OFFSHORE WIND TURBINES

One of the **main applications of sensor data analysis in offshore wind farms is early corrosion detection.** Researchers have developed advanced remote sensing technologies that monitor corrosion of the metal structures of offshore wind turbines in real time. Using ultrasonic sensors and Artificial Intelligence (AI) technologies, it is possible to predict surface wear, avoiding catastrophic failures and reducing maintenance downtime. In addition to corrosion, sensor data analysis is widely applied in monitoring the life cycle of offshore turbines.

Several studies demonstrate the use of IoT platforms to assess the condition of components throughout all phases of a wind project. These platforms **are capable of providing detailed predictions about the state or operational condition of components**, allowing planned and cost-effective maintenance.

The **use of sensors, combined with analytical methods, goes beyond simply supporting Operation and Maintenance (O&M) activities.** During the **feasibility study phase of offshore wind projects, wind testing and measurement phases are carried out at sea, using sensors distributed in the target region.** An example of this technology is Bravo, developed by Petrobras – a floating Lidar (Light Detection and Ranging) model designed for the collection, monitoring and assessment of offshore wind resources. This optical sensor uses laser beams to measure wind speed and direction, generating data compatible with the operational environment of wind turbines (Figure 9).

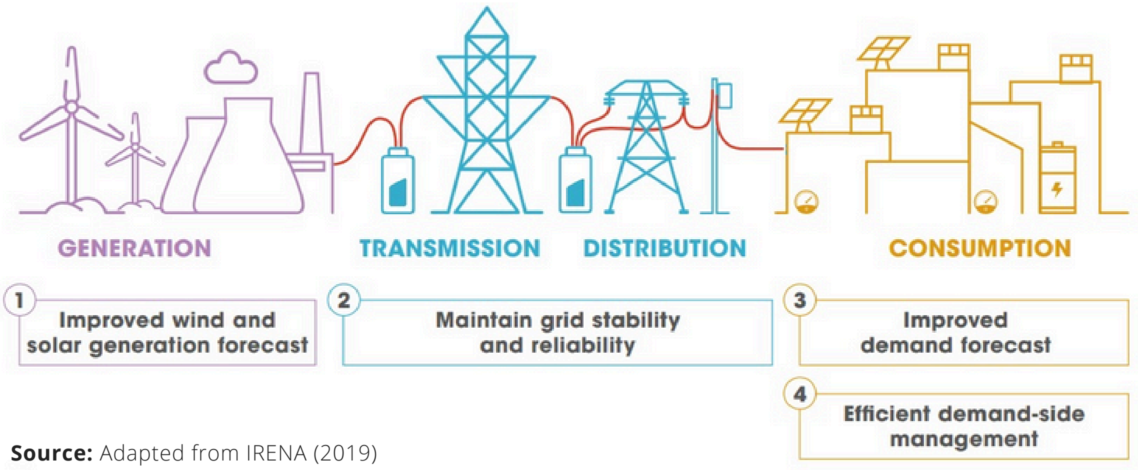
Figure 9: Remote Offshore Wind Assessment Buoy (Bravo)

Source: Agência Petrobras (2024)

ARTIFICIAL NEURAL NETWORKS

It is common knowledge that various Artificial Intelligence (AI) technologies have been emerging as a powerful and effective tool in the international energy scenario. IRENA's "Artificial Intelligence and Big Data" report (Figure 10) **indicates that AI applications can be used from the stages of energy generation from renewable sources to the purposes of forecasting energy demand by consumers.** Within this context, within the scope of applications related to generation, **Artificial Neural Networks (ANNs)** are extremely relevant for handling various applications within the offshore wind production chain. The use of ANNs has presented a paradigm shift and has been employed with the **aim of ensuring predictability and safety of operations and, as a result, providing greater revenue margins to entrepreneurs and managers of wind farms.**

Figure 10: Emerging applications of ANNs in energy fields



Source: Adapted from IRENA (2019)

Figure 11 demonstrates a study stage for the subsequent use of ANN to identify the characteristics of birds in wind farms. Image (a) is the original image of the bird and (b) is the binary image obtained as a result of the original segmentation to identify the size of the bird.

Figure 11: Segmentation process for identifying bird size

Source: Niemi (2018)

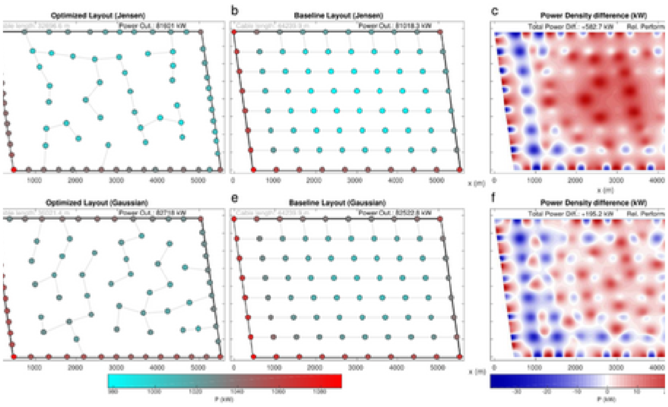
PATTERN IDENTIFICATION FOR OFFSHORE WIND FARM LAYOUT

The main objective of creating layouts for projects in the **offshore wind sector is to find the best position for wind turbines so that it is possible to make the most of the energy resources available in coastal regions**. Wind farm layouts are nothing more than the physical and structural organization of wind turbines, substations and other relevant equipment that make up the entire offshore wind complex.

Several AI applications have emerged, allowing for the **optimization of project layouts**, in addition to assisting in the final choice of the arrangement to be built. The use of AI linked to the study of energy resources can generate associated advantages such as t**he reduction of the wake effect, lower costs in project implementation, more attractive rates of return, in addition to making the most of the energy resource available in the region of interest.**

For this optimization to occur, there are several methodologies that encompass the use of AI and that can be applied. Among the various existing methodologies, we can highlight: **(a) Heuristic algorithms; (b) Genetic algorithms; (c) Machine learning techniques.**

Figure 12: Example of the results of an optimization study of a real offshore wind farm using genetic algorithm



Source: Kirchner-Bossi e Porté-Agel (2018)

The mathematical algorithms used seek **to discover the best coordinates for the turbines to occupy, which allows for better optimization to maximize the park's performance.** In addition, it also seeks the best positioning for the electrical grid that will interconnect the generating units of the offshore wind farm.

For the solution to work, **satellite data is used in addition to historical wind series, and the application of the solution results in different layout arrangements for the subsequent selection of the best solution**. Figure 12 shows an example of the use of genetic algorithms for the optimization of a real offshore park, where the optimized layouts are on the left, the reference layouts are in the center and the spatial difference in wind power is on the right.

TECHNOLOGICAL INNOVATION AND AEROSPACE SOLUTIONS

The large-scale viability of offshore wind depends on **multi-sectoral cooperation from different segments that explore innovations to accelerate the energy transition** through offshore wind. Among these segments, the **aerospace solutions** research and development sector stands out and brings **unique innovations** to both offshore and onshore wind sectors on the global stage.

Figure 13: ERDA-NASA's 200-kilowatt MOD-0A wind turbine project on Block Island, Rhode Island

Source: NASA | Article: *Glenn Responds to 1970s Energy Crisis*

The application of space technology practices in the area of renewable energy is broad and includes the **use of satellites, storage and management of large amounts of data ("Big Data"), and even the raw materials used to manufacture wind turbine** components, such as carbon fibers used in blades.

NIn the 1970s and 1980s, the aerospace agency NASA worked on research to study the possibilities for investigating the scale of wind turbines with support and funding from some departments such as the National Science Foundation and the Department of Energy (DOE). This research **tested the technical and commercial viability** of 13 wind turbine projects, considering wind turbines of 200 kilowatts, 2,000 kilowatts, 2.5 megawatts and 3.2 megawatts (Figure 13). This research confirms the **path between the proximity of the aerospace and wind energy sectors**.

Throughout history, space **technology and renewable energy innovation have been inextricably linked, driving progress and shaping our understanding and sustainable use of energy.** From the first satellites, which enabled climate analysis and provided massive amounts of data to inform the precise optimization of wind and solar power plants, to the most recent research into solar panels in space, the fields of energy and aerospace technology have collaborated to push the boundaries of what is possible, reflecting ongoing synergy and driving technological progress and the global transformation towards a greener, more efficient future.

CARBON MARKET: A DRIVING MECHANISM

The carbon market is an **economic mechanism developed to assist in addressing climate change**. It is based on the premise that carbon, being one of the main drivers of global warming, should be priced. This strategy aims to encourage the reduction of greenhouse gas (GHG) emissions by companies and nations, making it economically advantageous to adopt more sustainable practices.

RENEWABLE ENERGIES AND THE CARBON MARKET: PATHWAYS FOR VALUING SOCIO-ENVIRONMENTAL ATTRIBUTES

Renewable energy projects exemplify initiatives that generate carbon credits, preserve the environment, and can be a **source of financing for developing countries,** which often l**ack the resources to implement effective climate policies**. These renewable sources can include **onshore and offshore wind, solar, biomass, hydrogen, and other sources that avoid environmental impacts and offset emitted carbon**. Additionally, this compensation process can encompass initiatives involving legal mandates, emissions taxes, trading systems, subsidies, and even targets for adopting clean energy.

All these initiatives are **ways to value the socio-environmental attribute and are already being explored through various regulatory** and market mechanisms around the world, such as the **renewable energy certification market and applied taxes.** This valuation ensures the long-term continuous growth of renewable energy sources that are in the process of scaling up and can assist in achieving the climate goals set by Netzero 2050 to keep the temperature at 1.5°C.

CARBON MARKET AND OFFSHORE WIND: THE ROUTES TO ACCELERATE TECHNOLOGY

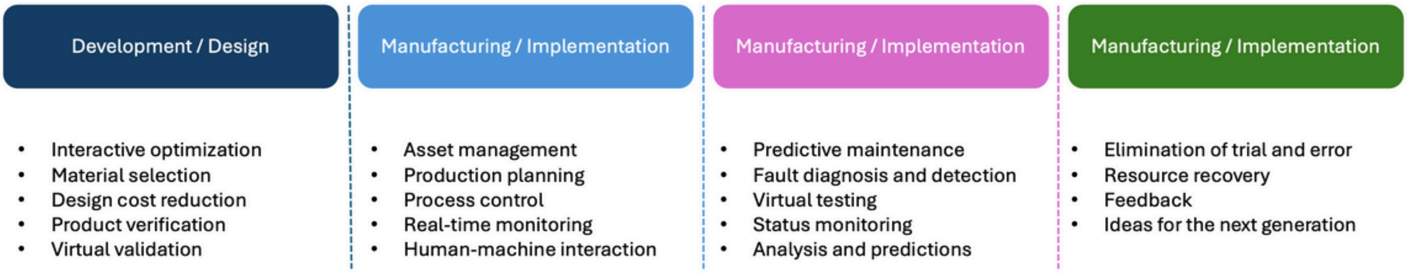
With well-established regulated carbon markets around the world, offshore wind projects could be made viable **without the need for subsidies** to be developed. Moreover, this market could become a driver in **reducing the cost gap between conventional technologies and new technologies**. This is a strategic mechanism for countries, **providing legal security, stimulating negotiation, innovation, and competitiveness**, preventing Brazil and other countries from facing trade barriers in foreign markets, given the growing global demand for decarbonization and sustainability.

DIGITAL TWINS AND INNOVATIVE TECHNOLOGIES

Digital Twins are a promising technology to help reduce the costs of offshore wind technology, expanding installed capacity. Digital Twins, also known as digital twins, can be defined as virtual models that **allow the combination of physical assets.** These virtual models have **indicators and sensors that assist in mathematical simulations to enable projects to be carried out more efficiently.**

The application of this technology depends on factors such as the application objective, types of physical assets and data analyzed, tools and technologies to be used, which are adaptable to each situation. Considering the main components of an offshore wind farm, as shown in Figure 15, the Digital Twin can be developed and applied to each of them. In recent years, **the focus of the sector's development has been on offshore wind turbines, a key component in energy generation.**

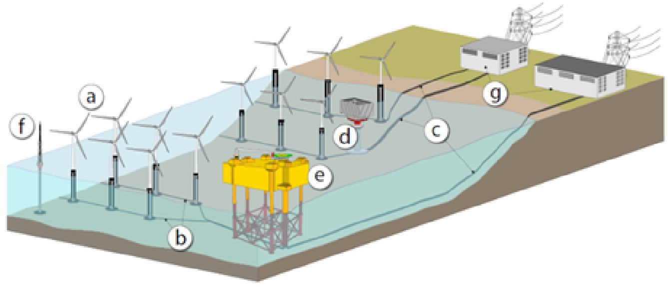
Figure 14: Application of Digital Twin in the product life cycle



Source: Adapted from Liu et al. (2024)

ATechnology is **based on the exchange of information between the physical environment and the digital environment. This exchange occurs through data (information) that is captured by data acquisition systems (sensor systems)**, having a major impact on the life cycle of products and services (Figure 14). The captured data is directed to the digital environment where it will have information about the operation of the equipment. This information can reach extremely detailed levels, such as: component parameters or environment simulation.

Figure 15: Main components of an OWT



Source: Rodrigues et. al, (2016)

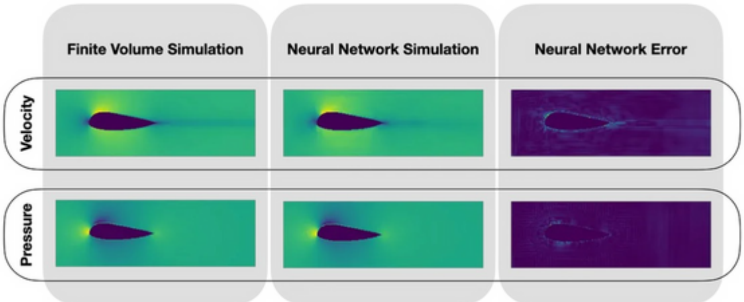
APPLICATIONS OF COMPUTATIONAL FLUID DYNAMICS AND AI

Computational fluid dynamics (CFD) **applications can be defined as a union of fluid mechanics with numerical methods, where the solution of calculations is performed computationally.** However, we can expand this definition to understand the importance of each of these topics. Numerical methods are mathematical techniques used to approximate solutions to complex problems or exact solutions.

ANeural networks trained with CFD simulation data can predict pressure and velocity distributions in flows with sufficient accuracy for industrial applications.

Reduced-Order Models are mathematical simplifications of complex systems. These models are developed to speed up simulations and analyses, significantly reducing computational costs without significantly compromising accuracy (e.g., Figure 17).

Figure 16: Comparison of an aerodynamic profile between computer simulation and the use of Neural Networks

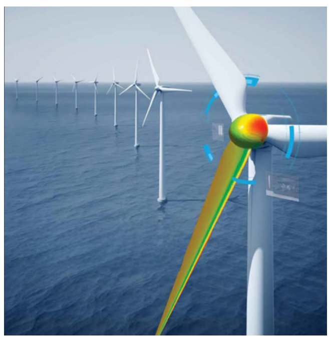


Source: Medium (2020)

Artificial Intelligence (AI) and CFD have synergy, as they can reduce the high computational cost, simulation time and complexity of physical phenomena, helping to solve numerical problems and computational simulations (Figure 16).

The models in which AI can assist in fluid dynamics simulations are: (a) Surrogate Models and (b) Reduced Order Models. Surrogate models are mathematical approximations that replace complex systems, such as detailed AI simulations. These models are trained to replicate the behavior of complete fluid dynamics simulations.

Figure 17: Wind turbine represented by fluid dynamics simulation



Source: ANSYS (2017)

APPLICATIONS OF COMPUTATIONAL FLUID DYNAMICS AND AI

ARTIFICIAL INTELLIGENCE, DATA CENTERS, AND PATHWAYS FOR DEMAND

Artificial Intelligence (AI) technologies have been growing rapidly in recent years, becoming a topic present in various technological discussions and in the social use of individuals. **Generative AI stands out for its ability to generate new data, such as images, texts and codes, which resemble real data produced by individuals.** However, the use of generative AI on a large scale will require high energy consumption.

At the same time, **the growth in the use of Data Centers is proving to be opportune to help address the energy demand for the use of AI**, considering that the energy consumption of DCs is high. In other words, in addition to contributing to the growth in the use of generative AI, t**he use of DCs will help increase the installed capacity of renewable energy sources (e.g. wind, solar and hydrogen)** in order to meet this great energy demand.

OFFSHORE WIND POWER: A ROUTE TO MARKET

Offshore wind farms represent one of the most promising global clean energy solutions to meet the growing electricity demand of Data Centers (DCs), especially in a scenario of rapid expansion of artificial intelligence (AI) technologies. With the capacity to generate large volumes of energy and located in hubs port facilities provide strategic infrastructure to supply high electrical loads, meeting the unique energy demands of DCs. Leading technology companies such as Google are already leveraging this technology to drive the energy transition. Google recently secured significant contracts with offshore wind farms in Europe to power its DCs, including a new $1 billion hub in the UK that will use wind power from Scotland.

These projects **show that offshore wind has the scale and economic viability to meet the constant load curve of DCs,** which requires an uninterrupted and high energy density supply (Figure 18).

Figure 18: Google Data Center in Eemshaven, Netherlands

Source: Google (2024)

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3D PRINTING: A POTENTIAL FACILITATOR FOR INFRASTRUCTURE

3D printing technology is a form of additive manufacturing that refers to any manufacturing process in which objects are created by adding material layer by layer until the final part is formed. This concept includes a variety of technologies, such as laser **sintering, electron beam melting, and 3D printing itself.**

3D printing uses **digital models to create three-dimensional objects**, building them up through the progressive layering of materials. This process can employ a variety of materials, such as plastic, metal, ceramics, and even biomaterials, depending on the application and technology used.

In the wind energy sector, the most common techniques include **FDM (Fused Deposition Modeling**), used to manufacture prototypes and parts, and SLS **(Selective Laser Sintering)**, which uses materials such as nylon.

BENEFITS OF 3D PRINTING

Industry players are increasingly recognizing the **advantages of 3D printing** in renewable energy, especially wind power. Some of the benefits of 3D printing include:

- **Reduced carbon footprint:** Distributed production, made on demand and close to where products are needed, minimizes the need for long-distance transportation.
- **Reduced costs and increased availability:** 3D printing reduces production costs and facilitates shorter delivery times.
- **Detailed prototypes:** More realistic versions of components.
- **Part customization:** Possibility to innovate by creating exclusive parts**.**

Figure 19: 3D printing of concrete components for offshore structures

Source: Rcam Technologies

3D PRINTING: A POTENTIAL FACILITATOR FOR INFRASTRUCTURE

EXPANDING HORIZONS AND NEXT STEPS

The chapters of the book were structured to **present a comprehensive overview of the role of Artificial Intelligence (AI) and Robotics in advancing offshore wind energy.** From wind forecasting and optimizing farm layouts to the use of autonomous robots for predictive maintenance, each section sought to detail how these emerging technologies are shaping the future of this industry.

The sections presented in the book, which go beyond this executive summary, demonstrate **how AI and robotics can directly contribute to reducing carbon emissions and achieving Net Zero goals**. Optimizing offshore wind farms increases the share of renewable energy in the global energy mix, reducing dependence on fossil fuels from this transition.

NEXT STEPS

In the coming years, the offshore wind energy market will need to closely monitor the advancement of emerging technologies, especially with regard to the increasing integration of AI and robotics. In order to effectively incorporate these **innovations, it will be essential to invest in technological infrastructure, promote the digitalization of processes and ensure interoperability between different systems**.

In addition to technological adoption, **issues such as port infrastructure, project financing and strengthening the supply chain will be critical factors for the success of offshore wind energy.** In addition, the need for professional training to deal with new technologies and the creation of public policies that encourage innovation and sustainability in the sector will be central aspects in building a more efficient and sustainable energy future. The success of offshore wind energy will depend on an integrated ecosystem that combines technological advances, optimized infrastructure and a favorable regulatory environment to ensure its competitiveness.

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ARTIFICIAL INTELLIGENCE AND ROBOTICS ACCELERATING THE DEVELOPMENT OF OFFSHORE WIND ENERGY

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