Universitetet i Stavanger

HANDELSHØGSKOLEN VED UiS

MASTEROPPGAVE

STUDIEPROGRAM:	ER OPPGAVEN KONFIDENSIELL?
Executive MBA	Nei

TITTEL:

What are the key multidimensional success criteria required for reducing LCOE through digital transformation in offshore wind farms?

LCOE: Levelized Cost of Energy

FORFATTER(E)		VEILEDER:
Kandidatnummer:	Navn:	Håkon Brydøy
257575	Marianne Hjørnevik Andersen	
…………………	………………………………………………………………	
217855	Nils Magne Reilstad	
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Sammendrag

Formålet med denne studien er å undersøke de flerdimensjonale suksesskriteriene som er avgjørende for å redusere energikostnaden også kjent som *Levlized cost of Energy* (LCOE) gjennom digital transformasjon innenfor offshore vind prosjekter. For å besvare problemstilling vil studien sette søkelys på fire underspørsmål som omhandler:
(1) For å sikre *operational excellence* og tilpasning til FNs bærekraftsmål gjennom digital transformasjon: Hvilke suksessfaktorer må være på plass? (2) Er data tilgjengelig for bruk til den digital transformasjon? (3) Hvordan kan man muliggjøre optimal Grid Integration ved bruk av digitale verktøy? (4) Kan man utnytte digitale verktøy for å redusere LCOE i en havvindpark? Studien fremhever den uunnværlige rollen av teknologi i form av digitale verktøy og data, som spiller som katalysatorer for å styrke operasjonell effektivitet og maksimere verdiskaping i offshore vindenergisektoren.

Studien er gjennomført som kvalitativ Case-studier og er en analyse i form av ti individuelle dybdeintervjuer med deltakere fra ulike selskaper i verdikjeden til offshore vind industri. Studien undersøker den betydelige påvirkningen FNs bærekraftsmål har på utviklingen av offshore vindprosjekter, samt den vitale rollen *operational excellence* har for å lykkes. Den vurderer om offshore vind industrien er klar for Industri 5.0, dens evne til å redusere LCOE, og dens innflytelse på sektorens fremtid. Funnene understreker betydningen av tilgjengelig data, optimalisert effektivitet, og bruk av sanntidsdata for å forbedre sikkerhet, bærekraft og effektiv energiproduksjon i vindparker.

Videre dykker studien ned i implementeringen av digital transformasjon, og viser til hvordan digitale verktøy og automatisering, sammen med menneskelig inngripen, driver informert beslutningstaking. Funnene legger vekt på nødvendigheten av datasamarbeid, kunnskapsdeling, og kompetent personell for å fremme industriell vekst, samtidig som det opprettholdes en balanse mellom kompleksitet og kompetanse, og utforsker avansert digital tvilling-teknologi og hvordan det kan påvirke i redusering av LCOE.

Studien tilbyr verdifull innsikt for interessenter og kan bidra til å håndtere utfordringer og muligheter i digital transformasjon av offshore vindparker. Den fremhever offshore vinindustriens avgjørende rolle i utviklingen av renere, effektive energisystemer, og støtter en bærekraftig og fremgangsrik fremtid.

Abstract

This purpose of this study is to thoroughly examine the multidimensional success criteria crucial in reducing the levelized cost of energy (LCOE) through digital transformation within the context of offshore wind farm projects. To help answer the research question, this study will focus on four preliminary research questions: (1) To ensure Operational Excellence and Alignment with UN SDGs through Digital Transformation: What success factors need to be in place? (2) Is Data available to be used to enable Digital Transformation? (3) Can you enable optimal Grid Integration with the use of digital tools? (4) Can you leverage digital tools to reduce LCOE in an offshore wind farm? The research spotlights the indispensable role of technology in form of digital tools and data, as catalysts for bolstering operational efficiency and maximizing value creation in the offshore wind energy sector.

The study has been carried out as a qualitative case study analysis in the form of ten individual in-depth interviews with participants from various companies in the value chain of the offshore wind industry. The study investigates the substantial impact of United Nations (UN) sustainability goals on offshore wind project development and the vital role of operational excellence. It evaluates the industry's preparedness for Industry 5.0, its capacity to reduce LCOE, and its influence on the sector's future. The research and findings underscore the significance of accessible data, optimized efficiency, and real-time data utilization to enhance safety, sustainability, and energy production in wind farms.

Additionally, the research delves into Industry 5.0's implementation, demonstrating how digital tools and automation, combined with human input, drive informed decision-making. The findings emphasize the necessity for data collaboration, knowledge sharing, and skilled personnel to foster industry growth while maintaining a balance between complexity and competence and explores advanced digital twin technology and how it can influence in reducing LCOE.

The study offers valuable insights for stakeholders and aids in addressing challenges and opportunities in offshore wind farm digital transformation. It accentuates the offshore wind industry's pivotal role in advancing cleaner, efficient energy systems, promoting a sustainable and prosperous future.

Acknowledgement

We would like to express our sincere gratitude to the University of Stavanger's (UIS) for providing us with an enriching and fulfilling experience during our Executive Master of Business Administration (EMBA) program. Over the past three years, we have been exposed to new perspectives and gained invaluable knowledge and skills that will undoubtedly shape our careers and personal lives for years to come.

We would like to extend a heartfelt thank you to our thesis advisor, Håkon Brydøy, for his dedication, guidance, and encouragement throughout the thesis writing process. Håkon's engagement, challenging discussions, and availability have been instrumental in shaping our work, and we are grateful for his support.

We would also like to acknowledge the companies and informants who contributed to this thesis, providing us with valuable insights and perspectives that have enhanced our understanding of the subject matter. Without their contribution, effort, and time, this work would not have been possible.

We would like to express our deep appreciation to our family's, colleagues, and friends, who have been our constant support system throughout our studies. Studying alongside a full-time job and other personal commitments can be demanding, and we are grateful for their understanding, patience, and unwavering support.

Finally, we would like to express our appreciation to each other for the excellent collaboration, the learning from each other, the drive, and motivation that helped us complete this thesis. It has been a privilege to work together and learn from each other, and we are grateful for the opportunity.

Thank you to all who have contributed to our academic and personal growth throughout this program. Your support, guidance, and encouragement are highly appreciated, and we are truly grateful.

Sincerely,
Marianne Andersen & Nils Magne Reilstad

Abbreviations

ESG	Environmental, Social and Governance
SDG	The United Nations' Sustainable Development Goals
O&M	Operations and Maintenance
AR	Augmented reality
VR	Virtual reality
SCADA	Supervisory Control and Data Acquisition
LCOE	Levelized Cost of Energy
UN	United Nations
WF	Wind Farm
PPA	Power Purchase Agreements
CfD	Contracts for Difference
OPEX	Operating expense
CAPEX	Capital expenditure
ML	Machine Learning
AI	Artificial Intelligence
IoT	The Internet of Things
GW	Gigawatts

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1 Introduction

The energy transition might be one of the greatest challenges of our time. The global community moves towards renewable energy sources to combat climate change and fulfill the ever-increasing demand for electricity. Offshore wind energy emerges as a vital component in this transition to meet global demand. As a clean, sustainable, and abundant source of power, it has the potential to significantly contribute to meeting the world's ever-growing energy demand while mitigating the impacts of climate change. According to Kühn, Liebach, Matthey, & Zivansky (2022) global installed offshore wind capacity is expected to reach 630 gigawatts (GW) by 2050, up from 40 GW in 2020, and with upside potential of 1,000 GW in a 1.5° pathway scenario. In 2050, a third of the EU's electricity consumption is to be covered by offshore wind (Tande, 2023). All regions globally are expected to contribute to growth in offshore wind, which can help reduce climate change.

Technology plays a vital part in making this transition possible. Digital technologies are rapidly advancing, the offshore wind industry is poised to undergo a digital transformation that can enhance efficiency, optimize operations, and create value throughout the entire project lifecycle. Advancements in technology will play a crucial role, both in the design and operational phase of offshore wind projects, as these stages is both complex and comprehensive according to Equinor (2023) and (Løvøy, 2021). However Kühn et al (2022) argues that companies must expect numerous of challenges and must excel across multiple domains. Tande (2023) underscores that significant progress is required to attain efficient utilization of offshore wind energy, and it is essential to recognize that substantial wind power capacity does not inherently integrate with the existing energy infrastructure.

For instance, offshore wind projects require multiple years to complete and rely on cost estimates determined months prior to the auction, as well as years before the project's actual commissioning. This implies that numerous companies could encounter significant risks related to their capital development expenses during the project phase, along with potential fluctuations in raw material prices. Multidimensional success criteria are needed to accurately measure the success of offshore wind projects due to the complexity and variety of factors that influence their outcomes. Traditional success criteria, such as time, cost, and scope, will not capture the full picture. However, fully realizing the potential of digital transformation requires a thorough understanding of the multidimensional success criteria that enable value creation and reducing Levelized Cost of Energy (LCOE) in offshore wind farms, considering various factors that contribute to its long-term viability and impact. This assignment aims to provide a comprehensive understanding of the multidimensional success criteria to succeed with enablement of successful digital transformation of offshore wind farms, as well as the challenges and opportunities that lie ahead. We hope the insights gained from this study will be instrumental in guiding stakeholders, policymakers, and industry players in harnessing the full potential of digital transformation in the offshore wind sector.

1.1 Research question and scope

The purpose of the thesis is to delve into multidimensional success criteria needed for reducing the Levelized Cost of Energy (LCOE) though digital transformation in offshore wind farms. It seeks to understand the complex interplay between various factors and how they contribute to the successful deployment of digital transformation strategies in the offshore wind energy. Through this we want to draw an overall model for an optimal strategic approach and realization. The thesis is limited to performance measure and value creation.

The research question is:

What are the key multidimensional success criteria required for reducing LCOE through digital transformation in offshore wind farms?

Preliminary research questions are:

1. To ensure Operational Excellence and alignment with UN SDGs through Digital Transformation: What success factors need to be in place?
2. Is Data available to be used to enable Digital Transformation?
3. Can you enable optimal Grid Integration with the use of digital tools?
4. Can you leverage digital tools to reduce LCOE in an offshore wind farm?

1.2 Significance and applicability of the study

The findings of this study on the multidimensional success criteria needed to enable value through digital transformation in offshore wind farms hold significant implications for various stakeholders involved in the renewable energy sector. By providing a comprehensive understanding of the critical factors contributing to the successful digital transformation of offshore wind farms, this study aims to offer valuable insights and practical guidance for the following stakeholders:

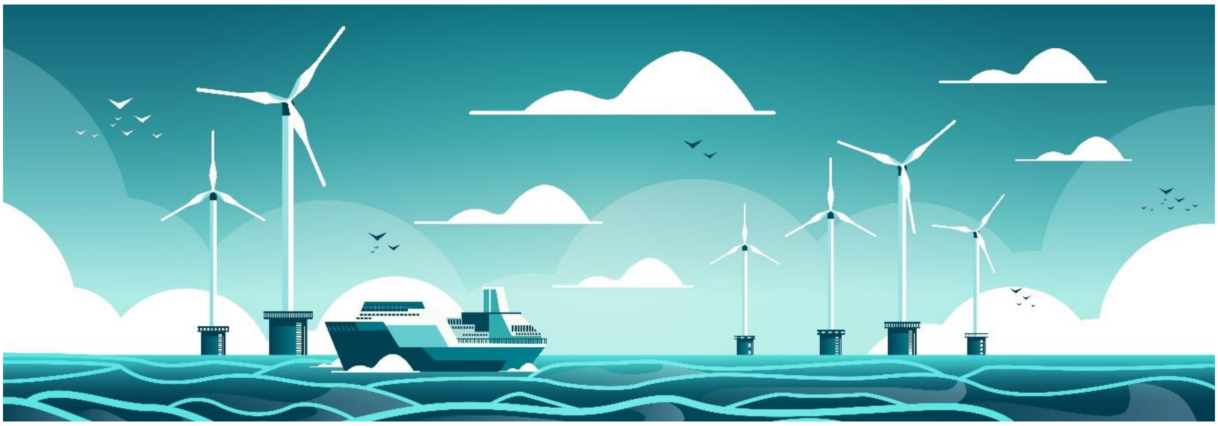

Figure 1: Offshore w*ind turbines.* («Offshore Wind bilder – Adobe stock», 2023)

Industry Players: Developers, operators, and service providers in the offshore wind industry can utilize the insights gained from this study to optimize their projects, enhance operational efficiency, and maximize value creation. By understanding the digital tools, technologies, and best practices that drive success in offshore wind projects, industry players can make informed decisions and develop innovative solutions that address the unique challenges of this emerging sector.

Policymakers and Regulators: Government agencies and regulatory bodies play a crucial role in shaping the future of the offshore wind industry through the development and implementation of supportive policies, incentives, and frameworks. This study provides a solid foundation for understanding the critical factors that drive value creation in offshore wind projects, enabling policymakers to design effective strategies and regulations that promote the growth and success of this renewable energy source.

Investors and Financial Institutions: As offshore wind projects require substantial capital investments, the insights from this study can help investors and financial institutions make informed decisions about the potential risks and rewards of investing in the offshore wind sector. By understanding the success criteria for digital transformation in offshore wind farms, investors can evaluate the potential profitability and sustainability of individual projects, as well as the overall industry.

Researchers and Academics: This study contributes to the existing body of knowledge on offshore wind energy and digital transformation by shedding light on the multidimensional success criteria needed to enable value creation in this growing sector. Researchers and academics can build upon these findings to explore new areas of inquiry, further enhancing our understanding of the offshore wind industry and its potential role in the global energy transition.

Local Communities and Environmental Organizations: As the development of offshore wind projects can have significant environmental and social impacts, this study can help local communities and environmental organizations better understand the potential benefits and challenges associated with offshore wind energy. By providing insights into the best practices and technologies for sustainable and efficient offshore wind operations, this study can support informed dialogue and stakeholder engagement that promotes the responsible development of offshore wind projects.

Finally, selecting this topic has proven to be a significant milestone for both of us, not only in terms of career advancement, but also as a means to deliver substantial value back to our respective organizations. We regard the topic as highly relevant, intriguing our curiosity while simultaneously aligning with our future career development goals. That said, the journey has not been without of challenges. The complexity of the topic, coupled with the difficulty in procuring reliable source materials due to the industry's early stage, has required a tremendous investment of effort. This experience has fostered a process of maturation along the way. Given the topic's complexity, we've decided to supplement our thesis with additional recommendations, which will be included in chapter 7. These insights are intended not only to foster interest around the thesis within our respective organizations, but also to identify and capitalize on potential commercial opportunities.

By providing valuable insights and practical guidance, the study aims to support the continued growth and success of the offshore wind industry, contributing to a more sustainable and prosperous future for all.

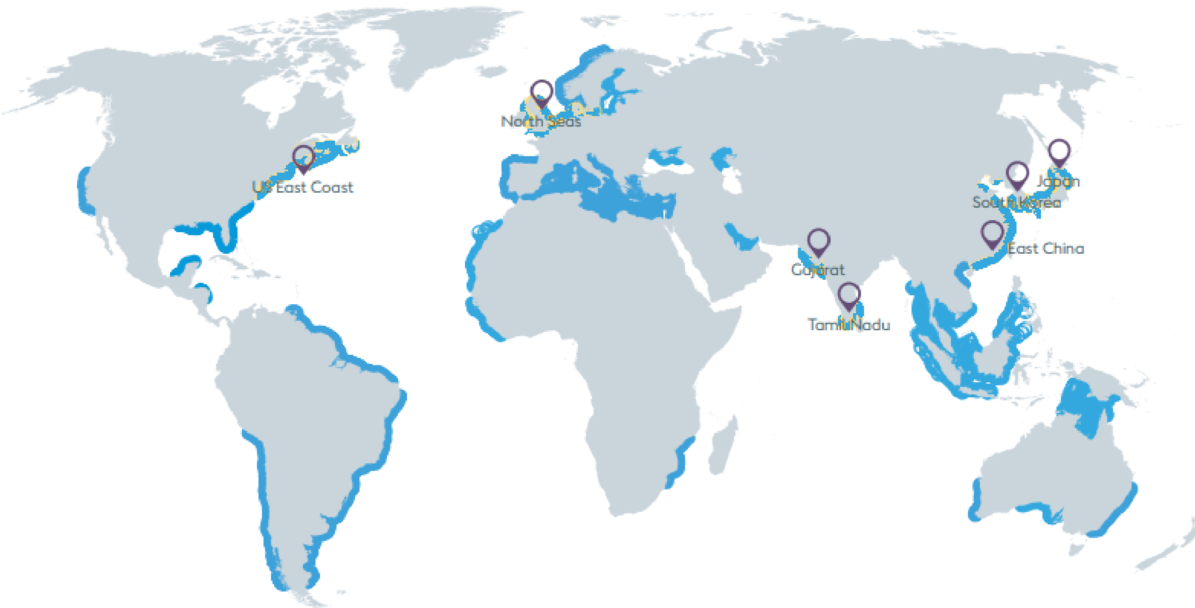

Figure 2: Global map with potential areas for offshore wind development in blue, but not limited to. *(Ørsted 2019)*

1.3 Scope and Delimitation of the Study

This study aims to provide an in-depth understanding of the multidimensional success criteria needed to reduce LCOE through digital transformation in offshore wind farms. To focus our analysis, we have chosen to concentrate on several key areas, including UN Sustainability Development Goals, offshore wind energy, digital tools and technologies, Industry 5.0, and operational excellence. While recognizing the importance of other renewable energy sources, such as onshore wind, solar, and hydropower, as well as other potential enablers for value creation, we believe that offshore wind presents unique opportunities and challenges that warrant a dedicated investigation.

Offshore wind energy offers distinct advantages compared to other renewable energy sources, such as stronger and more consistent winds, larger scale projects, and fewer spatial constraints. As such, it holds significant potential for contributing to the global energy transition and addressing the pressing need for clean, sustainable, and affordable energy.

Digital tools and technologies, as integral components of Industry 5.0, are transforming the offshore wind industry. Enhancing efficiency, optimizing operations, and enabling data-driven decision-making, they are crucial in uncovering the critical factors that drive value creation in offshore wind projects and identifying areas for further innovation and development.

The UN Sustainability Development Goals serve as a global framework for sustainable development and provide an essential context for understanding the role of offshore wind in promoting clean energy, climate action, and sustainable economic growth. By examining the relationship between offshore wind and these goals, we hope to illuminate the broader implications of the industry's development and its potential contribution to a more sustainable future.

Operational excellence is crucial for the long-term success and profitability of offshore wind farms. By exploring best practices, strategies, and challenges in achieving operational excellence, we aim to provide valuable insights for industry players, policymakers, and other stakeholders involved in the planning, construction, and operation of offshore wind projects.

While our study is primarily focused on offshore wind, we acknowledge the interconnected nature of the energy sector and the potential influence of other energy sources and enablers for value creation. However, by delimiting our scope in this manner, we hope to provide a comprehensive and focused analysis of the multidimensional critical success factors that contribute to the successful digital transformation of offshore wind farms and uncover the unique opportunities and challenges that this burgeoning industry presents.

1.4 Structure

The thesis is divided into six main chapters. Chapter 1 introduces the reader to offshore wind, research question and an insight into the relevance of the chosen theme. Chapter 2 present the theoretical framework of the thesis which is divided in five main sections: UN sustainability development goals, current state of offshore wind, digitalization, Industry 5.0, multidimensional success criteria and operational excellence. The five main themes are chosen to be able to answer the research question thoroughly and the same structure will be applied in chapter 4 and 5. However the five themes are not necessarily one to one towards the preliminary research questions, because they overlap each other and are chosen to give a holistic overview of a complex subject. Chapter 3 describes the methodological choices made in the thesis containing qualitative method. Moreover, Chapter 4 covers a systematic analysis and presents findings from the interviews. Chapter 5 includes the discussion of the results and findings. In the end of the chapter a self-developed framework for operational excellence in offshore wind industry is presented. Finally, chapter 6 answers the research questions and contain a conclusion. In addition, a chapter 7 is included to present recommendations to further work.

2 Theory

In this chapter the theoretical framework is presented. Initially, the theory shortly introduces the UN's sustainable development goals to place our thesis in context. Further, the theory presents five main areas and are divided in themes. First, Offshore wind's current state and market potential are presented. Next, digitalization and central literature on the concept of digitalization and data are reviewed. Then Industry 5.0 and digital tools in enabling digital transformation are presented. Furthermore, an overview of multidimensional criteria is given. Finally, an introduction to operational excellence is presented. This chapter incorporates sections dedicated to terminology, technical elements, and various contexts, thereby offering a comprehensive overview of the subject's complexity.

2.1 The UN's Sustainable Development Goals

The United Nations' Sustainable Development Goals (SDGs) are a set of 17 interconnected global goals designed to address various global challenges and create a better, more sustainable future for everyone by 2030 (United Nations, 2023). These goals encompass a wide range of issues, including poverty, inequality, climate change, environmental degradation, and social justice. By working together, countries, businesses, and civil society can contribute to the achievement of these goals and create lasting positive change.

Figure 3: UN's sustainable development goals (United Nations, 2023)

Offshore wind power development in Norway and other countries can contribute significantly to achieving several of the SDGs, particularly:

SDG 7: Affordable and Clean Energy - Offshore wind power can help increase the share of renewable energy in the global energy mix, promoting access to reliable, sustainable, and modern energy for all (United Nations, 2023).

SDG 13: Climate Action - By reducing greenhouse gas emissions and reliance on fossil fuels, offshore wind power can contribute to global efforts to combat climate change and its impacts, in line with the Paris Agreement's goals (United Nations, 2023).

SDG 8: Decent Work and Economic Growth - The development of offshore wind power can create new job opportunities and stimulate economic growth in the renewable energy sector, promoting inclusive and sustainable development (United Nations, 2023).

However, it is also essential to ensure that offshore wind power development does not negatively impact other SDGs, such as:

SDG 14: Life Below Water - It is crucial to balance offshore wind power development with the protection of marine ecosystems and biodiversity, minimizing any potential adverse effects on ocean life (United Nations, 2023).

The further development of offshore wind power has the potential to contribute significantly to the achievement of multiple UN Sustainable Development Goals. However, it is vital to strike a balance between the positive impacts of offshore wind power and any potential negative effects on other SDGs, ensuring a sustainable and inclusive approach to renewable energy development.

2.2 Offshore Wind

Offshore wind power is the generation of electricity through wind farms located in bodies of water at sea (Anaya-Lara, Tande, Uhlen, & Merz, 2018). Offshore wind energy, considered a renewable and clean energy source, captures the force of the wind through wind turbines and converts it into electricity that can be supplied to the onshore electricity network. There are two primary types of offshore wind farms: bottom-fixed and floating. Bottom-fixed wind farms have turbines mounted on the seabed, while floating wind farms use turbines anchored to the seabed, enabling them to move with the waves and capture more wind energy (Hansen, 2020).

There are several types of wind turbines in use today in offshore wind parks, including:

Horizontal Axis Wind Turbines (HAWT): HAWTs are the most common type of wind turbine, both onshore and offshore (Musial et al., 2016). They have a horizontal rotor axis, and the rotor blades face into the wind, allowing them to capture wind energy effectively.

Vertical Axis Wind Turbines (VAWT): VAWTs have a vertical rotor axis, making them less common in offshore wind parks. However, they offer advantages such as lower center of gravity and the ability to capture wind from any direction without needing to rotate the turbine (Eriksson, Bernhoff, & Leijon, 2008).

Floating Wind Turbines: Designed for deep waters, floating wind turbines are anchored to the seabed, allowing them to move with the waves and capture more wind energy. Floating wind farms are a promising solution for regions where the seabed is too deep for bottom-fixed installations (Carbon Thrust, 2022).

Emerging technologies and experimental designs are being developed and are some of the potential contributors for bringing down the LCOE in the offshore wind industry going forward according to Carbon Thrust (2022). These technologies are still in the early stages of development but have the potential to provide new and innovative ways of generating wind energy offshore.

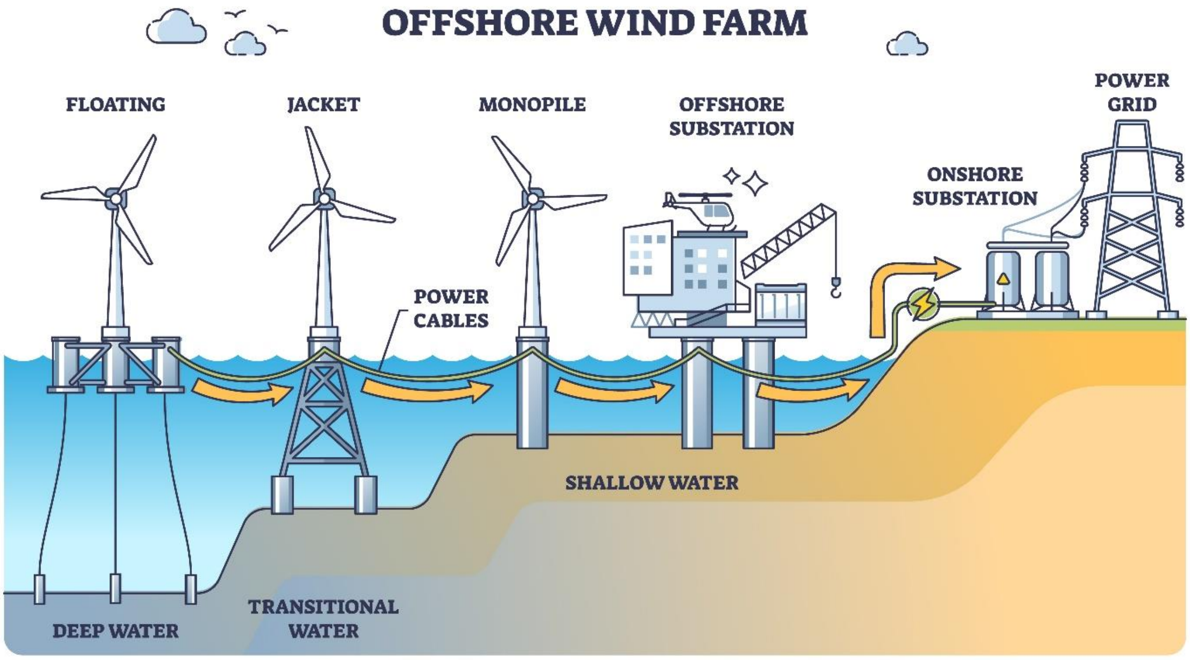

Figure 4: Wind turbine parks. («Offshore Wind bilder – Adobe stock», 2023)

2.2.1 Offshore Wind Farm Development and Components

Developing an offshore wind farm requires careful planning and coordination. Key components of an offshore wind farm include:

Site Selection: Selecting an appropriate site for an offshore wind farm involves considering factors such as wind conditions, water depths, seabed conditions, and potential environmental impacts (GWEC, 2021). Advanced modeling and analysis techniques can help identify the most suitable locations for wind farms.

Permitting and Regulatory Approvals: Obtaining necessary permits and regulatory approvals is a critical step in the development process. This may include conducting environmental impact assessments, engaging with local communities, and ensuring compliance with national and international regulations (IRENA, 2018).

Turbine and Foundation Design: The choice of turbine and foundation design depends on factors such as water depth, seabed conditions, and wind resource. Engineers and designers must consider these factors when selecting the most appropriate turbine and foundation technology for a given project (IEA, 2019).

Installation and Construction: Installation and construction of offshore wind farms involve specialized vessels, equipment, and personnel. Construction activities may include seabed preparation, foundation installation, turbine assembly, and electrical system installation (Ait Alla, Quandt, & Lütjen, 2013).

Operation and Maintenance: Offshore wind farms require regular inspection, maintenance, and repair to ensure optimal performance and to extend their lifespan. Advanced digital technologies, such as data analytics, remote monitoring, and autonomous systems, can help improve the efficiency and effectiveness of operation and maintenance activities (GWEC, 2021).

Decommissioning: At the end of their lifespan, offshore wind farms must be decommissioned and removed. This process involves dismantling the turbines, foundations, and electrical infrastructure, as well as restoring the seabed to its original condition (IRENA, 2018).

2.2.2 Challenges and Opportunities in Offshore Wind Industry

The offshore wind industry faces several challenges, but also offers significant opportunities for growth and innovation:

Cost Reduction: Although the costs of offshore wind have decreased significantly in recent years, they are still higher than those of onshore wind. Continued innovation and economies of scale can help further reduce costs, making offshore wind more competitive with other energy sources (IRENA, 2018).

Grid Integration and Storage: Integrating offshore wind energy into the existing power grid requires careful planning and investment in infrastructure, such as substations and transmission lines. Energy storage solutions, such as batteries or pumped hydro storage, can help balance variable wind generation with demand and improve grid stability (IEA, 2019).

Environmental Impact: Offshore wind farms can have potential impacts on marine ecosystems, migratory birds, and other wildlife. Careful site selection, design, and construction practices can help minimize these impacts and ensure the sustainable development of offshore wind resources (BOEM, 2023).

Technological Innovation: Emerging technologies, such as floating wind turbines and advanced blade designs, offer new opportunities for offshore wind development, particularly in deeper waters and more challenging environments (Carbon Thrust, 2022).

Workforce Development and Safety: Developing a skilled workforce is critical to the growth of the offshore wind industry. Investments in training, education, and safety programs can help ensure that workers have the necessary skills and knowledge to work in this rapidly evolving industry (GWEC, 2021).

By addressing these challenges and capitalizing on emerging opportunities, the offshore wind industry can continue to grow and play a critical role in the global transition to renewable energy.

2.2.3 Grid connection

The integration of electricity generated by offshore wind farms into the electrical grid is a complex process that requires careful planning and infrastructure development according to the International Energy Agency (IEA, 2019). The process involves transporting electricity from offshore wind turbines to the onshore grid, where it can be distributed to consumers.

Key components involved in this process include:

Offshore Substations

Offshore substations are platforms located within the wind farm, responsible for collecting the electricity generated by the wind turbines (Ørsted, 2019). They transform the voltage from the lower voltage used in the turbines to a higher voltage suitable for long-distance transmission (Siemens Gamesa, 2023).

Submarine Power Cables

Submarine power cables transmit electricity from the offshore substation to the onshore grid (Equinor, 2023b). These cables are laid on the seabed and designed to withstand the harsh marine environment, providing a reliable connection between the offshore wind farm and the onshore grid (IRENA, 2018).

Onshore Grid Connection

Once the electricity reaches the onshore grid, it needs to be integrated with the existing power infrastructure (Vineyard Wind, 2023). This may involve further voltage transformation, as well as the construction of new substations, transmission lines, or upgrades to existing infrastructure to accommodate the additional power generated by the offshore wind farm (GWEC, 2021).

Grid Management and Balancing

The integration of offshore wind energy into the grid requires careful management and balancing to ensure the stability of the power system (IEA, 2019). As wind generation can be variable due to changing wind conditions, grid operators must continuously monitor and adjust the electricity supply to meet demand (IRENA, 2018). This may involve using energy storage systems, demand-side management, or other flexible resources to help balance the grid (GWEC, 2021).

2.2.4 Operations & Maintenance

Operations and maintenance (O&M) play a crucial role in the long-term success and profitability of offshore wind farms. Effective O&M strategies can help ensure the optimal performance of wind turbines, minimize downtime, and extend the lifespan of the equipment, thus maximizing the return on investment (Musial, Beiter, Spitsen, Nunemaker, & Gevorgian, 2018).

There are several key aspects to consider in the O&M of offshore wind farms, including:

Preventive maintenance: This involves regular inspections, servicing, and repairs to prevent equipment failures and extend the life of the wind turbines. Scheduled maintenance tasks include lubrication, component replacement, and software updates (Musial et al., 2018).

Corrective maintenance: When equipment failures occur, corrective maintenance is necessary to restore the wind turbine to its normal operating condition. This can involve emergency repairs, unscheduled maintenance, and component replacements (Athanasia & Genachte, 2013).

Condition monitoring: Advanced condition monitoring systems use sensors and data analytics to monitor the health of wind turbines and detect early signs of equipment degradation. This information allows operators to schedule maintenance more effectively and reduce the likelihood of unexpected equipment failures (Carroll, McDonald, & Mcmillan, 2015).

Remote monitoring and control: Offshore wind farms often utilize remote monitoring and control systems to oversee the performance of the turbines and make adjustments as needed. These systems can help minimize the need for onsite personnel and reduce O&M costs (Musial et al., 2018).

Logistics and personnel: Effective O&M strategies require efficient logistics and skilled personnel. This includes transporting maintenance crews and equipment to and from the offshore wind farm, as well as ensuring that staff have the necessary training and expertise to perform maintenance tasks safely and effectively (Rademakers, Braam, Asgarpour, & van de Pieterman, 2003).

Challenges and Opportunities: Offshore wind O&M faces several challenges, including harsh environmental conditions, remote locations, and higher costs compared to onshore wind farms. These challenges can be addressed through the development of innovative technologies and strategies, such as autonomous vehicles for inspections, advanced condition monitoring systems, and digitalization (Carroll et al., 2015; Musial et al., 2018).

Effective O&M strategies are essential for the long-term success of offshore wind farms. By addressing the key aspects of O&M and overcoming challenges through innovation, the offshore wind industry can continue to grow and contribute to a sustainable energy future.

2.2.5 Third largest energy source in 2050

The offshore wind industry is still in its early growth phase compared to onshore wind but has experienced significant growth in recent years. The industry has gained substantial momentum, particularly in light of current global circumstances such as the Ukraine war and the vulnerability of gas supplies (Kühn et al., 2022). Today, bottom-fixed offshore wind turbines are the most common type of offshore wind installations (Kühn et al., 2022).

Onshore wind, on the other hand, benefits from being more established, with a mature supply chain and a lower overall cost (IRENA, 2021). The accessibility of onshore wind sites makes installation and maintenance easier compared to offshore wind, which faces logistical and environmental challenges such as harsh weather conditions, greater water depths, and potential impacts on marine ecosystems (EIA, 2021). However, onshore wind also faces challenges, such as land use conflicts, public opposition, and limitations in suitable sites Additionally, onshore wind turbines may face issues related to noise, visual impact, and potential harm to wildlife, particularly birds and bats (EIA, 2021).

A report by Kühn et al (2022) suggests that by 2050, a large portion of electricity could come from offshore wind if expertise from the oil and gas industry is utilized. Offshore wind has the potential to become the next great Norwegian industrial adventure in the North Sea. The complexity of wind turbines aligns well with Norwegian expertise in the North Sea. Having an industry experienced in constructing complex and technologically advanced offshore installations is advantageous. This installation experience, along with the existing infrastructure and supplier industry, are essential building blocks for a significant Norwegian investment in offshore wind. Given the favorable conditions and expertise, Norway should begin charting its course for offshore wind development now to ensure success in the future (McKinsey, 2022).

Offshore wind is projected to be the third-largest energy source in Europe by 2050, accounting for 21% of the EU's total power production in that year (Kühn et al., 2022). However, offshore wind will require substantial capital investments, creating a valuable market. Since 2015, capital investments have increased from only 6% to 36% in 2020, and by 2030, annual capital investments are expected to double for offshore wind, representing equivalent to 62% of the capital investments in offshore upstream oil and gas (McKinsey, 2022).

McKinsey (2022) states that a successful large-scale investment in offshore wind could result in an increased value creation (GDP) and new jobs. The primary value creation is linked to offshore wind projects in the North Sea, but there could also be significant income if the Norwegian supplier industry becomes a key contributor to the European and international offshore wind industry. The jobs created in the offshore wind industry could serve as viable future alternatives for individuals currently employed in the oil and gas sector.

2.2.6 Levelized Cost of Energy (LCOE) in Offshore Wind

This section will present Levelized Cost of Energy (LCOE) in Offshore Wind including considering Operating Expenses (OPEX) and Capital Expenditures (CAPEX).

Levelized Cost of Energy (LCOE) is a widely used metric to compare the costs of different energy sources over their respective lifetimes. It represents the cost of generating electricity from a specific source and is typically expressed in dollars per megawatt-hour ($/MWh) or similar currency units (EIA, 2021). LCOE considers various factors such as capital costs, operational expenses, fuel costs, and the expected lifetime of the energy source.

In the context of offshore wind, understanding operating expenses (OPEX) and capital expenditures (CAPEX) is crucial for evaluating the financial viability of offshore wind energy projects. These two categories of expenses impact the LCOE and the profitability of a project over its lifetime.

Operating Expenses (OPEX)

Operating expenses (OPEX) refer to the recurring costs incurred during the normal operation of a business, including the expenses associated with producing, maintaining, and selling goods or services (Ioannou, Angus, & Brennan, 2018). In the context of offshore wind energy, OPEX includes costs related to:

Operations and maintenance (O&M): These expenses encompass regular monitoring, repairs, and maintenance of turbines, substations, and other equipment, as well as personnel costs and logistics (IRENA, 2018).

Lease and royalty payments: Some offshore wind projects may require payments to governments or other entities for leasing the land or sea space where the wind farm is situated (IRENA, 2018).

Insurance and decommissioning: Insurance costs protect against potential damage, and decommissioning costs cover the eventual dismantling and removal of turbines and other equipment at the end of the project's lifespan (Ioannou et al., 2018).

Capital Expenditures (CAPEX)

Capital expenditures (CAPEX) are the costs incurred for acquiring or upgrading long-term physical assets, such as equipment, facilities, and infrastructure (Ioannou et al., 2018). In offshore wind energy projects, CAPEX includes costs related to:

Turbine procurement: Purchasing wind turbines represents a significant portion of CAPEX, as these are the primary energy-generating assets of a wind farm.

Balance of plant (BOP): This includes the costs of other essential infrastructure, such as substations, cables, and foundations (Ioannou et al., 2018).

Installation and commissioning: These costs involve the deployment of turbines and other equipment, as well as the setup and testing of the entire wind farm to ensure optimal performance (IRENA, 2018).

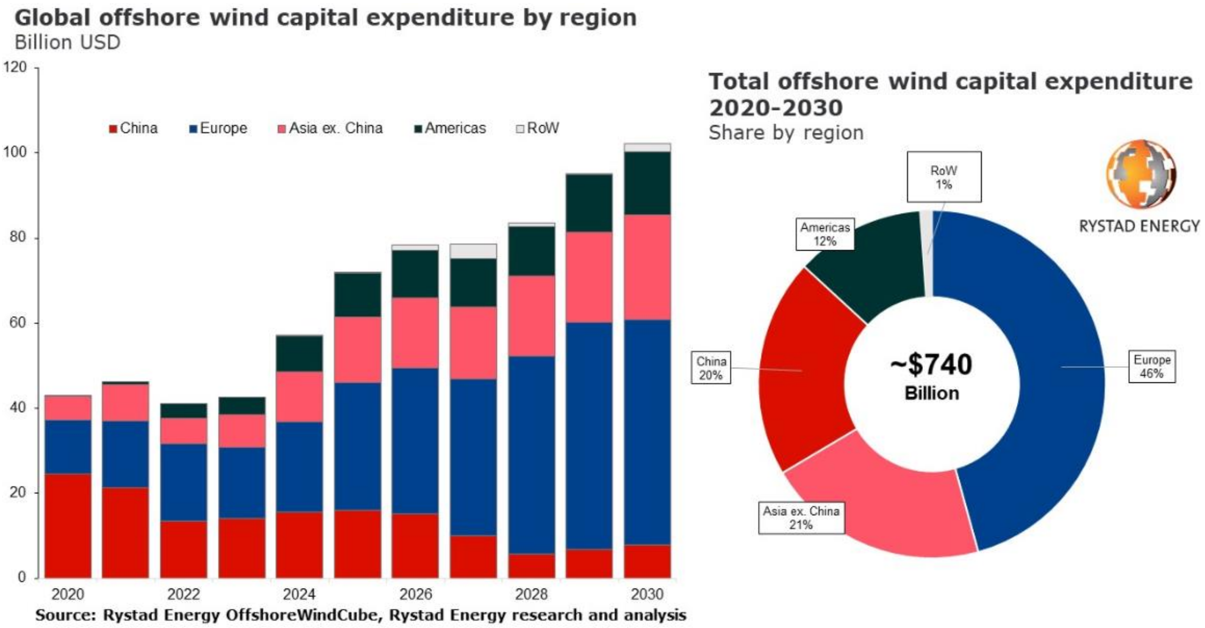

Figure 5: Global offshore wind capital expenditure toward 2030 (Rystad Energy 2023)

Financing: Obtaining financing for a project usually involves interest payments, fees, and other associated costs.

Both OPEX and CAPEX contribute to the overall LCOE of an offshore wind energy project.

By minimizing these costs through efficient planning, design, and execution, project developers can improve the competitiveness of offshore wind energy and help drive its adoption as a sustainable, low-cost energy source (Ioannou et al., 2018).

Offshore wind has historically been more expensive than onshore wind due to factors such as higher capital costs for turbine installation and more complex operations and maintenance (O&M) requirements (IRENA, 2018). However, recent technological advancements and economies of scale have led to a significant reduction in the LCOE for offshore wind. According to the International Renewable Energy Agency (IRENA), the global weighted average LCOE for offshore wind fell significantly over the past decade (IRENA, 2021). This decline can be attributed to several factors, including the increased use of larger and more efficient turbines, improved installation methods, and the implementation of competitive auction mechanisms for securing power purchase agreements (PPAs) (IRENA, 2018).

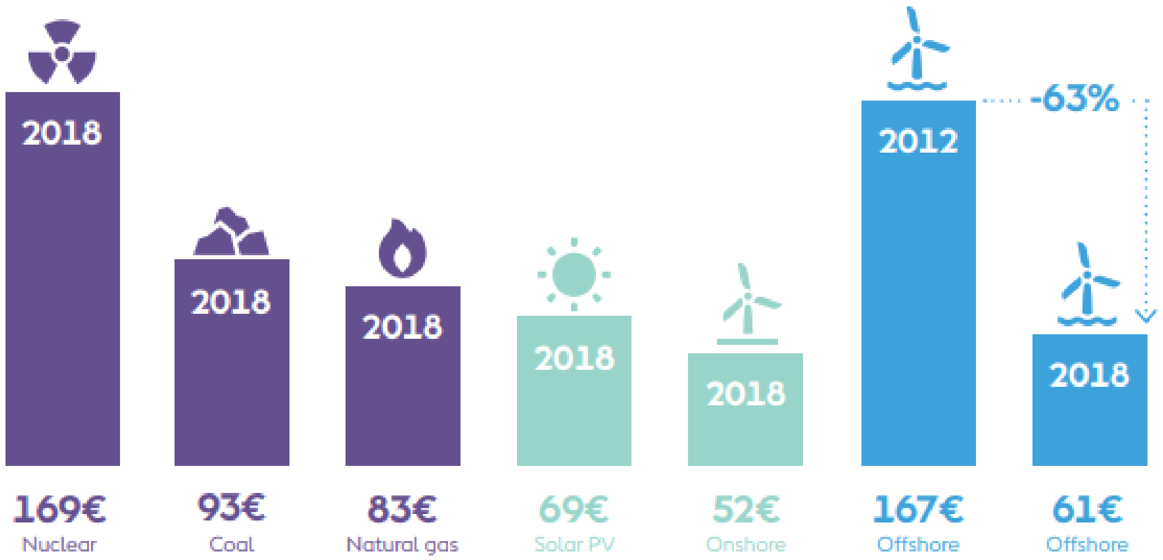

Figure 6: Levelized cost of electricity for different energy technologies (LCOE). EUR/MWh, 2018 prices, Northwestern Europe (Ørsted 2019)

Despite these cost reductions, the LCOE of offshore wind remains higher than that of onshore wind and solar photovoltaic in many regions. However, it is important to note that LCOE does not capture the full value of offshore wind, as it may provide additional benefits, such as increased energy security, reduced greenhouse gas emissions, and more stable power generation due to stronger and more consistent wind resources at sea (BloombergNEF, 2022).

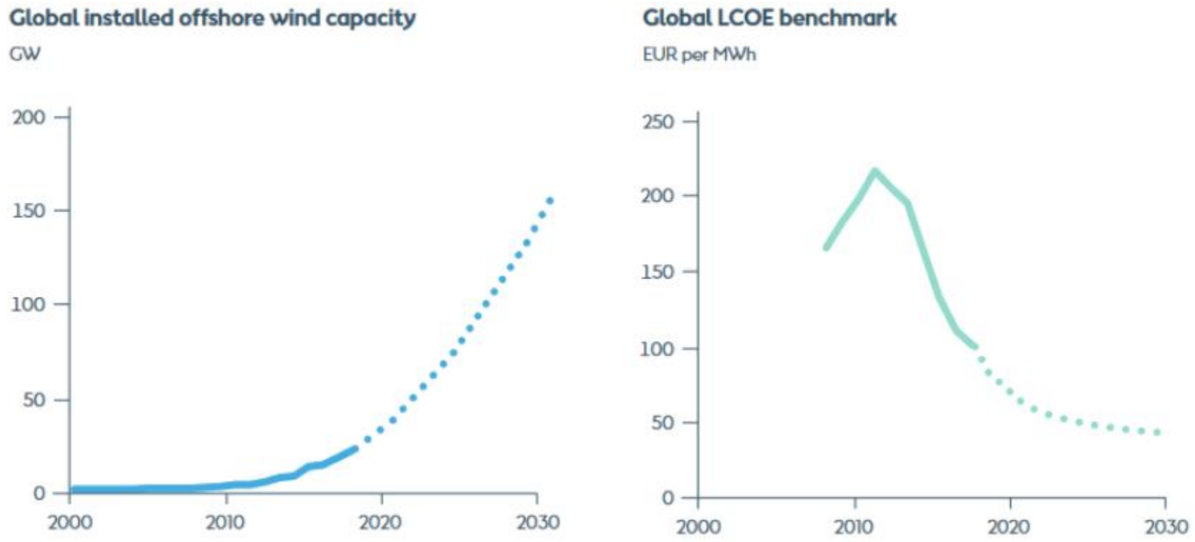

Figure 7: Global offshore wind installed vs. LCOE benchmark (Ørsted, 2019)

In conclusion, LCOE is a useful metric for comparing the costs of different energy sources, including offshore wind. By considering both OPEX and CAPEX, it helps stakeholders understand the financial viability of offshore wind projects. While offshore wind has historically been more expensive than other renewable energy sources, recent advancements have led to significant cost reductions. As the industry continues to mature and innovate, it is expected that the LCOE for offshore wind will become increasingly competitive with other energy sources, making it an attractive option for meeting future energy demands.

2.3 Digitalization

Digitalization can be characterized as one of the greatest and most important trends of our time. Digitalization can be defined as the utilization of new technology, which can create great opportunities through increased productivity, improved customer experience, streamlining operations and processes, or creating new business models (Fitzgerald, Kruschwitz, Bonnet & Welch, 2013). In addition, Parviainen, Tihinen, Kääriäinen, & Teppola (2017), argues how digitalization causes changes for companies due to the adoption of digital technologies in the organization or the operating environment, which again can lead to changes in key operational functions, processes, organizational structure, and management concepts (Matt, Hess, & Benlian, 2015).

The rapid development of technology has challenged many industries to fully embrace digitalization (Galliers, Leidner, & Simeonova, 2020). For the offshore wind industry, there is a significant competitive advantage in adopting and utilizing rapid technological advancements to establish itself as a renewable energy leader (Tande, 2023). Digitalization is becoming increasingly important in the offshore wind industry as it can help improve safety, efficiency, and productivity. There are several areas where digitalization can have an impact within offshore wind:

Design and Planning: Digital tools can optimize the design and planning of offshore wind farms, including using data analytics to identify the best locations for turbines based on wind conditions, water depths, and seabed conditions (Sprenger, 2017).

Construction: Digitalization can improve the construction process by providing real-time monitoring and analysis of construction activities (Tao, Zhang, Liu, & Nee, 2019). This includes using sensors to monitor the installation of turbines and drones to inspect infrastructure.

Operation and Maintenance: Digitalization can enhance the operation and maintenance of offshore wind farms, including using data analytics to predict and prevent equipment failures, and utilizing remote monitoring and control systems to reduce the need for human intervention (Barthelmie et al., 2010).

Safety: Digitalization can improve safety within the offshore wind industry, such as using digital tools to simulate and test emergency scenarios and employing virtual reality to train workers in hazardous environments (Florian & Sørensen, 2017).

Digitalization has the potential to revolutionize the offshore wind industry by improving efficiency, reducing costs, and enhancing safety (IEA, 2019).

2.3.1 Digital Strategy

Many organizations fail to utilize new technology, with 70% of digitalization projects ending in failure (Tabrizi, Lam, Girard, & Irvin, 2019). For offshore wind industry, if companies are to succeed with digitalization, a digitalization strategy must be defined and established. Key goals and objectives of the wind farm must be identified so that the right digital tools can be selected to support the goals. A plan must also be established for implementing and using digital technologies within the operation of wind farms, including a timeline, budget, and key milestones. Furthermore, sufficient knowledge and training must be ensured to effectively use digital technologies (Tande, 2023). The key to a successful digitalization strategy for an offshore wind farm is to approach it in a holistic and strategic way and engage with all stakeholders to ensure that the strategy aligns with the wind farm's goals and objectives (Parviainen et al, 2022).

2.3.2 Digital Transformation

Digital transformation is defined as the integration of digital technology into all areas of a business, fundamentally altering how it operates and delivers value to its customers. It's not just about substituting analog processes with digital ones, but it's about leveraging technology to create new or modify existing business processes, culture, and customer experiences in order to meet changing business and market requirements (Westermann, Bonnet & McAfee, 2014). Berman, (2012) also discuss how digital transformation represents a pivotal shift in the way organizations conduct business, characterized by the integration of digital technology into all areas of operations. The process fundamentally changes how businesses operate and deliver value to customers, fostering a more flexible, responsive, and innovative operational approach.

Digital transformation has become an essential factor in the offshore wind industry, driving increased efficiency, cost reduction, and enhanced operational performance (Ren et al, 2021). In the era of Industry 4.0, where data and digital technologies are the key enablers of innovation, offshore wind is no exception. Offshore wind farms are complex to construct, operate, and maintain, with harsh environments and accessibility issues often hindering efficient operations (Hameed & Vatn, 2012). This is where digital transformation steps in, providing solutions that can significantly mitigate these challenges which can be integrated into a digital twin an applying the use of Internet of things, artificial intelligence, machine learning, Scada, data analytics and many more.

Digital transformation in the offshore wind industry is not just about technology, it's also about people and processes. It requires a cultural shift within organizations, encouraging openness to change, fostering innovation, and promoting collaboration across various domains. By embracing digital transformation, the offshore wind industry is poised to achieve greater sustainability, resilience, and efficiency in the face of evolving global energy demands (Westerman et al, 2014).

2.3.3 Data

According to Porter & Heppelmann (2014) data was generated primarily by internal operations and through transactions historically. This has however been supplemented with data from the products themselves, generating real-time readings that are unprecedented in variety and volume. Moreover, big data is defined as “the ability to process and analyze huge amounts of data” (Manyika et al., 2013). In an operational context, data that is valuable from a windmill can include the wind speed and direction, the output power of the windmill, the rotation speed of the blades, and the temperature of the windmill's various components. This data can be used to monitor the performance of the windmill and identify any potential issues that may need to be addressed. Additionally, this data can be used to optimize the operation of the windmill and ensure that it is generating electricity as efficiently as possible (Vandenberge, 2017).

Smith (2020) define The Internet of Things (IoT) as sensors and actuators by networks to computing systems, and these systems can monitor or manage the health and actions of connected objects and machines. According to Smith (2020), IoT is also becoming increasingly important in the offshore wind industry, as it enables the collection and analysis of real-time data from a range of sensors and devices. For example, IoT sensors can be used to collect data on wind speeds, wave heights, and turbine performance, which can then be analyzed to optimize the operation of the wind farm. By leveraging IoT, operators can gain a more comprehensive understanding of the performance of the wind farm and make data-driven decisions to improve efficiency and reduce costs (Smith, 2020).

2.3.4 Contextualized Data

Contextualized data refers to data that is enriched with additional information or metadata that provides context to the data, helping users understand its relevance, origin, and relationships with other data points. The context surrounding data can include information about the environment, time, location, or other factors that influence the data or are influenced by the data (Schmarzo & Borne, 2020). By incorporating contextual information, data becomes more meaningful and valuable, as it allows for a more comprehensive understanding of the relationships between data points and the factors affecting them. This, in turn, leads to more accurate analysis, insights, and decision-making (Chen, Chiang, & Storey, 2012).

According to García Márquez, Tobias, Pinar Pérez, & Papaelias (2012); Draxl, Clifton, Hodge, & McCaa, (2015), different type of contextual information for dataset for wind turbines can be categorized into:

Timestamps: The exact time when each wind speed measurement was taken. This allows users to analyze wind speed variations throughout the day and identify patterns or trends.

Turbine identification: Information about the specific wind turbine associated with each wind speed measurement, such as its make, model, and capacity. This enables users to compare the performance of different turbines under similar wind conditions.

Environmental factors: Additional data on factors that may affect wind speed and turbine performance, such as air temperature, humidity, and atmospheric pressure. This helps users understand the impact of these factors on wind speed and turbine efficiency.

Turbine operational status: Information about the operational status of the turbine, such as whether it is running at full capacity, undergoing maintenance, or experiencing technical issues. This context allows users to correlate wind speed data with the performance and potential issues of specific turbines.

Predictive Maintenance: Contextualized data can be used to build more accurate predictive maintenance models, enabling operators to identify potential maintenance needs before they become critical.

2.3.5 Real-Time Data

Real-time data, which refers to information that is collected, processed, and disseminated promptly, is becoming crucial in the offshore wind industry, providing valuable insights into the performance and condition of wind turbines and other equipment (Snijders, Matzat, & Reips, 2012). By leveraging real-time data, operators can optimize the efficiency, safety, and sustainability of offshore wind farms, reducing downtime, increasing energy production, and enhancing overall operations (Sprenger, 2017). In this context, real-time data sources can include IoT devices, sensors, and streaming analytics platforms, offering a range of potential applications for offshore wind farm management. In this section, we will explore the use of real-time data in an offshore wind farm, its types, and potential applications.

Real-Time Data Collection and Types

Real-time data collection is a critical component of an offshore wind farm, providing operators with accurate and timely information about the performance and condition of wind turbines and other equipment. This data can be collected from a variety of sources, including sensors, control systems, and other monitoring devices. The data can then be transmitted to a central control center or cloud-based platform, where it can be analyzed and used to make informed decisions about the operation and maintenance of the wind farm (Mcmillan, 2022).

Types of real-time data available in an offshore wind farm include:

Wind Speed and Direction: Real-time monitoring of wind speed and direction is essential for ensuring the optimal performance of wind turbines. This data can be used to adjust the pitch of the blades and the output of the generator to maximize energy production (Li, Huang, & Guedes Soares, 2022).

Oceanographic data and Humidity: Real-time monitoring of temperature and humidity can help operators detect potential issues with the cooling systems of wind turbines, which can lead to downtime and decreased performance (García Márquez et al., 2012). Oceanographic data, such as wave height and water temperature, which can be used to monitor the condition of the wind farm's foundation structures and ensure that they are operating safely and efficiently (Li et al., 2022).

Vibration and Noise: Real-time monitoring of vibration and noise levels can help operators detect potential issues with the mechanical components of wind turbines, such as bearings and gears (Amirat, Benbouzid, Al-Ahmar, Bensaker, & Turri, 2009).

Power Output: Real-time monitoring of the power output of wind turbines is essential for optimizing energy production and ensuring that the wind farm is operating at peak efficiency (Sun, Huang, & Wu, 2012).

Real-Time Data Analysis

Real-time data analysis is another critical component of an offshore wind farm, enabling operators to make informed decisions about the performance and condition of wind turbines and other equipment. By analyzing real-time data, operators can detect potential issues before they become critical, optimizing maintenance schedules, reducing downtime, and increasing energy production. Real-time data has a wide range of potential applications in an offshore wind farm, including condition monitoring, energy optimization and safety enhancement (Kang & Guedes Soares, 2020).

2.4 Industry 5.0 and digital tools in enabling digital transformation

Digital Transformation represents a crucial shift across all sectors, and this is particularly true in the offshore wind industry. Digital tools, from software applications to advanced technologies, serve as the backbone of this transformation. They facilitate the collection, analysis, and dissemination of information, leading to enhanced efficiency, superior communication, and improved decision-making processes (Lankshear & Knobel, 2005; Brynjolfsson & McAfee, 2014).

At the forefront of this transformation is Industry 5.0, which is considered the next evolution of Industry 4.0, characterized by automation, data exchange, and Internet of Things (IoT) integration in industries (Schwab, 2016). Industry 5.0 takes these principles further, leveraging AI and machine learning for even greater levels of automation and efficiency, while giving a renewed emphasis on the human factor (Jafari, Azarian & Yu, 2022).

Industry 5.0 technologies can significantly benefit the offshore wind farm industry. The use of AI and machine learning allows for sophisticated monitoring of wind turbines and other equipment, leading to early problem detection and prediction (Zhang et al., 2019). Additionally, advanced robotics and automation technologies can perform complex tasks, such as maintenance and repairs, improving safety and reducing operational costs by limiting human exposure to potentially hazardous environments (Gardner, 2022).

Industry 5.0 also re-emphasizes the human aspect, a shift from Industry 4.0's primary focus on technology (Jafari, Azarian, & Yu, 2022). This new paradigm ensures human needs and societal sustainability are at the strategic and operational forefront. It acknowledges the vital role of human creativity and innovation while integrating sustainable practices into business strategies, which is crucial for achieving the UN sustainable development goals (Alexa, Pîslaru, & Avasilcăi, 2022; Jafari et al., 2022).

Figure 8: Digital Transformation. support wind mill turbine (Adobe stock», 2023)

Moreover, the potential applications of Industry 5.0 technologies within the offshore wind farm industry extend to operational optimization and environmental impact reduction. Advanced robotics, AI, and IoT sensors, for instance, can reduce the need for human intervention in potentially hazardous environments, consequently enhancing safety and operational costs (Mitchell et al., 2022).

These advanced technologies can also aid in the optimal placement and orientation of wind turbines within a wind farm, thus maximizing energy generation (Yang, Kwak, Cho, & Huh, 2019). Furthermore, they can support better integration of renewable energy sources into the power grid, making it more resilient and adaptable to supply-demand fluctuations (Jafari et al., 2022).

The concept of the "Digital Twin" is another transformative digital tool within the Industry 5.0 framework. A digital twin is a model-based representation of a real-world asset developed using real data (LeBlanc & Ferreira, 2020). In the context of a windmill, data can be used to create a virtual model accurately reflecting its current state and behavior, enabling simulation, problem identification, and performance improvement. This optimizes the windmill's operation, ensuring efficient electricity generation (Mathieson, 2022).

Simultaneously, emerging concepts like the "Industrial Metaverse" further extend the potential of digital transformation. The industrial metaverse, powered by AR/VR technologies, creates a digital twin of physical environments for immersive visualization, simulation, and analysis (Parrott & Warshaw, 2017; Wang, Yang, Wang, Li, & Han, 2023). This metaverse, along with AI tools such as language models like ChatGPT, underlines the transformation from algorithmic intelligence to linguistic intelligence, signifying an evolution in AI's role within digital transformation. It fosters real-time, interactive activities between human and machine, the physical and the virtual, giving rise to novel opportunities for efficiency and productivity improvements.

The industrial metaverse and Industry 5.0 both focus on the transformative power of advanced technologies. While they share a common aim of efficiency, productivity, and sustainability enhancement, their primary focus areas differ. The industrial metaverse emphasizes immersive and interactive digital environments, while Industry 5.0 leans more towards leveraging AI and machine learning for automation and efficiency (De Giovanni, 2023).

Notwithstanding their focus areas, both these concepts have tremendous potential within the offshore wind industry. The industrial metaverse, through the creation of a digital twin of the wind farm environment, enables improved visualization, simulation, and analysis of complex data. This enhancement could improve the design and planning of wind farm projects, the training of personnel, and the maintenance of equipment (Pizoń & Gola, 2023).

Similarly, Industry 5.0 can enhance offshore wind operations' efficiency and productivity. Using AI and machine learning, it can optimize processes, reduce downtime, and improve the performance of wind turbines and other equipment. This, in turn, enhances the environmental sustainability of offshore wind farms by minimizing waste and improving energy efficiency

(Pizoń & Gola, 2023).

In conclusion, the theoretical framework of Industry 5.0 and digital tools illustrates the potential for Digital Transformation within the offshore wind industry. Emphasizing the human aspect, integrating sustainability and resilience, and leveraging advanced technologies can collectively drive future development in the sector. Thus, Industry 5.0, along with its associated digital tools, presents a pivotal path to achieving increased efficiency, reduced costs, and improved environmental performance in the offshore wind industry.

Figure 9: Digital twin (Adobe stock», 2023)

2.4.1 Artificial intelligence and Machine learning

In the realm of digital tools, two significant technologies that have gained substantial attention are Artificial Intelligence (AI) and Machine Learning (ML). Although they are often used interchangeably, they have distinct differences and applications in various contexts.

Artificial Intelligence (AI) refers to the development of computer systems that can perform tasks that typically require human intelligence, such as problem-solving, learning, and understanding natural language (Russell, Norvig, & Davis, 2010). AI can be categorized into two types: narrow AI, which is designed to perform a specific task or a set of tasks, and general AI, which can perform any intellectual task that a human can do (Yudkowsky, 2008).

Machine Learning (ML), on the other hand, is a subfield of AI that focuses on the development of algorithms that enable computers to learn and improve from experience, without being explicitly programmed for each specific task (T. M. Mitchell, 1997; Samuel, 1959). In other words, ML allows computers to adapt and optimize their performance based on the data they process, leading to more accurate predictions and outcomes over time (Hastie, Tibshirani, & Friedman, 2009).

AI encompasses a broader scope of creating intelligent computer systems, while ML is a specific approach within AI that emphasizes learning from data. Both AI and ML are crucial digital tools that have transformative implications across numerous industries including the offshore wind industry, enhancing decision-making processes, automation, and overall efficiency (Hastie et al., 2009; Russell et al., 2010).

Figure 10: Wind turbine parks. (Adobe stock, 2023)

2.4.2 Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) systems are essential components in modern industrial operations, including the offshore wind industry. SCADA systems allow for the monitoring and control of various processes in real-time, providing critical data to operators and managers for decision-making (Wind Energy The Facts, 2009). According to Wind Energy The Facts (2009) SCADA acts as a 'nerve center' for the project. It connects the individual turbines, the substation and meteorological stations to a central computer. This computer and the associated communication system allow the operator to supervise the behavior of all the wind turbines and the wind farm as a whole. The primary function of SCADA systems is to collect real-time data from various sensors and devices, providing insights into the performance of the system. SCADA systems have evolved over the years, with advances in sensors and communication technologies leading to more efficient and accurate data collection (Mittelmeier, Blodau, & Kühn, 2017). According to IEC TS 61400-26-1 (2011), the use of modern sensors and communication protocols has resulted in improved data quality and reliability in SCADA systems.

The vast amounts of data collected by SCADA systems can be overwhelming for operators to analyze manually. Big data analytics has emerged as a solution to this problem, providing powerful tools to analyze and extract insights from large datasets. According to Naghib, Jafari, Navimipour, Hosseinzadeh, & Sharifi (2023) the use of big data analytics in SCADA systems is expected to grow significantly in the coming years, enabling operators to make data-driven decisions to optimize performance and reduce costs.

SCADA systems play a crucial role in the offshore wind industry, providing real-time data to enable effective decision-making and optimize performance (Wind Energy The Facts, 2009). The use of modern sensors and communication protocols has resulted in improved data quality and reliability, while big data analytics has provided powerful tools for data analysis (Naghib et al., 2023).

2.5 Multidimensional success criteria's

Numerous investment projects adhere to explicit directives established by clients and stakeholders, which outline the desired value creation to be generated by the project. However, there is frequently an absence of comprehensive evaluations regarding the specific opportunities for enhancing value creation and the strategies required to actualize these benefits (Skyttermoen & Vaagaasar, 2021). Karlsen (2021) states that an important means of increasing the opportunities for value creation is to have a good understanding of what success is, and what contributes to success in various contexts.

According to Shenhar & Dvir, (2007) projects have had a strong focus on result targets like time, cost, and scope. Gradually, it has been seen that it is much more important that projects contribute to value creation and contribute to the organization achieving the desired effects. Success criteria cannot only be measured by time, cost and scope, that only gives indications of the project manager's success, not the extent to which the results produce long-term effects and how it contributes to value creation. Traditionally, performance targets were a goal and impact targets & value creation a purpose. Furthermore Shenhar & Dvir (2007), argues there should be more focus on effect targets than result targets. Impact measures can be measured at a later stage to see if it had an effect. There has therefore been an increased focus the recent years on managing according to multidimensional success criteria and a new approach and framework was introduced by Shenhar & Dvir (2007). Multidimensional success criteria refer to a set of criteria that are used to evaluate the success of a project or initiative in multiple dimensions or aspects. This means that the success of the project is not judged based on a single metric or criterion, but rather on a range of different factors that is linked to the companies' objectives and long-term strategy (Cooke-Davies, 2002). In the context of an offshore wind farm, multidimensional success criteria may include factors such as the efficiency and output power of the wind turbines, the safety and reliability of the wind farm's infrastructure, and the level of community engagement and support for the project (World Bank Group, 2021). By using multidimensional success criteria, it is possible to evaluate the success of the wind farm in a more comprehensive and nuanced way, considering a range of different factors that are relevant to its operation and impact because it will provide the owners and stakeholders with a more complete picture.

Shenhar & Dvir (2007) presents a model which represent five main dimensions of project success criteria in short and long term is: project efficiency, impact on the customer, impact on the team, business and direct success and preparation of the future.

Figure 11: Main dimensions for project success (A. Shenhar & Dvir, 2007, s. 27)

The different dimensions describe in a different grader the complexity in and around a project are able to catch both short- and long-term aspects of success. This study will focus on *Business and direct success*. Shenhar & Dvir, (2007) describe this dimension 'business results' to have several sub measures and it differs from project to project based on importance and purpose. Some of the metrics might be return on investment, market share and growth. Shenhar & Dvir (2007) further argues that this dimension typical represent a business plan including expected future sales, growth, and profit from the product. Shenhar, Dvir, Levy, & Maltz, (2001) argues that this dimension can only be passed after a significant level of sales has been achieved, usually after two years.

Skyttermoen & Vaagaasar (2021) discusses and nuances the model and dimension above even further to make value creation visible to an even greater extent. Moreover, Skyttermoen & Vaagaasar (2021) describes this dimension as *Impact measures and value creation* and argue that effect-objectives are designed with value creation in mind. The value creation of the project is linked to the effects of the result target itself, and an assessment of project success must be particularly linked to this dimension. When it comes to evaluating project success, Skyttermoen & Vaagaasar (2021) claim that this dimension is the most important.

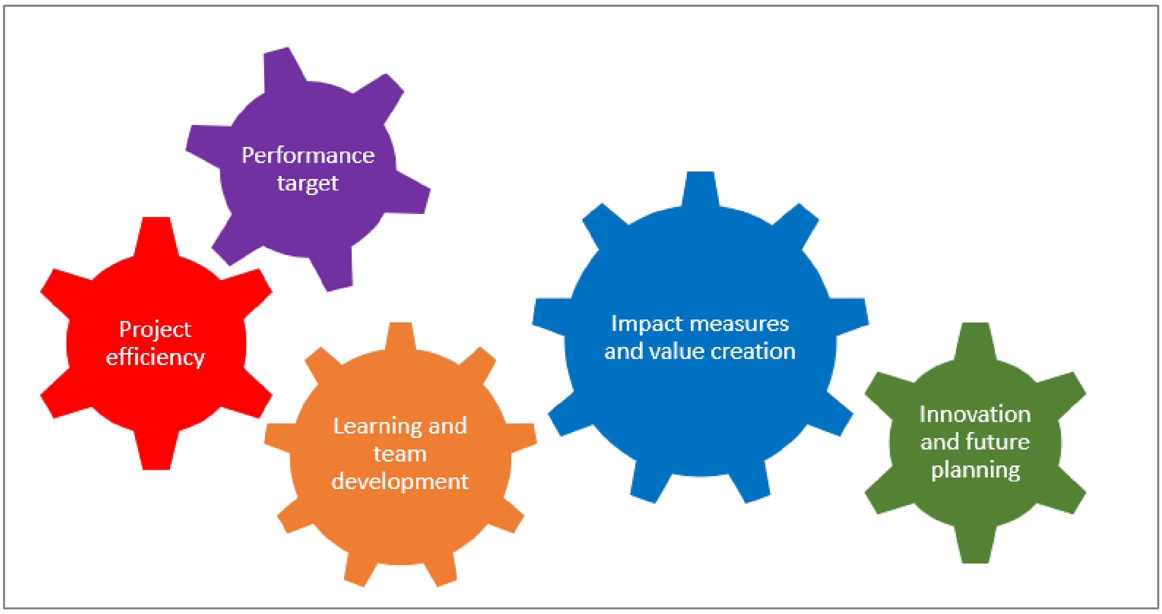

Figure 12: Main dimensions for project success from a value creation perspective (Skyttermoen & Vaagaasar, 2021, s. 57).

2.6 Operational excellence

Operational excellence is the ability to execute a business strategy with greater efficiency and consistency than the competitors (Bhuiyan & Baghel, 2005). Achieving operational excellence leads to higher revenue, reduced operational risk, and lower operating expenses. Although the concept may seem straightforward, defining operational excellence can be a complex task (Barthelmie et al., 2010). In today's dynamic business environment, harnessing data across various functions and processes is essential to stay ahead of the competition (Porter & Heppelmann, 2014). Companies must leverage data to drive operational improvements and support strategic decision-making (Brynjolfsson & McAfee, 2014).

The offshore wind industry can greatly benefit from applying the principles of operational excellence to optimize the design and operation of wind farms (Musial et al., 2016). By reducing downtime and operational costs, improving energy production, and enhancing safety measures, companies can strengthen their competitive position and foster growth in this growing sector (Barthelmie et al., 2010).

By implementing operational excellence, organizations within the offshore wind industry can unlock a numerous of benefits. By streamlining processes and improving efficiency, companies can outperform their rivals and establish a strong foothold in the market with enhanced competitiveness (Porter & Heppelmann, 2014). As operational excellence leads to higher revenues and reduced costs, organizations can reinvest their resources into expanding their operations and capturing a larger share of the market by increased growth (Koller, Goedhart, & Wessels, 2020).

Operational excellence is a vital strategy for organizations seeking to thrive in the offshore wind industry (Kühn et al., 2022). By focusing on efficiency, consistency, and safety, companies can increase their competitiveness and drive growth in this rapidly expanding market (Levitt, 2002).

3. Methodology

In this following section the methodology and research design will be discussed and presented. First the choice of method and research design will be argued for, the following section will provide reader with information on how the study was conducted and how data was gathered and analyzed. Finally, validity and reliability of the collected data will be considered as well as some ethical reflections.

3.1 Research design

When conducting a study, one must choose an approach and a plan to conduct the study which is called research design. Research design is the strategy you decide for your study and to ensure you address you research question a proper way. The research design includes method and procedure for collecting and analyzing data. The research design should help the researcher to collect data with a method that fits the research question (Jacobsen, 2015). This section will explain the chosen research design and why it was chosen.

We have chosen to follow Poth & Creswell (2018) principles of case study and will in the next section argue for the following choices.

There is made a distinction between qualitative and quantitative method for research, although these can also be combined. Quantitative data involves the collection and analysis of numerical data while qualitative on the other hand involves the collection of words and is used to explore and understand people's experiences and perspective in more in-depth way. Qualitative method is used when you want to understand a phenomenon and why it occurs (Poth & Creswell, 2018, s. 47). Furthermore, qualitative research is conducted because a problem needs to be explored and one need a detailed understanding of the complex issue (Poth & Creswell, 2018, s. 47). We have chosen qualitative approach for this study. The reason for not choosing quantitative method is that it often involves the use of numerical data and statistical analysis, which can make it difficult to capture the complexity and nuance of a phenomena, while qualitative method allows the researcher to delve deeper into complexities which fits the purpose of this study better.

Moreover, we have chosen abductive method. There already exist theory (deductive) about the topic that could give us a starting point followed by a collection of data (inductive).

Research is often made in a continuous process combining both inductive and deductive, and therefor called abduction (Jacobsen, 2015).

3.2 Case study

The chosen approach for this study is a collective case study which is defined as a qualitative approach where the researcher investigates a bounded system or several over time by using in depth data collections through multiple sources of informants as observation or interviews (Poth & Creswell, 2018). Yin (2014) also describes case studies as an in-depth, multi-faceted exploration of complex issues in real-life settings. Moreover, case studies give the research the ability to understand the context and complexity of the phenomena they are studying by being provided detailed qualitative data. Case studies remain as a valuable tool in many research fields. They provide a rich source of data and the potential for unique insights into complex phenomena, human behavior, and decision-making processes (Flyvbjerg, 2006). These collective case studies will be in form of in-depth interviews with informants from central roles working in the Norwegian Energy sector and Academia. Case studies are valuable for their detailed examination of specific situations or individuals.

It must also be mentioned that there are some limitations to this approach. The findings in case studies may not be broadly applicable due to their narrow focus, limiting their generalizability. Subjectivity is another concern, as the researcher's interpretation can inherently influence the outcomes. The process of conducting a case study can be time-consuming and require significant resources, which can be a deterrent. The volume of data collected can sometimes be overwhelming, making thorough analysis and meaningful interpretation challenging. There's also a risk of overemphasizing a specific case or outlier, potentially leading to biased conclusions. The unique circumstances that influence data in case studies may hinder the reliability of the findings and their ability to be replicated. Due to limited time, this study relies on data gathered from interviews at one fixed point instead of a longer period. Preferably, a mix of method of longer period could get a large sample of data and affect the reliability, due to limited time and resources this was not possible for this research. However, the amount of data gathered from this study from valid resources should be sufficient for the purpose of this study.

3.3 Data collection

The data collected is defined as primary source of data in this study. The data is gathered by conducting ten in-depth interviews from different companies in the value chain of the offshore wind industry. The interviews were conducted via video calls on Teams using recording. The informants consented to the recording and none of them has withdrawn their consent. These interviews were transcribed shortly afterwards, and notes were made during the interviews. The transcribing resulted in 59 pages in MS Word.

The interviews were structured in a semi-structured way as this research method gave us the opportunity to explore the topic in more depth and gather more rich and detailed data. In the interview guide a general outline of topic and questions was predefined but this method allows the researcher more flexibility in the direction of the conversation (Yin, 2003). We chose to build the interview like semi structured to be able to have a more natural tone in the interview and allow the interviewees to talk open and freely about the topics. In this way it also gives the researcher the opportunity to get into the subject matter based on the flow and that contributes to create a safe dialogue while the interviewees so that they can express their honest opinions. The interview guide is attached in Appendix 9.1, however it is worth highlighting that the guide does not provide full insight due to the chosen method, but it covers the main topics all interviews touched upon. Secondary data will come from information gathered from company websites, articles, reports, and other relevant studies.

3.4 Informants and selection

We chose to interview 10 participants that have an impact in the business and is employed by companies that are leading the way within offshore wind. The informants were contacted through our own network or through LinkedIn. It must also be mentioned that identify the right interview candidates are time consuming. There was also a list of asked candidates that said no because they did not want to comment on behalf of their company. In addition, it is easier to get accept from candidates that there is some sort of relation or greeting beforehand.

Interview number	Company Category	Company Size	Duration of interview
Interviewee 1	Service	Medium	53 minutes
Interviewee 2	Operator	Large	27 minutes

Interviewee 3	Government	Medium	54 minutes
Interviewee 4	Service	Medium	40 minutes
Interviewee 5	Academia	Medium	36 minutes
Interviewee 6	Service	Large	43 minutes
Interviewee 7	Operator	Small	26 minutes
Interviewee 8	Service	Medium	32 minutes
Interviewee 9	Service	Small	39 minutes
Interviewee 10	Operator	Large	50 minutes

Table 1 – List of interviews

Table 1 summarize the conducted interviews, industry category, duration and size/role anonymized. The company category and size are not a predefined standard categorization but a rather an indication for the reader in this specific study.

3.5 Coding

Coding data is an important and crucial step in the analysis process and will help the researcher make sense of large amount of data and possible draw meaningful conclusions or prosed hypothesis for future research (Saldaña, 2021).

Template Analysis by Brooks & King (2014) was chosen as coding method for the transcribed interviews for this study. The coding method was chosen to be able to perform the analysis and is often used in relation to case studies. Moreover, this technique is a thematic analysis meaning that more specific themes narrowed or nested in within wider themes. The template can be developed in a excel sheet identifying themes and sorts the text in an understandable way.

Template analysis has six steps (Brooks & King, 2014):

1. Define predetermined themes (a priori themes)
2. Transcribe and read the interviews (or other data sources) carefully
3. Initial coding
4. Create your initial code template
5. Further develop your code template as you apply it to the entire dataset
6. Interpret data and discuss findings

The data was carefully handled by going through the data and highlighting and marking relevant themes within each category (research topics). First the transcription of the recording was done shortly after the interview and has been transcribed word by word. Each interview was done in English. The transcribed data was gathered in a excel sheet and organized in a matrix where the content was categorized.

Because of confidentiality and company policy the interviews were as mentioned anonymized. Therefor the complete set of the template for coding and the transcripts will not be included in the appendix. However, quotes and categories will be included in the analysis and attached in Appendix 9.2.

3.6 Trustworthiness

The choice of method will affect the quality of the study and it is therefore important to discuss different criteria to consider if the findings and conclusion in our study is to be trusted. To evaluate if the study is trustworthy and whether findings can be trusted Lincoln & Guba (1985) uses four terms: *credibility*, *transferability*, *dependability,* and *confirmability.*

3.6.1 Credibility

In terms of credibility, it is a measure of whether the data and findings are correct. There are numbers of tools that can be used to increase the credibility of the study. Long-term involvement, continuous observation, triangulation, negative case analysis and constant comparison are examples on techniques that can be used to increase the credibility (Poth & Creswell, 2018).

In this study we conducted interviews and have in addition gathered theory from different literature sources and reports, in this way triangulation is covered. Observation is to some degree also covered in the interviews based on informant’s experience.

3.6.2 Transferability

Transferability measures whether the study results are applicable within other settings. Yin (2014) describes how replication logic can be used in multiple case studies where the analyze is repeated and findings are compared. However, transferability can also be demonstrated with thick description which means to provide adequate details about the research method like participants and the process on how data is collected.

The findings in the study are compared with theory and sorted by theme and categories in the analysis. Each of the themes are compared and discussed upon existing literature. During our last 2-3 interviews we noticed that some of the same information was mentioned and identified in our analysis. In this way we could predict that our research has achieved saturation of information.

3.6.3 Dependability

This criterion requires an external evaluation of the research process (Lincoln & Guba, 1985; Poth & Creswell, 2018). The meaning is to measure or proof the consistency and reliability of the study. The method should be precisely written in terms of data collection, analysis and the contextual information should be thoroughly described so that the study can be repeated by other research and provide same generic results.

During this study we have discussed and sparred with our supervisor. In addition, we attended a method course and had some discussions with the lecture to verify our research design.

3.6.4 Confirmability

The confirmability means to have an external evaluation of the confirmability, meaning the study be confirmed by other researchers (Lincoln & Guba, 1985; Poth & Creswell, 2018). Moreover, Poth & Creswell (2018) discuss that the researcher wants to prove that the research is neutral and objective, not influenced by assumptions. One can use audit trail and describe the research process to illustrate that the findings are not influenced by assumptions or bias but actual portray the participants response.

Interviewed participants are asked through network and LinkedIn. In that way, they would have no relation to the researchers and hopefully answered in a neutral way. However, all interviews were conducted in English which might have affected some informant in elaborating their answers. In addition, there is given a detailed description of the research process together with transcriptions to cover the confirmability in the study.

3.7 Ethical reflections

As a researcher one is obliged to follow general research ethics guidelines and take ethical considerations into account when conducting interviews (Poth & Creswell, 2018) Since this is still an early phase in the industry both company name and name of interview object has been anonymized and will if necessary be cited according to numbers or category of company from Table 1. The confidentiality has been an important factor for the interviews candidates as well.

The thesis complies with NSD requirement of handling personal information and NSD have approved the submitted information to be in accordance with the privacy legislation. The interviews have been conducted anonymously without handling personal data.

All participants were informed in advance about the purpose of the thesis before they committed to the interview. Before starting the interview and recording, participants were reminded of the confidentiality and anonymity. In addition, they agreed to carry out the interview in English. The candidates were informed and gave their consent that the interview was recorded. Moreover, they were informed when the record started and stopped. In addition, they were informed that the records will be deleted when thesis is completed 2nd of June 2023. Neither is names or companies mentioned in the notes to ensure anonymity so they will not be possible to be identify.

4. Analysis

The following section will present the findings derived from the conducted interviews. The data will be presented in a thematic order with focus on five priority themes, (1) General thoughts of offshore wind, (2) Digitalization, (3) Industry 5.0, (4) Multidimensional success criteria and (5) Operational excellence. Within each section, we have identified relevant perspectives and viewpoints through the process of coding. It was determined that providing an overview of the principal discoveries was the most appropriate approach, even though some nuances may have been overlooked. The data used is an extract of concepts and quotes from the informants which are attached in Appendix 9.2 in same thematic order. Here the reader can find the essence, while only perspectives is presented in each theme in this chapter. The following figure provides a clearer overview of how the five themes attempt to address the primary questions, while also illustrating the complexities of their interconnectedness.

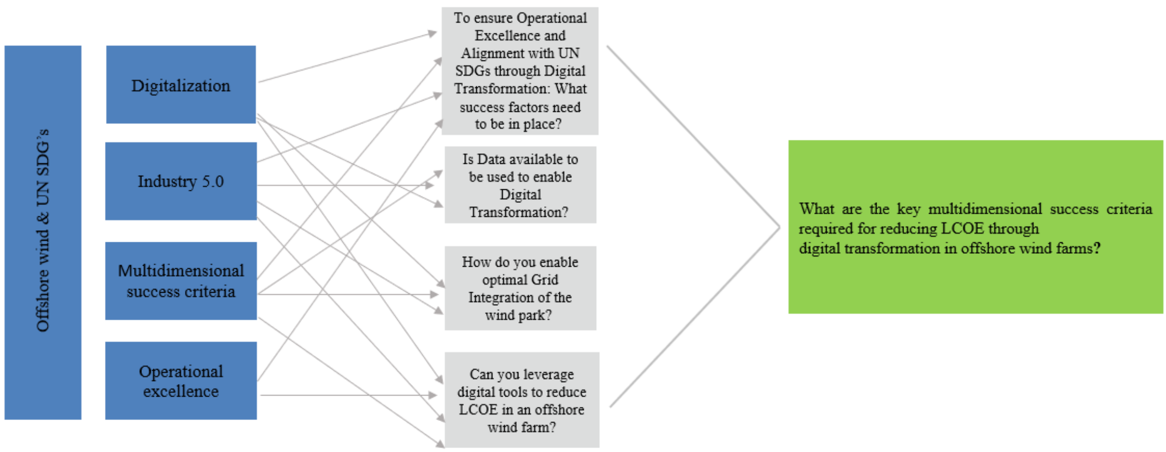

Figure 13: Framework for priority theme and research question connection (Andersen & Reilstad, 2023).

4.1 Priority theme #1 General thoughts of offshore wind

In the beginning of the interviews, the informants were asked about their general thought on offshore wind and their understanding of the industry's future. The priority theme of the analysis is General, with second-order themes of *Thoughts*, *Offshore strategy, and UN's sustainability goals.*

Thoughts

Informants (1-10) express optimism towards offshore wind as a necessary and promising solution to reduce climate change and meet energy demands. They also highlight the importance of diversifying energy sources and developing renewable energy quickly.

Offshore strategy

Regarding offshore strategies, the informants express that the respective companies have set ambitious goals for installed capacity, and they are investing in renewables to become leading players in the industry. Some companies are looking to replicate their success in oil and gas by delivering complementary value propositions in the offshore wind market.

UN's sustainability goals

In terms of UN sustainability goals, informants recognize their importance and understand their impact on policymaking. Many companies contribute directly or indirectly to these goals, with a focus on renewable energy and energy security. However, some informants suggest that the UN sustainability goals may not be governing the strategy of their company.

Overall, the informants highlight the significance of offshore wind in achieving sustainability goals and reducing carbon footprint. Companies are investing in the technology and developing strategies to become leaders in the industry, while policymakers consider its role in meeting UN sustainability goals.

4.2 Priority theme #2 Digitalization

The second priority theme is digitalization. The goal is to reveal valuable insights into how technology in terms of data and digital tools can help industry challenges and improve project outcomes.

4.2.1 Data

The priority theme of the analysis is Data, with second-order themes of *Utilization, Contextualized,* and *Real-time.*

Utilization

The analysis reveals that informants recognize the potential of data for operational planning and resource efficiency, particularly in the installation and operational phases of wind turbines. Informant 2 emphasizes the need for data integration and connecting theoretical parts with practical parts. Informant 9 mentions the importance of linking asset data to metocean data for yield and production estimates.

Contextualized

The informants also highlight the need for data to be presented in a meaningful way. Informant 1 mentions the need for data to be contextualized for effective decision-making, while Informant 5 notes that data today lacks context, making it difficult to understand why alarms are raised. Informant 6 implies that there is too much information and a need for more contextualization.

Real-time

Finally, informants emphasize the importance of having access to data in real-time. Informant 4 mentions the need for real-time metric data from wind turbines for optimal measurement, while Informant 7 emphasizes the need for ocean data to be sent back to the control room in real-time.

Overall, the analysis indicates that informants recognize the potential of data for operational planning and resource efficiency, but also emphasize the importance of data contextualization and real-time access for effective decision-making. They see the need for data integration and linking of asset data to metocean data for yield and production estimates, while also acknowledging that current data lacks context and there is a need for more effective presentation and interpretation of data.

4.2.2 Digital tools

The priority theme of the analysis is Digital Tools, with second-order themes of *Digital Twin*, *Scada*, and *Artificial Intelligence*.

Digital Twin

Informant 1 sees digital twin as a key enabler for the energy transition towards renewables. Informant 5 recognizes the lack of a proper digital twin solution and is interested in selling it to operators. Informant 8 sees an opportunity for partnership with other asset-specific digital twins. Informant 10 believes that digital twin has huge potential for simulation, optimization, and automation of wind turbines.

Scada

The informants also discuss Scada systems and their importance in collecting data for predictive maintenance. For instance, informant 1 that there is Scada systems today, but one need to develop them with twins monitoring and also human oversights. Informant 2 mentions testing various digital tools, including advanced Scada systems, while Informant 8 emphasizes the need to integrate different Scada systems for maintenance and operation.

Artificial Intelligence

In terms of Artificial Intelligence (AI), informants recognize the importance of data collection and knowledge management. Informant 3 sees the potential for AI to enable good and timely decisions, while Informant 5 highlights the importance of quality data and knowledge management. Informant 9 believes that the industry is moving towards completely automated control systems with little human interaction. Finally, Informant 10 suggests the use of AI and machine learning for optimizing solutions and detecting and analyzing equipment issues.

Overall, the analysis prioritizes digital tools, encompassing digital twin, Scada, and artificial intelligence. The analysis reveals that Digital Twin is viewed as a crucial facilitator for the energy transition to renewables, with potential for simulation, optimization, and automation of wind turbines. Scada systems are important for data collection for predictive maintenance, and integration of different systems for operation is emphasized. AI's role is recognized in data collection and knowledge management, with potential to enhance decision-making, optimize solutions, and automate control systems while reducing human interaction.

4.3 Priority theme #3 Industry 5.0

The third priority theme is Industry 5.0, which aims to explore the potential influence of Industry 5.0 on the offshore wind industry and assess the sector's current knowledge and readiness for it. This theme has second-order themes of readiness and utilization.

Readiness

Readiness for Industry 5.0 is a topic of discussion among informants 1, 2, 7, and 9. They emphasize the importance of balancing technology and human aspects, recognizing that humans will continue to play a vital role in the industry for the foreseeable future. Informant 2 suggests that neither the business nor the technology is currently mature enough for Industry 5.0, while informants 1, 7, and 9 argue that the human aspect is essential for the industry to progress.

Utilization

Informants 7, 8, and 9 discuss the utilization of Industry 5.0 concepts in the offshore wind sector. They mention the potential benefits of using IoT and connected wind farms to improve operations, as well as the trend towards completely automated control systems with minimal human interaction. Moreover, informant 9 highlights the role of Industry 5.0 as an enabler, providing the ability to capture, process, and contextualize vast amounts of disparate data in a short amount of time using advanced tools.

In summary, not all the informants are thoroughly familiar with the term Industry 5.0, they still recognize its importance in the professional context and acknowledge its potential impact on the offshore wind industry. The informants emphasize the need for a balance between technology and human expertise to ensure the successful implementation of Industry 5.0 concepts.

4.4 Priority theme #4 Multidimensional success criteria

The fourth priority theme is multidimensional success criteria. As this is the main part of the research question it was important to identify what the informants identified as success criteria based on their experience. The informants identified several success criteria for the offshore wind industry, which can be categorized into four second-order themes: *Scale, Operation uptime, Data collaboration, and Knowledge & competence*.

Scale

Informants 1, 2, 8, 9, and 10 identifies scale as a critical factor for the success of offshore wind projects. Informant 1 raise the challenge that focuses on how to maximize profitability. Moreover informant 2 point out that there will be a lot of growing pains. In addition, the informants emphasize the importance of maximizing profitability, ensuring sufficient project volumes, and addressing supply chain challenges to facilitate industry growth. Informant 9 also highlight the need for more steady projects to continue to build the industry.

Operation uptime

Operation uptime is another critical success factor mentioned by informants 1, 3, 5, 6, 8, and 10. They agree on the need to optimize operations to minimize downtime, maintain high uptime, and ensure profitability. Informant 1 highlight the need to optimize operation so the running cost can be handled. Furthermore, both informants 6 and 8 emphasize the operation uptime as main measurement. Finally, informant 10 suggests considering innovative maintenance approaches, such as towing floating turbines back to shore for maintenance.

Data collaboration

Informants 1, 2, 3, 4, 7, 8, and 10 discussing the need for improved data sharing and cooperation among industry players and identify data collaboration as a critical success factor. They mention the current protective stance of large turbine manufacturers and the lack of collaboration, emphasizing that data sharing is essential for multi-dimensional optimization and industry growth.

Knowledge and competence

Knowledge and competence also play an important part in this context, as mentioned by informants 2, 3, 5, 6, 7, 8, and 10. They point out the importance of having skilled personnel to operate wind farms, maintaining a balance between complexity and competence, and focusing on quality data and knowledge management. Additionally, they discuss the potential of using virtual reality or simulators for training purposes and the need to increase knowledge and competence at both company and industry levels.

Overall, scale is identified as a critical success factor, with focus on maximizing profitability, ensuring sufficient project volumes, and addressing supply chain issues to boost industry growth. Operation uptime is another key factor, where the need to optimize operations to minimize downtime and maintain high uptime is stressed for ensuring profitability. The research also highlights the importance of data collaboration, suggesting improved data sharing and cooperation among industry players for multi-dimensional optimization and industry growth. Lastly, the importance of knowledge and competence is underscored, with emphasis on skilled personnel, quality data, knowledge management, and the potential of virtual reality for training. These factors collectively contribute to the industry's growth and multi-dimensional optimization.

4.5 Priority theme #5 Operational excellence

The final priority theme is operational excellence, and, in this regard, it was important to understand the underlaying operational challenges and opportunities to gain a comprehensive perspective of the research question.

4.5.1 Operational Challenges

The informants identified several challenges related to offshore wind energy, which were categorized into four main second-order themes: *cost*, *complexity*, *silos*, and *infrastructure*.

Cost

Cost is identified as one of the main challenges and was mentioned by all informants during the interviews. As informants 4 and 5 point out, there are extremely high costs involved when entering a new industry, and the cost offshore is 10-20 times higher than onshore due to complexity. According to informants 1, 2, and 8, the challenge is also related to profitability, especially during operation. Informant 10 also point out that waiting on the ‘right’ weather during operation and maintenance is a big cost driver.

Complexity

Another important aspect is the complexity around offshore wind. Informants 4 and 9 highlight the complexity around the supply chain harbor and vessels in specific, and how to align all the different parts and standardize it. Informants 6, 7 and 10 also highlight the complexity around maintenance, which requires good instrumentation and digital applications. Informant 10 highlights the challenge of poor communication, procedures, and responsibilities in the wind industry. It is mentioned that regulations from the government are lacking, and developers and operators must set the regulations themselves, which leads to uncertainty and drives up costs.

Silos

A third second-order theme identified is silos within the industry. Informants 1, 2, 4, 5, 6 and 10 agree that silos exist today and specify that many operate in silos because of competition and the desire to create an internal edge. Informants 5 and 6 emphasize that there is many silos thought the value change today. Moreover, informants 8 and 9 add that there is little data collaboration and that industry players need to come together to find the most economical way and work together.

Infrastructure

A fourth second-order theme that was identified is infrastructure. All informants agree that critical infrastructure is one of the biggest challenges to overcome. Informant 5 highlight that for new projects where there is no nearby infrastructure, there will be a CAPEX need when installation is made, both on the grid side to shore and on the security and supply chain side. In Norway and other countries where there is already built-out offshore infrastructure in the petroleum industry, utilizing this will be one of the drivers keeping the overall CAPEX needed down, say informants 8 and 9.

Overall, the informants identified multiple challenges within the offshore wind energy sector. High costs, particularly related to entering the new industry and offshore operations, were emphasized, with weather-dependent maintenance being a significant cost driver. Complexity, especially around supply chain management, maintenance, and lack of clear regulatory guidelines, was another issue highlighted. The industry's siloed nature, driven by competition and lack of data collaboration, was seen as an obstacle to finding economical solutions. Finally, the necessity for robust infrastructure, particularly in new projects without nearby facilities, was underscored, although leveraging existing offshore infrastructure could help minimize capital expenses.

4.5.2 Operational Opportunities

The informants discussed operational opportunities for offshore wind energy, which were categorized into the second-order theme of *grid integration* and *data-based decision.*

Grid integration

Grid integration is a significant opportunity and challenge in the offshore wind industry. Informants 1, 2, 3, 5 6, 7, and 8 mention the difficulties in integrating the variable and sometimes unpredictable energy output from offshore wind farms into the existing grid system. Additionally, they highlight the importance of having a grid that can handle the potential influx of energy from offshore wind sources. Informants 1, 3, 5, and 7 emphasize the need for better tools and systems to optimize grid integration, including condition-based monitoring, digital twins, and improved infrastructure. Informant 1 suggests that working with stakeholders to develop these tools will be essential for addressing grid integration challenges. Informant 3 mentions the importance of having enough data to optimize the power system, while Informant 5 highlights the need for a comprehensive digital twin to help address grid integration challenges.

Informants 2, 6, and 8 raise concerns about the current grid's capacity to handle the additional energy from offshore wind farms. Informant 8 specifically mentions the UK market, where more licenses have been issued than there is grid capacity to accommodate. This highlights the need for careful planning and investment in grid infrastructure to support the growth of offshore wind energy.

Data-based decision

In terms of operational opportunities related to data-based decision-making, informants 1, 4, 7, 8, 9, and 10 have provided their perspectives recognize the potential of using data and technology to improve wind energy operations and identify several ways to achieve this. Informant 1 points out the potential for integrated digital twins, which can simulate and optimize wind turbines and farms. Informant 4 emphasizes the importance of data integration and optimization for decision-making, but also notes that it takes time to get there. Informant 7 highlights the role of technology as an enabler for enhancing operational efficiency, especially in remote locations. Informant 8 stresses the need to consider the entire farm and multiple farms in the digital system to improve efficiency, and notes that wind energy operations differ from oil and gas operations. Informant 9 points out the importance of contextualizing different subsystems in a farm-scale digital solution to identify inefficiencies, while Informant 10 notes that adding automation and AI has significant potential for optimizing wind energy operations, but it is currently underutilized.

In summary, grid integration is a critical challenge and opportunity for the offshore wind industry. To address this issue, industry players need to invest in improved tools, systems, and infrastructure, collaborate with stakeholders, and develop strategies to optimize grid integration for offshore wind energy. The informants highlight that while there are challenges associated with grid integration and data-based decision-making, there is a significant potential for technological advancements to enhance operational efficiency.

5. Discussion

This chapter aims to provide a discussion of the empirical findings obtained from interviews in Chapter 4 Analysis in relation to the theoretical framework in Chapter 2. This chapter will examine each priority theme utilized in Chapter 4 analysis and explore them separately. Each priority theme will be summarized by evaluating the degree of concurrence between the theoretical constructs and the empirical evidence, as well as the significance of these findings for project impact.

5.1 Priority theme #1 General thoughts on Offshore Wind

Thoughts on Offshore Wind

The interviewees' optimism towards offshore wind as a crucial and promising solution to tackle climate change and meet energy demands aligns with the theoretical framework. The development of offshore wind power can significantly contribute to SDGs 7, 13, and 8 by increasing the share of renewable energy in the global energy mix, reducing greenhouse gas emissions, and creating job opportunities, respectively (United Nations, 2023). These findings indicate a strong concurrence between the theoretical constructs and the empirical evidence, emphasizing the importance of offshore wind power in addressing global challenges.

Offshore Strategies

The analysis reveals that companies have ambitious goals for installed capacity and are investing in renewable energy to become leading players in the industry. This is in line with the theoretical framework, which highlights the need for innovative technologies such as floating wind turbines and advanced blade designs (Carbon Thrust, 2022). The empirical findings imply that companies are aware of the potential benefits of offshore wind power and are strategically positioning themselves to capitalize on this emerging market.

The informants' observation is that some companies are looking to replicate their success in oil and gas by delivering complementary value propositions in the offshore wind market and reflects the need for a transition from fossil fuels to renewable energy sources. This aligns with the theoretical framework emphasizing the importance of balancing offshore wind power development with other SDGs, such as SDG 14, which focuses on protecting marine ecosystems and biodiversity (United Nations, 2023).

UN's Sustainability Goals

The informants recognize the importance of the UN sustainability goals and their impact on policymaking. They also note that many companies contribute directly or indirectly to these goals, focusing on renewable energy and energy security. However, some informants suggest that the UN sustainability goals may not be governing the strategy of their company. This highlights a potential gap between the theoretical constructs and the empirical evidence, indicating that some companies may not fully integrate the SDGs into their strategic decision-making processes.

Nevertheless, the overall findings demonstrate a significant degree of concurrence between the theoretical constructs and the empirical evidence. The informants emphasize the importance of offshore wind power in achieving sustainability goals and reducing the carbon footprint, which supports the theoretical framework's emphasis on the potential contributions of offshore wind power to the SDGs. In summary, the discussion of empirical findings from the interviews in relation to the theoretical framework highlights the potential of offshore wind power to contribute to several UN Sustainable Development Goals. Companies are investing in the technology and developing strategies to take part of this industry, while policymakers consider its role in meeting these global goals. The degree of concurrence between the theoretical constructs and the empirical evidence, along with the significance of these findings for project impact, underlines the importance of offshore wind power as a key solution to address global energy challenges and create a more sustainable future.

5.2 Priority theme #2 Digitalization

5.2.1 Data

The concept of data refers to the collection, storage, and analysis of information that can be used to inform decision-making. The findings from the empirical evidence highlights the importance of data in monitoring and optimizing the performance of wind turbines.

Utilization

According to Vandenberge (2017) the right use of data in operational context of windmills can have many benefits. The data can be used to optimize the operation of the windmill and ensure that it is generating electricity as efficiently as possible. There seem to be a consistency between the informants that the industry is not using all the data available today. Furthermore, the informants argue the unique potential of data for operational planning and resource efficiency, particularly in the installation and operational phases of wind turbines.

Contextualized

The informants recognize the importance of contextualized data for effective decision-making. For example, the informants mention the need for data to be enriched with contextual information such as timestamps, turbine identification, environmental factors, and turbine operational status, which enables them to analyze wind speed variations, compare the performance of different turbines, understand the impact of environmental factors, and correlate wind speed data with the performance of specific turbines. This is supported by Chen et al., (2012) which also argue that contextual information can lead to more accurate analysis, insights, and decision-making.

Real-time

The concept of real-time data refers to the collection and analysis of data in real-time, providing operators with accurate and timely information about the performance and condition of wind turbines and other equipment (Sprenger, 2017). The informants confirm the importance of real-time data for optimal measurement, performance monitoring, and condition-based maintenance. The informants emphasize the need for real-time metric data from wind turbines and the importance of ocean data being sent back to the control room in real-time.

In summary, the analysis reveals that informants recognize the potential of data for operational planning and resource efficiency, but also highlight the importance of data contextualization and real-time access for effective decision-making. By leveraging these concepts, the wind energy industry can optimize the performance of wind turbines, reduce costs, and improve overall efficiency. However, as Mathieson (2022) argues the industry is just in the beginning of understanding this and to allow technology to work effectively, the data and software used in wind power will need to become even more powerful.

5.2.2 Digital Tools

The informants highlight the potential benefits of digital tools, such as digital twin, Scada systems, and Artificial Intelligence, for the offshore wind industry. In the chapter of theory Lankshear & Knobel, (2005) describes how these tools have transformative implications for the industry by enabling better decision-making, automation, and overall efficiency.

Digital twin

Digital twin is described in the theory as a model-based representation of real asset trained or developed using real-data (LeBlanc & Ferreira, 2020). One significant tool discussed by informant in the analysis is digital twin. Informants recognize the potential of digital twin for simulation, optimization, and automation of wind turbines. They also see it as a key enabler for the energy transition towards renewables. The lack of a proper digital twin solution is also acknowledged, indicating an opportunity for further development and implementation.

Scada

Scada systems are another critical tool discussed in the analysis, and their importance in collecting data for predictive maintenance is recognized. SCADA systems play a crucial role in the offshore wind industry, providing real-time data to enable effective decision-making and optimize performance (Wind Energy The Facts, 2009). Informants suggest testing various digital tools, including advanced Scada systems, and integrating different Scada systems for maintenance and operation as an important part.

Artificial Intelligence

Artificial Intelligence is acknowledged as an important tool for data collection and knowledge management (Hastie et al., 2009; Russell et al., 2010). Informants see its potential for enabling good and timely decisions, optimizing solutions, and detecting and analyzing equipment issues. The informants also suggest the use of AI and machine learning for optimizing solutions and detecting and analyzing equipment issues.

In summary, the significance of these findings highlights the potential benefits of digital tools for the offshore wind industry, such as digital twin, Scada systems, and Artificial Intelligence. These tools can improve efficiency, reduce costs, enhance safety, and optimize operations Mathieson (2022). The findings highlight the need for further development and implementation of these tools to fully realize their potential in the offshore wind industry.

5.3 Priority theme #3 Industry 5.0

The concept of Industry 5.0 is considered the next evolution of Industry 4.0 adding the human aspect and is in this section presented with two second order themes readiness and utilization. Thereby a section of the potential impact of industry 5.0 on the offshore wind industry is discussed.

Readiness

Readiness for Industry 5.0 is a topic of discussion among informants 1, 2, 7, and 9. They emphasize the importance of balancing technology and human aspects, recognizing that humans will continue to play a vital role in the industry for the foreseeable future which is also supported by Jafari et al, (2022). Informant 2 suggests that neither the business nor the technology is currently mature enough for Industry 5.0, while informants 1, 7, and 9 argue that the human aspect is essential for the industry to progress.

Utilization

Informants 7, 8, and 9 discuss the utilization of Industry 5.0 concepts in the offshore wind sector. They mention the potential benefits of using IoT and connected wind farms to improve operations (Chen et al., 2012) as well as the trend towards completely automated control systems with minimal human interaction (Gartner, 2021). Moreover, informant 9 highlights the role of Industry 5.0 as an enabler, providing the ability to capture, process, and contextualize vast amounts of disparate data in a short amount of time using advanced tools (Wang et al., 2023).

While not all the informants are thoroughly familiar with the term Industry 5.0, they still recognize its importance in the professional context and acknowledge its potential impact on the offshore wind industry. The informants emphasize the need for a balance between technology and human expertise to ensure the successful implementation of Industry 5.0 concepts (Alexa et al., 2022).

The Potential Impact of Industry 5.0 on the Offshore Wind Industry

Industry 5.0 technologies have the potential to significantly improve efficiency, reduce costs, and enhance safety and environmental performance in the offshore wind industry compared to the use of Industry 4.0 technologies (Schwab, 2016). By emphasizing the human aspect and incorporating sustainability and resilience, Industry 5.0 technologies can help drive the future development of the offshore wind industry (Jafari et al., 2022).

Potential applications of Industry 5.0 technologies in the offshore wind industry include more accurate and sophisticated monitoring of wind turbines and other equipment (Li et al., 2022), improved safety through advanced robotics and automation technologies (Gartner, 2021), optimization of wind farm layouts (Li et al., 2022) increased grid flexibility, and better collaboration between different stakeholders within the industry (Jafari et al., 2022).
In summary, the use of Industry 5.0 technologies in the offshore wind farm industry has the potential to significantly improve efficiency, reduce costs, and enhance safety and environmental performance compared to the use of Industry 4.0 technologies (Schwab, 2016). By emphasizing the human aspect and incorporating sustainability and resilience, Industry 5.0 technologies can help drive the future development of the offshore wind industry (Alexa et al., 2022).

5.4 Priority theme #4 Multidimensional success criteria

According to Shenhar & Dvir (2007) multidimensional success criteria refer to a set of criteria that are used to evaluate the success of a project or initiative in multiple dimensions or aspects. This means that the success of the project is not judged based on a single metric or criterion like time, cost, and scope, but rather on a range of different factors that is linked to the companies' objectives and long-term strategy. In the interviews, there was a general opinion that this area is complex and must be seen in a wider picture in terms of value creation and criteria.

Scale, Operation uptime, Data collaboration, and Knowledge & competence

Main identify different success criteria's among the informants are scale, operation uptime, data collaboration, knowledge & competence. The informants emphasized the importance of maximizing profitability and addressing supply chain challenges, optimizing operations to maintain high uptime, improving data collaboration, and increasing knowledge and competence. These factors can be seen as contributing to the success of an offshore wind project in multiple dimensions. For instance, maximizing profitability and ensuring sufficient project volumes are important for the financial success of the project. Additionally, optimizing operations to minimize downtime and maintaining high uptime are critical for the technical success of the project. This is an important factor to consider as it determines how much electricity the wind farm is able to generate. Improving data collaboration can optimize planning and decision-making. By prioritizing knowledge and competence in data collaboration, organizations can develop a skilled workforce, facilitate knowledge transfer, improve decision-making, and foster innovation, ultimately contributing to the success of offshore wind projects. Therefore, when evaluating the success of an offshore wind project, it is important to consider these multidimensional success criteria. By setting targets for each of these factors and regularly measuring progress against those targets, it is possible to effectively evaluate the success of the project and identify areas for improvement (Shenhar & Dvir, 2007).

In summary by using multidimensional success criteria, it is possible to evaluate the success of the wind farm in a more comprehensive and nuanced way, considering a range of different factors that are relevant to its operation and impact because it will provide the owners and stakeholders with a more complete picture Cooke-Davies (2002). The theory of multidimensional success criteria provides a useful framework for evaluating the success of investment projects such as offshore wind farms. By considering a range of different factors that are relevant to the project's operation and impact, it is possible to gain a more complete picture of the project's success and identify opportunities for value creation.

5.5 Priority theme #5 Operational excellence

The theory of operational excellence provides a useful framework for understanding how the offshore wind industry can address the challenges identified in the analysis. According to Bhuiyan & Baghel (2005), operational excellence is the ability to execute a business strategy with greater efficiency and consistency than the competition. Achieving operational excellence leads to higher revenue, reduced operational risk, and lower operating expenses (Porter & Heppelmann, 2014).

5.5.1 Operational Challenges

The challenges identified in the analysis, such as high costs, complexity, silos, and infrastructure, can be effectively addressed by leveraging the principles of operational excellence. By focusing on efficiency, consistency, and safety, companies can increase their competitiveness and drive growth in the offshore wind industry (Levitt, 2002).

Cost

Several informants mentioned cost as a critical challenge and that the industry needs to optimize efficiency. Addressing the challenge of cost can involve improving operational efficiency through the use of data and technology to optimize the design and operation of wind farms. This can lead to reduced downtime and operational costs, improved energy production, and enhanced safety measures, resulting in increased profitability (Barthelmie et al., 2010).

Complexity

Another critical aspect is the great complexity of offshore wind. As the findings points out the complexity regards the supply chain and vessels, the maintenance part of operation and lack of regulations. Th theoretical framework also highlight that the challenge of complexity can involve streamlining the supply chain through standardization and improving instrumentation and digital applications for maintenance, leading to greater consistency and efficiency in operations (Musial et al., 2016).

Silos

A third second-order theme identified is silos within the offshore wind industry. The findings confirm that there is a strong consensus about the already established silos in the industry and that it prevents collaboration and good synergies. Addressing the challenge of silos can involve greater collaboration and data sharing among industry players to achieve greater alignment and improved decision-making. This can help companies to identify and eliminate redundancies, leading to greater efficiency and reduced operational costs (Brynjolfsson & McAfee, 2014).

Infrastructure

Finally, critical infrastructure was identified as one of the biggest challenges to overcome, also emphasizing the need of CAPEX when the installation is made. Focusing on the challenge of infrastructure can involve a comprehensive plan that leverages existing infrastructure and establishes new infrastructure as needed. This can help to reduce capital expenditure and improve the overall sustainability of the industry (Koller et al., 2020).

In summary, by leveraging the principles of operational excellence, companies in the offshore wind industry can improve their competitiveness, drive growth, and achieve greater sustainability by addressing the identified challenges in the empirical findings such as cost, complexity, silos, and infrastructure. These are some challenges that the industry must overcome to maximize profitability.

5.5.2 Operational Opportunities

The findings suggest that the offshore wind industry can greatly benefit from implementing the principles of operational excellence, particularly in the areas of grid integration and data-based decision-making. Musial et al. (2016) confirms that achieving operational excellence leads to higher revenue, reduced operational risk, and lower operating expenses, which are critical benefits for companies in the offshore wind industry. However, defining operational excellence can be a complex task (Barthelmie et al., 2010), and companies must utilize data across various functions and processes to stay ahead of the competition (Porter & Heppelmann, 2014).

Grid integration

Grid integration is identified as a significant opportunity and challenge in the offshore wind industry. Informants highlight the difficulties in integrating the variable and unpredictable energy output from offshore wind farms into the existing grid system, and the importance of having a grid system that can handle the potential influx of energy from offshore wind sources. Better tools and systems, including condition-based monitoring, digital twins, and improved infrastructure, are needed to optimize grid integration, according to informants. This is supported by Kühn et al., (2022) highlighting the need for careful planning and investment in grid infrastructure to support the growth of offshore wind energy.

Data-based decision-making

In terms of data-based decision-making, informants recognize the potential of using data and technology to improve wind energy operations, which is consistent with previous research (Brynjolfsson & McAfee, 2014). Informants suggest that integrated digital twins can simulate and optimize wind turbines and farms, while data integration and optimization are crucial for decision-making. The informants states that technology is seen as an enabler for enhancing operational efficiency, particularly in remote locations, and the need to consider the entire farm and multiple farms in the digital system is emphasized. The potential for automation and AI to optimize wind energy operations is also noted, which is consistent with previous research (Levitt, 2002), but is currently underutilized.

In summary, these findings demonstrate the importance of operational excellence in the offshore wind industry, particularly in optimizing grid integration and data-based decision-making. By streamlining processes and improving efficiency, companies can outperform their rivals and establish a strong foothold in the market with enhanced competitiveness (Porter & Heppelmann, 2014). The findings suggest that the offshore wind industry can benefit from embracing operational excellence as a vital strategy for organizations seeking to thrive in this rapidly expanding market.

5.6 Framework operational excellence

The operational excellence model is a self-developed framework, designed specifically for this research. It was built on the deep understanding through this study of the offshore wind industry, the challenges, and opportunities it faces and the latest advancements in digital transformation. The framework captures our perspective on achieving operational excellence reducing LCOE through digital transformation. The framework developed for operational excellence consists of a set of critical success criteria that contribute to improving efficiency and reducing the Levelized Cost of Energy (LCOE) in offshore wind farms. The model's strengths lie in its comprehensive approach and multidimensional criteria, which encompass digital tools, data management, collaboration, and human input. It is also adaptable and considers the evolving landscape of Industry 5.0. On the downside, the model's complexity could be a weakness, as it might require significant resources to be implemented fully. Additionally, as it is built on current knowledge and technology, it may need constant updating as the field advances. The framework is only intended as a starting point for further development.

The model fits into the context of this research, which aims to investigate how digital transformation can reduce LCOE in the offshore wind energy sector. The operational excellence model, with its focus on adaption of digital tools, strategic data usage, data optimization, and commitment to sustainability, directly addresses the research question. It provides a framework for understanding and implementing strategies to reach the objective. CAPEX and OPEX are included in the model because they are fundamentals elements in the financial and decision-making process of any business and industry. The LCOE, which is a crucial metric in your study, is heavily influenced by both CAPEX and OPEX. CAPEX impacts the initial cost of setting up a wind farm, whereas OPEX influences the ongoing costs of running it. Lowering either or both can contribute to reducing the LCOE. In addition, it gives companies the opportunity to identify areas for optimization. The elements contribute to provide a more holistic, accurate, and actionable view of operational efficiency of offshore wind farms.

The model serves as a guide for future studies to understand and evaluate operational efficiency within offshore wind farms. It outlines potential areas of improvement and innovation in digital transformation efforts, allowing future research to build upon these aspects. Future research could also use the model as a benchmark for comparisons or to test the model's assumptions and results in different settings or contexts.

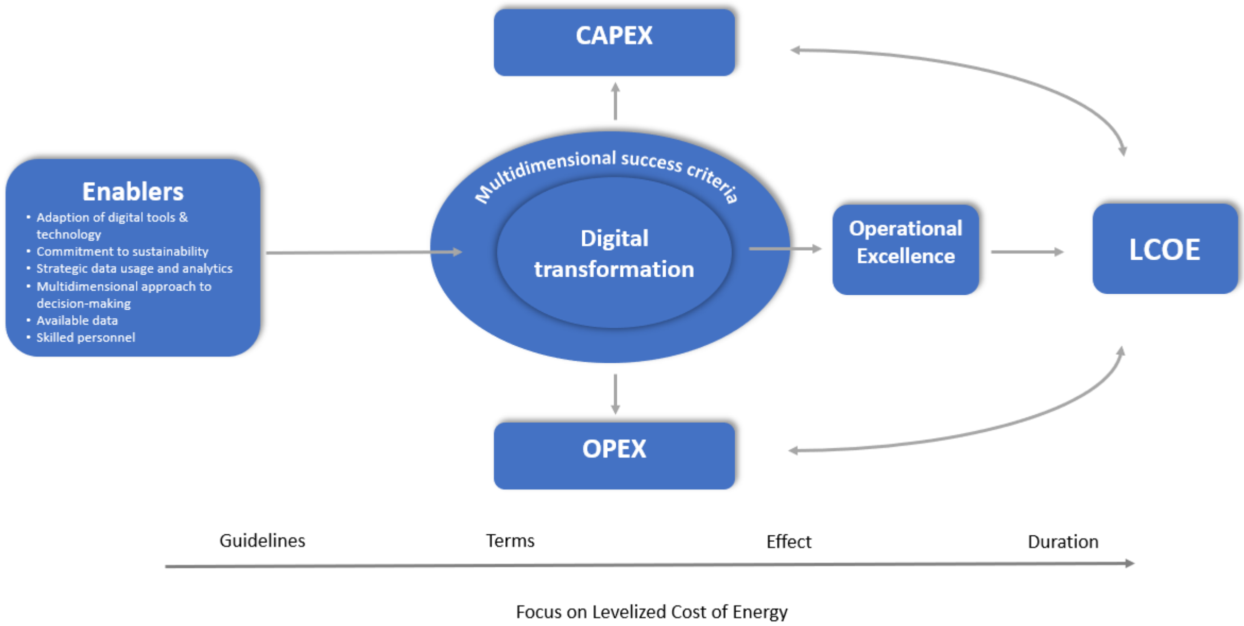

Figure 14: Framework for enabling digital transformation & critical success factors for ensuring operational excellence and LCOE reduction (Andersen & Reilstad, 2023).

6. Conclusion

The purpose of this study is to do research on *what are the key multidimensional success criteria required for reducing LCOE through digital transformation in offshore wind farms***.** The study aims to identify concrete multidimensional success criteria and by answering following preliminary research questions:

1. To ensure Operational Excellence and Alignment with UN SDGs through Digital Transformation: What success factors need to be in place?

Based on the findings and discussions, it is evident that several success factors need to be in place to ensure operational excellence and alignment with UN SDGs through digital transformation in offshore wind farms. Digital transformation in offshore wind farms, shaped by the principles of Industry 5.0, hinges upon multiple success factors. These include the adoption of digital tools like AI and digital twins, essential components of Industry 5.0 that facilitate automated decision-making and optimize operations.

A commitment to sustainability, aligning operations with UN SDGs, is essential, shifting from compliance to a strategic prerequisite for long-term value creation. This sustainable orientation, amplified by Industry 5.0's emphasis on environmental sustainability, can yield substantial operational benefits. Effective data usage and analytics improve operational efficiency, enabling companies to optimize turbine maintenance, enhance longevity, reduce costs, and contribute to a lower LCOE. This, when paired with Industry 5.0's principle of human-machine collaboration, fosters more efficient, informed decision-making processes.

Lastly, the embrace of a multidimensional perspective is crucial, ensuring that the breadth of success criteria inherent in digital transformation are considered. This approach, reflecting the holistic view promoted by Industry 5.0, allows for informed decisions about future investments, contributing to a comprehensive understanding of offshore wind project success.

In summary, the digital transformation's success, guided by Industry 5.0, rests upon strategic digital tool utilization, a strong sustainability commitment, smart data usage, and a multidimensional approach to decision-making.

2. Is Data available to be used to enable Digital Transformation?

This study verifies that data accessibility and effective utilization are key in enabling digital transformation and reducing LCOE in the offshore wind sector.

Advanced digital tools such as AI, machine learning, and digital twins, cornerstones of Industry 5.0, allow expansive data collection from varied operational aspects of offshore wind farms. This includes turbine performance, energy output, weather conditions, and maintenance schedules. Thus, such extensive data availability fundamentally improves decision-making and operational efficiency.

However, simply having data is only the initial step in digital transformation. The crucial task is to transform this raw data into actionable insights via advanced data analytics tools. These tools can identify trends, potential issues, and predict future scenarios, fostering proactive problem-solving and decision-making.

Data silos need dismantling to truly benefit from available data. Encouraging collaboration and knowledge sharing among industry stakeholders can foster a more comprehensive operational view and opportunities for multidimensional optimization.
Data availability also brings the challenge of data management and governance. As such, robust data management practices, ensuring data quality, privacy regulations adherence, and managing large data volumes, become vital.

In conclusion, while available data can enable digital transformation in the offshore wind farm industry, its effective use requires advanced digital tools of Industry 5.0, solid data analytics, cross-industry collaboration, and strong data management practices. By focusing on these areas, companies can leverage data optimally, driving digital transformation, achieving operational excellence, and reducing LCOE.

3. Can you enable optimal Grid Integration with the use of digital tools?

Our study supports the pivotal role of digital tools, as underpinned by Industry 5.0, in optimizing grid integration for offshore wind farms, with implications for LCOE reduction.

Advanced grid management software, AI, and machine learning, pillars of Industry 5.0, provide real-time data analysis and predictive capabilities that boost grid integration's efficiency and reliability. These tools help manage wind-induced energy production variations, improve power output predictability, and enhance grid stability, consequently lowering operational costs and the LCOE.

Additionally, digital twins simulate grid behavior under varying conditions, facilitating informed decisions and improved planning, thus mitigating costly grid failures or underperformance, and further lowering the LCOE. Digital tools, by allowing real-time monitoring and control, increase grid flexibility and promote effective demand-response management, mitigating overproduction, energy wastage, and subsequently, the LCOE. Advanced digital tools enhance communication and interoperability within the grid and with other renewable energy sources, enabling a more integrated, efficient energy system, reducing costs, and bolstering performance.

However, these benefits require competent personnel skilled in utilizing digital tools, underlining the human-centric focus of Industry 5.0. Proficiency in interpreting data from these tools, maintaining, and troubleshooting digital systems is paramount.
In conclusion, digital tools, when optimally used, can greatly improve offshore wind farm grid integration, leading to more reliable operation, and potential LCOE reduction. Yet, this requires skilled personnel and a holistic data management and collaboration approach, echoing Industry 5.0's principles.

4. Can you leverage digital tools to reduce LCOE in an offshore wind farm?

The evidence from our discussions and findings suggests that digital tools and data, key aspects of Industry 5.0, can markedly influence an organization's success. Employing a diverse range of success indicators allows businesses to fully comprehend the effectiveness of their digital assets and make informed decisions concerning future investments. Moreover, digital tools and data can significantly optimize offshore wind turbine maintenance, thereby enhancing turbine lifespan and decreasing operational costs.

Digitalization, within the broad construct of a digital ecosystem comprising diverse industries and an interdisciplinary environment, emerges as a vital enabler. It offers opportunities for data gathering across an entire offshore wind park, facilitating autonomous decision-making systems or providing valuable insights for optimal operation. Tools and data associated with artificial intelligence and digital twins are set to play a significant role in offshore wind projects. These enable the analysis of large volumes of data and the simulation of operational adjustments, contributing to optimized facility operations.

A commitment to sustainability is not merely an obligation, but a prerequisite for creating enduring value. Organizations should be strategically oriented to capitalize on adjustments that enhance sustainability.

By considering these multifaceted criteria, companies can develop a more comprehensive and holistic understanding of their offshore wind projects' success. This broad perspective will enable them to make informed decisions about their future operations and investments, truly embodying the human-centric approach promoted by Industry 5.0.

7. Future recommendations of work

The emergence of the digital age, characterized by a proliferation of digital tools and the advent of Industry 5.0, has provided an opportunity for a revolution in offshore wind energy production. The possibilities seem boundless; from leveraging digital twins for efficient project management to employing artificial intelligence for optimal grid integration. However, as we have seen throughout this thesis, the journey towards full digital transformation and the realization of Industry 5.0 within the offshore wind industry still holds many unexplored areas. This presents a plethora of opportunities for future research to build on the foundational work we have undertaken here.

In this chapter, we aim to set the agenda for subsequent studies, pointing towards the areas that remain less explored and that deserve attention to maximize the benefits of digital tools and Industry 5.0 for offshore wind power generation. We'll delve into several promising research topics, providing a brief overview of each, as well as reasons why these areas merit further investigation.

The intention of these future recommendations is to stimulate scholarly inquiry in directions that can generate actionable knowledge for the offshore wind industry. We strongly believe that the successful navigation of the complex interplay between digital tools, human factors, environmental sustainability, and market realities requires ongoing and future-focused research. In this pursuit, we hope the forthcoming recommendations will act as a compass, guiding future explorations to continue accelerating the digital transformation of the offshore wind industry.

Digital Twin Technology in Offshore Wind Farms

The advent of digital twin technology in the offshore wind energy sector has opened new horizons for operational efficiency and predictive maintenance. Yet, the implementation and integration of this technology in existing infrastructure calls for comprehensive research. Key questions that emerge include: how can digital twin technology be seamlessly incorporated into existing processes, and what are the accompanying challenges? Further investigation is required to draw upon best practices from successful case studies and identify the role of artificial intelligence and machine learning in enhancing the predictive capacities of digital twins.

As this technology involves real-time data management, cybersecurity and data privacy become crucial areas for exploration. An examination of specific threats and potential safeguarding measures in the context of digital twins within offshore wind farms is warranted. Equally important is understanding the degree to which digital twin technology improves performance and efficiency of wind turbines. Empirical studies exploring performance parameters pre- and post-implementation could provide valuable insights.

Financial implications also demand attention. Does digital twin technology, despite initial implementation costs, yield positive returns in the long run? Cost-benefit analyses could elucidate long-term financial outcomes. Additionally, to successfully employ digital twin technology, a certain skill set, and training might be necessary. Understanding these workforce requirements will inform the preparation for this technology's adoption. As such, research into digital twin technology in offshore wind farms is essential to maximize its potential benefits while mitigating any emerging challenges.

Digital transformation of Grid Integration

Research on utilizing digital tools for grid integration of offshore wind energy is pivotal in a digital, renewable-centric era. Key areas to be explored include the application of AI and machine learning for predictive analysis in power generation forecasting, and the role of IoT in real-time data acquisition from offshore wind farms for optimizing the production and grid integration.

Equally vital is examining the potential cybersecurity threats in this digital landscape. Research needs to assess risks associated with grid digitalization and propose robust countermeasures. Lastly, an economic analysis is necessary to understand the cost-effectiveness of these digital tools' implementation for grid integration. By thoroughly investigating these facets, the research will contribute significantly to a sustainable, reliable, and digitally integrated energy system.

Grid Integration of Offshore Wind Farms

As the prominence of offshore wind energy escalates in global power systems, there arises an exigency for intelligent strategies to ensure seamless and efficient grid integration. The transformative potential of digital tools in this sector necessitates a comprehensive research investigation. The proposed research could evaluate how advanced technologies, such as machine learning algorithms, can leverage real-time data to enhance the precision of offshore wind power forecasting, a key factor in reliable grid management. This focus could extend to probe the role of digital tools in enabling real-time communication between wind farms and grid operators, offering potential improvements in grid responsiveness and stability.

Moreover, navigating the intricate labyrinth of grid codes is often a challenging aspect of offshore wind farm operations. An exploratory study could assess how digital solutions might simplify this process, aiding in more efficient grid integration. This proposed research has the potential to offer substantial insights, refining the digital strategies employed for the efficient integration of offshore wind farms into the grid and thereby informing industry practices and policy decisions.

Assessing Batteries and Hydrogen Storage for Grid Balancing in Offshore Wind Farms

As offshore wind farms proliferate, assessing the role of batteries and hydrogen in grid balancing becomes crucial. A focused investigation into the technical, economic, and environmental aspects of employing such energy storage mechanisms for offshore wind farm integration could offer valuable insights.

Research could explore the feasibility and cost-effectiveness of battery storage and hydrogen production in buffering wind intermittency. Specifically, the study could investigate whether batteries or hydrogen could better accommodate fluctuating wind power, and under which circumstances. Evaluations could also include energy loss during storage and conversion processes, along with lifespan and recycling considerations of batteries.

Furthermore, the research could delve into the employment of digital tools like AI and IoT in optimizing the operation of these storage solutions. Such analysis may include the development and validation of AI algorithms for predictive control of storage operations based on wind forecasts and grid demand.

This targeted research can provide significant contributions to academia and industry, aiding the development of efficient and sustainable practices for the integration of offshore wind power into the grid.

The Human Element in Industry 5.0

Further research could focus on the human element in Industry 5.0 within the offshore wind industry, with a particular emphasis on the interactions between human workers and advanced digital technologies. There are three main facets to this potential study.

First, it could examine how offshore wind professionals adapt to and collaborate with AI, machine learning, and other sophisticated technologies. This could include explorations of the user-friendliness of these technologies and how they might be optimized for easier human interaction.

Second, the study could investigate the new roles and skills that are emerging in this digital industrial landscape. This might involve identifying the types of roles and skills that are in high demand as work evolves due to digitalization and automation.

Lastly, the research could analyze the impacts of these technological advancements on employee satisfaction and productivity in the offshore wind industry. This could include understanding effects on job satisfaction, work-life balance, and work culture.

In sum, this research could provide key insights for managing the transition to Industry 5.0, ensuring the human factor is adequately considered amidst the adoption of advanced technologies. The outcomes of such a study would have implications not only for the offshore wind industry but also for other sectors transitioning to Industry 5.0.

Interdisciplinary Collaboration in the Offshore Wind Industry

The offshore wind industry is inherently interdisciplinary, bringing together a wide range of fields such as engineering, environmental science, economics, and policy making. Research could explore how digital tools and Industry 5.0 principles can facilitate collaboration among these diverse disciplines, thereby promoting efficiency and innovation. Key topics could include the role of digital twins in fostering shared understanding, the potential of data analytics and machine learning to bridge gaps between professions, and the human-centric focus of Industry 5.0 in enhancing cross-disciplinary teamwork. The investigation should also consider the challenges that arise in such a context, proposing strategies to overcome technical and human barriers to effective collaboration. This research could lead to a more integrated, dynamic offshore wind industry, with lessons that may extend to other sectors.

8. Bibliography

Ait Alla, A., Quandt, M., & Lütjen, M. (2013). *Simulation-based aggregate installation planning of offshore wind farms*. *7*, 23–30.

Alexa, L., Pîslaru, M., & Avasilcăi, S. (2022). From Industry 4.0 to Industry 5.0—An Overview of European Union Enterprises. I A. Draghici & L. Ivascu (Red.), *Sustainability and Innovation in Manufacturing Enterprises* (s. 221–231). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-16-7365-8_8

Amirat, Y., Benbouzid, M. E. H., Al-Ahmar, E., Bensaker, B., & Turri, S. (2009). A brief status on condition monitoring and fault diagnosis in wind energy conversion systems. *Renewable and Sustainable Energy Reviews*, *13*(9), 2629–2636. https://doi.org/10.1016/j.rser.2009.06.031

Anaya-Lara, O., Tande, J. O., Uhlen, K., & Merz. (2018). Offshore Wind energy technology. Hentet 6. mai 2023, fra SINTEF website: https://www.sintef.no/en/publications/publication/1582013/

Andersen. M & Reilstad N.M. (2023). Framework for enabling digital transformation & critical success factors for ensuring operational excellence and LCOE reduction / Framework for priority theme and research question connection.

Athanasia, A., & Genachte, A. B. (2013). Deep Offshore and New Foundation Concepts. *Energy Procedia*, *35*, 198–209. https://doi.org/10.1016/j.egypro.2013.07.173

Barthelmie, R. J., Pryor, S. C., Frandsen, S. T., Hansen, K. S., Schepers, J. G., Rados, K., … Neckelmann, S. (2010). Quantifying the Impact of Wind Turbine Wakes on Power Output at Offshore Wind Farms. *Journal of Atmospheric and Oceanic Technology*, *27*(8), 1302–1317. https://doi.org/10.1175/2010JTECHA1398.1

Bhuiyan, N., & Baghel, A. (2005). An overview of continuous improvement: From the past to the present. *Management Decision*, *43*(5), 761–771. https://doi.org/10.1108/00251740510597761

BOEM. (2023). Guidelines for Providing Information on Fisheries for Renewable Energy Development on the Atlantic Outer Continental Shelf. *Bureau of Ocean Energy Management*.

Brooks, J., & King, N. (2014). *Doing Template Analysis: Evaluating an End-of-Life Care Service*. 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom: SAGE Publications, Ltd.

https://doi.org/10.4135/9781446273050135127555

Brynjolfsson, E., & McAfee, A. (2014). *The second machine age: Work, progress, and prosperity in a time of brilliant technologies* (s. 306). New York, NY, US: W W Norton & Co.

Carbon Thrust. (2022). *Unlocking the next generation of offshore wind: Step change to 132kV array systems*.

Carroll, J., McDonald, A., & Mcmillan, D. (2015). Failure rate, repair time and unscheduled O&M cost analysis of offshore wind turbines. *Wind Energy*, *19*. https://doi.org/10.1002/we.1887

Chen, Chiang, & Storey. (2012). Business Intelligence and Analytics: From Big Data to Big Impact. *MIS Quarterly*, *36*(4), 1165. https://doi.org/10.2307/41703503

Cooke-Davies, T. (2002). The “real” success factors on projects. *International Journal of Project Management*, *20*(3), 185–190. https://doi.org/10.1016/S0263-7863(01)00067-9

De Giovanni, P. (2023). Sustainability of the Metaverse: A Transition to Industry 5.0. *Sustainability*, *15*(7), 6079. https://doi.org/10.3390/su15076079

Definition of Digitalization—Gartner Information Technology Glossary. (2021). Hentet 25. mai 2021, fra Gartner website: https://www.gartner.com/en/information-technology/glossary/digitalization

Digital Twin/ Digital Transformation. - Adobe Stock (2023) Hentet 6.Mai 2023, fra Adobe Stock Website:
https://stock.adobe.com/no/search?k=digital+twin&search_type=usertyped&asset_id=501192827

Draxl, C., Clifton, A., Hodge, B.-M., & McCaa, J. (2015). The Wind Integration National Dataset (WIND) Toolkit. *Applied Energy*, *151*, 355–366. https://doi.org/10.1016/j.apenergy.2015.03.121

Energy Information Administration (EIA). (2021). Electricity generation from wind—U.S. Energy Information Administration (EIA). Hentet 7. mai 2023, fra https://www.eia.gov/energyexplained/wind/electricity-generation-from-wind.php

Equinor (Regissør). (2023a). *Becoming Digital: Equinor*. Hentet fra https://www.youtube.com/watch?v=sJl_pZUQAbc

Equinor. (2023b). Floating wind. Hentet 7. mai 2023, fra https://www.equinor.com/energy/floating-wind

Eriksson, S., Bernhoff, H., & Leijon, M. (2008). Evaluation of different turbine concepts for wind power. *Renewable and Sustainable Energy Reviews*, *12*(5), 1419–1434. https://doi.org/10.1016/j.rser.2006.05.017

Florian, M., & Sørensen, J. D. (2017). Risk-based planning of operation and maintenance for offshore wind farms. *Energy Procedia*, *137*, 261–272. https://doi.org/10.1016/j.egypro.2017.10.349

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, *12*(2), 219–245. https://doi.org/10.1177/1077800405284363

Galliers, R. D., Leidner, D. E., & Simeonova, B. (2020). *Strategic Information Management -. Theory and Practice* (Fifth Edition).

García Márquez, F. P., Tobias, A. M., Pinar Pérez, J. M., & Papaelias, M. (2012). Condition monitoring of wind turbines: Techniques and methods. *Renewable Energy*, *46*, 169–178. https://doi.org/10.1016/j.renene.2012.03.003

GWEC. (2021). Global Wind Report 2021. Hentet 7. mai 2023, fra Global Wind Energy Council website: https://gwec.net/global-wind-report-2021/

Hansen, T. (2020, mai 15). Havvind_enkelt_forklart.pdf. Hentet 6. mai 2023, fra https://www.uib.no/sites/w3.uib.no/files/attachments/havvind_enkelt_forklart.pdf

Hastie, T., Tibshirani, R., & Friedman, J. H. (2009). *The elements of statistical learning: Data mining, inference, and prediction* (2nd ed). New York, NY: Springer.

IEA. (2019). IEA – International Energy Agency. Hentet 7. mai 2023, fra IEA website: https://www.iea.org/reports/offshore-wind-outlook-2019

Ioannou, A., Angus, A., & Brennan, F. (2018). Parametric CAPEX, OPEX, and LCOE expressions for offshore wind farms based on global deployment parameters. *Energy Sources, Part B: Economics, Planning, and Policy*, *13*(5), 281–290. https://doi.org/10.1080/15567249.2018.1461150

IRENA. (2018). Renewable power generation costs in 2018. *Internation Renewable Energy Agency*.

IRENA. (2021). World Energy Transitions Outlook: 1.5°C Pathway. *Internation Renewable Energy Agency*.

Jacobsen, D. I. (2015). *Hvordan gjennomføre undersøkelser?* (3. utg.).

Jafari, N., Azarian, M., & Yu, H. (2022). Moving from Industry 4.0 to Industry 5.0: What Are the Implications for Smart Logistics? *Logistics*, *6*(2), 26. https://doi.org/10.3390/logistics6020026

Kang, J., & Guedes Soares, C. (2020). An opportunistic maintenance policy for offshore wind farms. *Ocean Engineering*, *216*, 108075. https://doi.org/10.1016/j.oceaneng.2020.108075

Karlsen, J. T. (2021). *Prosjektledelse: Fra initiering til gevinstrealisering* (5. utg.).

Koller, T., Goedhart, M. H., & Wessels, D. (2020). *Valuation: Measuring and managing the value of companies* (Seventh edition; McKinsey and Company, Red.). Hoboken, New Jersey: Wiley.

Kühn, F., Liebach, F., Matthey, T., & Zivansky, J. (2022). Succeeding in the global offshore wind market | McKinsey. Hentet 7. mai 2023, fra https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/how-to-succeed-in-the-expanding-global-offshore-wind-market#/

Lankshear, C., & Knobel, M. (2005). Digital Literacies: Policy, Pedagogy and Research Considerations for Education. *Nordic Journal of Digital Literacy*, *1*.

LeBlanc, B., & Ferreira, C. (2020). Experimental characterization of H-VAWT turbine for development of a digital twin. *Journal of Physics: Conference Series*, *1452*(1), 012057. https://doi.org/10.1088/1742-6596/1452/1/012057

Levitt, T. (2002, august 1). Creativity Is Not Enough. *Harvard Business Review*. Hentet fra https://hbr.org/2002/08/creativity-is-not-enough

Li, H., Huang, C.-G., & Guedes Soares, C. (2022). A real-time inspection and opportunistic maintenance strategies for floating offshore wind turbines. *Ocean Engineering*, *256*, 111433. https://doi.org/10.1016/j.oceaneng.2022.111433

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, Calif: Sage Publications.

Løvøy, A. (2021, september 16). Havvind betyr enorme it-prosjekter. Hentet 7. mai 2023, fra https://www.cw.no/energyworld-it-bransjen/havvind-betyr-enorme-it-prosjekter/499324

Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P., & Marrs, A. (2013). Disruptive technologies: Advances that will transform life, business, and the global economy | McKinsey. Hentet 7. mai 2023, fra https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/disruptive-technologies

Mathieson, S. (2022, mars 15). How data analytics drives wind turbine power generation | Computer Weekly. Hentet 7. mai 2023, fra ComputerWeekly.com website: https://www.computerweekly.com/feature/How-data-analytics-drives-wind-turbine-power-generation

Mcmillan, M. (2022, november 8). Real-time sea state data are invaluable in improving the safety of offshore wind operations. Hentet 7. mai 2023, fra Miros Group website: https://miros-group.com/blog/real-time-sea-state-data-are-invaluable-in-improving-the-safety-of-offshore-wind-operations/

Mitchell, D., Blanche, J., Harper, S., Lim, T., Gupta, R., Zaki, O., … Flynn, D. (2022). A review: Challenges and opportunities for artificial intelligence and robotics in the offshore wind sector. *Energy and AI*, *8*, 100146. https://doi.org/10.1016/j.egyai.2022.100146

Mitchell, T. M. (1997). *Machine Learning*. New York: McGraw-Hill.

Mittelmeier, N., Blodau, T., & Kühn, M. (2017). Monitoring offshore wind farm power performance with SCADA data and an advanced wake model. *Wind Energy Science*, *2*(1), 175–187. https://doi.org/10.5194/wes-2-175-2017

Musial, W., Beiter, P., Schwabe, P., Tian, T., Stehly, T., Spitsen, P., … Gevorgian, V. (2016). *2016 Offshore Wind Technologies Market Report*.

Musial, W., Beiter, P., Spitsen, P., Nunemaker, J., & Gevorgian, V. (2018). *2018 Offshore Wind Technologies Market Report*.

Naghib, A., Jafari Navimipour, N., Hosseinzadeh, M., & Sharifi, A. (2023). A comprehensive and systematic literature review on the big data management techniques in the internet of things. *Wireless Networks*, *29*(3), 1085–1144. https://doi.org/10.1007/s11276-022-03177-5

New Energy Outlook 2022 | BloombergNEF | Bloomberg Finance LP. (2022). Hentet 7. mai 2023, fra BloombergNEF website: https://about.bnef.com/new-energy-outlook/

Offshore Wind bilder – Adobe stock. (2023). Hentet 6. mai 2023, fra Adobe Stock website: https://stock.adobe.com/no/search/images?k=offshore+wind

Parrott, A., & Warshaw, L. (2017). Industry 4.0 and the digital twin. Hentet 14. mai 2023, fra Deloitte

Insights website: https://www2.deloitte.com/content/www/us/en/insights/focus/industry-4-0/digital-twin-technology-smart-factory.html

Parviainen, P., Tihinen, M., Kääriäinen, J., & Teppola, S. (2022). Tackling the digitalization challenge: How to benefit from digitalization in practice. *International Journal of Information Systems and Project Management*, *5*(1), 63–77. https://doi.org/10.12821/ijispm050104

Pizoń, J., & Gola, A. (2023). Human–Machine Relationship—Perspective and Future Roadmap for Industry 5.0 Solutions. *Machines*, *11*(2), 203. https://doi.org/10.3390/machines11020203

Porter, M. E., & Heppelmann, J. E. (2014, november 1). How Smart, Connected Products Are Transforming Competition. *Harvard Business Review*. Hentet fra https://hbr.org/2014/11/how-smart-connected-products-are-transforming-competition

Poth, J. W., & Creswell, C. N. (2018). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches* (4. utg.).

Rademakers, L. W. M. M., Braam, H., Asgarpour, M., & van de Pieterman, R. P. (2003). A structured approach for data collection and analysis Assess the offshore O&M strategy with OMCE. Hentet 7. mai 2023, fra https://publicaties.ecn.nl/PdfFetch.aspx?nr=ECN-M--13-044

Russell, S. J., Norvig, P., & Davis, E. (2010). Artificial intelligence: A modern approach (3rd ed). Upper Saddle River: Prentice Hall.

Rystad Energy (2023). Global offshore wind capital expenditure to more than double, top $100 billion in 2030, from https://www.rystadenergy.com/news/global-offshore-wind-capital-expenditure-to-more-than-double-top-100-billion-in-2

Saldaña, J. (2021). *The coding manual for qualitative researchers* (4E [Fourth editiion]). Thousand Oaks, California: SAGE Publishing Inc.

Samuel, A. L. (1959). Some Studies in Machine Learning Using the Game of Checkers. *IBM Journal of Research and Development*, *3*(3), 210–229. https://doi.org/10.1147/rd.33.0210

Schmarzo, B., & Borne, K. (2020). *The the Economics of Data, Analytics, and Digital Transformation: The Theorems, Laws, and Empowerments to Guide Your Organization's*

Digital Transformation. Birmingham: Packt Publishing, Limited.

Schwab, K. (2016). *The fourth industrial revolution* (First U.S. edition). New York: Crown Business.

Shenhar, A., & Dvir, D. (2007). *Reinventing project management: The diamond approach to successful growth and innovation*. Boston, Mass: Harvard Business School Press.

Shenhar, A. J., Dvir, D., Levy, O., & Maltz, A. C. (2001). Project Success: A Multidimensional Strategic Concept. *Long Range Planning*, *34*(6), 699–725. https://doi.org/10.1016/S0024-6301(01)00097-8

Siemens Gamesa. (2023). Offshore Wind Turbines I Siemens Gamesa. Hentet 7. mai 2023, fra https://www.siemensgamesa.com/en-int/products-and-services/offshore

Skyttermoen, T., & Vaagaasar, A. L. (2021). *Verdiskapende prosjektledelse* (2. utg.).

Smith, K. T. (2020, mai 15). How IoT technology can improve offshore wind power. Hentet 7. mai 2023, fra https://www.nsenergybusiness.com/features/iot-wind-power/

Snijders, C., Matzat, U., & Reips, U.-D. (2012). «Big Data»: Big Gaps of Knowledge in the Field of Internet Science. *International Journal of Internet Science*, *7*, 1–5.

Sprenger, M. (2017). Wind Energy Data Space_Englisch_Interaktiv.pdf. Hentet 7. mai 2023, fra Https://www.iee.fraunhofer.de/ website: https://www.iee.fraunhofer.de/content/dam/iee/energiesystemtechnik/en/documents/Veroeffentlichungen_e/Whitepaper_Wind%20Energy%20Data%20Space_Englisch_Interaktiv.pdf

Sprenger, Mona. (2017, april 14). Vindkraft-produsenten sparer millioner på å forutsi været mer nøyaktig enn meteorologene. Hentet 7. mai 2023, fra Tu.no website: https://www.tu.no/artikler/vindkraft-produsenten-sparer-millioner-pa-a-forutsi-vaeret-mer-noyaktig-enn-meteorologene/379833

Sun, X., Huang, D., & Wu, G. (2012). The current state of offshore wind energy technology development. *Energy*, *41*(1), 298–312. https://doi.org/10.1016/j.energy.2012.02.054

Tabrizi, B., Lam, E., Girard, K., & Irvin, V. (2019, mars 13). Digital Transformation Is Not About Technology. *Harvard Business Review*. Hentet fra https://hbr.org/2019/03/digital-transformation-is-not-about-technology

Tande, J. O. (2023, april 26). Debatt: Havvind smelter ikke sammen med kraftsystemet av seg selv.

Hentet 7. mai 2023, fra Www.dn.no website: https://www.dn.no/innlegg/havvind/teknologi/kraftproduksjon/havvind-smelter-ikke-sammen-med-kraftsystemet-av-seg-selv/2-1-1441197

Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital Twin in Industry: State-of-the-Art. *IEEE Transactions on Industrial Informatics*, *15*(4), 2405–2415. https://doi.org/10.1109/TII.2018.2873186

United Nations. (2023). Take Action for the Sustainable Development Goals. Hentet 6. mai 2023, fra United Nations Sustainable Development website: https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Vandenberge, R. (2017, mars 17). Big Data in Offshore Wind. Hentet 7. mai 2023, fra Offshore Wind website: https://www.offshorewind.biz/2017/03/17/big-data-in-offshore-wind/

Vineyard Wind. (2023). Vineyard Wind 1. Hentet 7. mai 2023, fra Vineyard Wind website: https://www.vineyardwind.com/vineyardwind-1

Wang, F.-Y., Yang, J., Wang, X., Li, J., & Han, Q.-L. (2023). Chat with ChatGPT on Industry 5.0: Learning and Decision-Making for Intelligent Industries. *IEEE/CAA Journal of Automatica Sinica*, *10*(4), 831–834. https://doi.org/10.1109/JAS.2023.123552

Westerman, G., Bonnet, D., & McAfee, A. (2014). Leading Digital: Turning Technology into Business Transformation. Harvard Business Review Press.

Wind Energy The Facts. (2009). SCADA and instruments. Hentet 7. mai 2023, fra https://www.wind-energy-the-facts.org/scada-and-instruments.html

World Bank Group. (2021). *Key Factors for Successful Development of Offshore Wind in Emerging Markets*. World Bank. https://doi.org/10.1596/36399

Yang, K., Kwak, G., Cho, K., & Huh, J. (2019). Wind farm layout optimization for wake effect uniformity. *Energy*, *183*, 983–995. https://doi.org/10.1016/j.energy.2019.07.019

Yin, R. K. (2014). Robert K. Yin. (2014). *Case Study Research Design and Methods (5th ed.). Canadian Journal of Program Evaluation*, *30*(1), 108–110. https://doi.org/10.3138/cjpe.30.1.108

Yudkowsky, E. (2008). Artificial Intelligence as a positive and negative factor in global risk. I E.

Yudkowsky, *Global Catastrophic Risks*. Oxford University Press. https://doi.org/10.1093/oso/9780198570509.003.0021

Ørsted. (2019). Making-green-energy-affordable-June-2019.pdf. Hentet 7. mai 2023, fra https://orsted.com/-/media/WWW/Docs/Corp/COM/explore/Making-green-energy-affordable-June-2019.pdf

9. Appendix

9.1 Interview guide

1. What are your thoughts on offshore wind?
2. Do your company have an Offshore Wind strategy, if so, could you tell us about it?
3. How is the UN sustainability goals influence your company's strategy within offshore wind?
4. What phase in the windfarm do you see your company engage in?
5. What projects are you currently engaged in with Wind projects?
6. What do you see as the biggest operational opportunities within offshore wind today?
7. What challenges are the biggest to solve to make the offshore wind industry more profitable during operation today?
8. What do you believe will be critical success factors within an operational Offshore Wind farm?
9. What technologies do you see as key to be able to solve some of the challenges identified in question 3?
10. What data from the windmill do you see as the most operational critical?

11. What do you believe is critical to succeed with digital value based digital operations model for offshore wind?
12. What do you believe digital tools could enable in an operational wind farm?
13. Are you familiar with industry 5.0?
14. How do you see Industry 5.0 in an operational context, within offshore wind?
15. Are you currently using any digital tools to enable value within offshore wind in your company today?
16. Are you familiar with any data standard within the Wind industry?
17. What you currently using data for in your organization/industry offshore wind?
18. Is there data for the windmill or park today that is not being utilized to its full potential?
19. Regards to vendors of windmills the OIM`s do you see any kind of data collaboration between the vendors today in the market?

A. Are there anything we should have asked you on the bases of the questions before?
B. Other?

9.2 Quotes from Coding Template

Due to differences in levels of comprehension, not all participants are featured in each theme.

Priority theme #1 Current state of offshore wind

Table 1: General thoughts of offshore wind

Priority theme #1	Second order themes	Concepts and example quote	Interview#
General	Thoughts on offshore wind	OK my thoughts on offshore wind are that it's absolutely required in order to meet the energy amount which we see is needed not only in Europe, but around in the world if you're going to be able to have an impact on reducing climate change, we need renewals and we need more Renewable energy quickly.	1
General	Thoughts on offshore wind	It’s definitely a part of the climate solution I believe renewables will be and is an important part of the solution to solve the climate issues	2
General	Thoughts on offshore wind	Well in a general perspective I think it’s a promising future as renewable energy. I think the development we have seen in Europe. Around the North Sea have demonstrated that this tech, have gone from being unmature to mature in a short time.	3

General	Thoughts on offshore wind	It's a necessary part of the green transition, and something that have common quick from when R&D have been done until it is in operation. It's necessary and happy to see that it is happening.	4
General	Thoughts on offshore wind	There is already alt of fixed offshore wind, but now the industry is moving towards the floating aspect of wind. Special for Norway we are good at the floating tech, but when you combine this with wind turbines it will have an impact and it is clearly a lot of opportunities.	5
General	Thoughts on offshore wind	I Think there is plenty of potential, in theory it should be easy to execute. Looking at our previous background in Oil and gas, where you need seismic, test drilling and so on. So, it should be easier to develop.	6
General	Thoughts on offshore wind	Growing industry at the moment because of that there is a lot of innovation and different technologies to make it more commercial	7
General	Thoughts on offshore wind	to actually succeed we need to think globally at least European in the beginning just look at ourselves I think that's very important to be able to scale this and at the rate that we need and also utilize building out the infrastructure	8
General	Thoughts on offshore wind	I don't have to deliver these projects from an outside point of view fascinating but it's very challenging but I think it's I think it's absolutely the right thing for the world to be doing this is my personal view um even if an evolution in nuclear technology or something like this comes along for a low carbon solution the likelihood of that being commercially viable within the	9

		next 20 years 30 years is extremely unlikely	
General	Thoughts on offshore wind	My general thoughts are that it’s really exiting, it’s not something that will not cancel out oil and gas. But it will be a good complement to the energy mix. And it’s important that energy companies diversified, and offshore wind is a good option to do this.	10
General	Offshore strategy	They are currently making it and trying to define what is their part in the offshore wind industry.	1
General	Offshore strategy	Yes, Goal of having 12-16GW installed in 2030. Need to install a turbine every 3-day going forward.	2
General	Offshore strategy	We have a focus on renewables but not in offshore wind specific, and we see that its part of our strategy. We just need to find our way into that.	4
General	Offshore strategy	The department that I’m working in, the strategy of the university is smart cities intelligent health and urban ocean. So, the wind comes in under urban ocean, and we follow that.	5
General	Offshore strategy	We are an early phase developer; we are focusing on electrification and development at the moment we are trying to figure out what our journey is.	7
General	Offshore strategy	In general, has huge ambitions within the green kind of energy domain and the our company is a big part of that we have obviously ambitions within the vessel and the supply services towards the wind form but also we want to take part of the energy transition partner	8

General	Offshore strategy	We want to replicate what we're doing in oil & gas. We're not trying to create a new product we're not trying to present a different business model it's about taking the complementary elements of what you have already been successful with oil & gas and then delivering that value proposition into a new market	9
General	Offshore strategy	Yes, we do. We are investing now more into renewables, and we are looking for options in different places, and we are trying to be the leading company in offshore wind in the world. We are finding the areas that is high valuable to develop.	10
General	Un's sustainability goals	Yes, there is 17 goals, and they are kind of connected. In offshore wind the point 7, 13 and 14 highlighted as important	1
General	Un's sustainability goals	It's part of why we do it. We fully support the Paris agreement. That consists of 3 strategies we need to extract oil and gas with low carbon footprint, we need to remove CO2 and focus of capture and storage. And we need to increase our renewables production and clean energy.	2
General	Un's sustainability goals	The UN sustainability goals are more geared towards policy making and that is first of all important for the ministry above us. We understand that such sustainability goals and take them into account on the policies that we have to act on.	3
General	Un's sustainability goals	I'm talking on the reached and near are RRI and they talk a lot of sustainable goals, there is one on ocean and on employability. Last October, different universities got a 13 mill NOK from Norway legal counsel to look into this	5
General	Un's sustainability goals	Right now, the demand is important, the future of all engaged in renewable looks good.	6

General	Un's sustainability goals	We also contributing kind of directly and indirectly towards the UN goals mostly on the SDG's that cover anergy and security	7
General	Un's sustainability goals	I'm familiar with the goals but I don't believe it's the UN SDG`s is governing the strategy in our company.	9

Priority theme #2 Digitalization

Table 2: Data

Priority theme #2	Second order themes	Concepts and example quote	Interview#
Data	Utilization	Utilize the data more for operational planning, especially how you utilize recourses and vessels in the most efficient way. Particularly in an installation face, but also in an operational phase. 2. You need to know the direction of the turbine is in, you need to know the production, wind speed, temperature, and nasal temperature.	2
Data	Utilization	Data integration making sure you have everything available and then yeah connecting the theoretical part from sitting in the office and having the data to practical parts where people are out in the field actually supposed to utilize this	4

Data	Utilization	The wind park will just be out there running. In the maintenance season the people will go out to do the Maintenance like you do on the car. So, I think to improve to do it faster and better to optimize and predict a bit.	6
Data	Utilization	Rotational angle and the and the wing angle would be super important to get into a centralized because the positioning of the turbines could be quite different whether the wind is blowing from north or from South	8
Data	Utilization	We want our product to be able to deal with what the metadata structure needs to be for those assets that we're discussing and the underlying data model. So, an example, we can have turbines in our and foundations in our asset library now in order to make sense of that turbine or deliver value from that turbine in terms of yield per turbine and then and range production across a farm you need to go and link it to met ocean data. So, we need to be able to link it to historical wind data and be able to you know estimate what that met ocean condition for a given location would deliver as a yield for a given turbine and capacity and power curve, so we are using that that that that kind of data to establish our data model	9
Data	Utilization	I don't think we are using all the available data today.	10
Data	Contextualized	Which is about having access to data and having data contextualized for you and presented in a meaningful way that solution that we have already on the when we are discussing the strategic opportunities for offshore wind we are showcasing the capabilities over kind of traditional energy solutions an and use that use that in the in the strategy work but we haven't deployed in operation and this solutions visual offshore wind solutions yet but hopefully things get move that faster forward.	1

Data	Contextualized	It's the collection of data and how you orchestrate the data, and how you present this. There is not any good system that can do this in a dynamical way that you can extract valuable data. It's a lot of really fear attempts but not many systems that can do this in a good way.	2
Data	Contextualized	Data flow, integration, making sure we have all data available, connecting the theoretical part connecting the theory with the reality is going to be important. And create an understanding for that.	4
Data	Contextualized	The data today is lacking context, we are after the failures, we know an alarm is raised we don't know why. This can happen due to miss alignment.	5
Data	Contextualized	We have to much info coming, and we need to contextualize more.	6
Data	Real time	You need real time metrical data around the wind turbine, in the operational phase, so you have a lot of focus on these measurements before it comes into production or its installed, so you need to you believe you know what you know, but it could be more optimal, and to measure on the turbine in front and behind it.	4
Data	Real time	When the wind park is running its strait forward, but you have connection to the turbines real time with the new ones.	6
Data	Real time	Ocean data back to the central control room so if you have shared data, you will know you're not only based yourself on forecasts for the weather, but you will actually have real data and more wind farms are connected the better the data will be.	7

Table 3: Digital tools

Priority theme #2	Second order themes	Concepts and example quote	Interview#

Digital tools	Digital Twin	Today we are market leading with digital twins special specifically the oil and gas for operational visual twins' assets that have already been constructed and installed in operation. We can help them in the energy transition towards renewables they have a pressure on them you know they had not reduced emissions, so the strategy is to help them doing this during this transition.	1
Digital tools	Digital Twin	Yes, there is definitely a lack of a proper digital twin, I want to sell this to Equinor, it is often a multi displayers, most people are looking at it, seeing performance, and looking at the met ocean condition, the cabling, the grid the access, how far for shore should it be?	5
Digital tools	Digital Twin	Asset specific digital twins and generally we see the latter so there could be partnership opportunities to interface with other digital twins that are very much asset focused	8
Digital tools	Digital Twin	I do engage with the market on a regular basis and they you know you people's natural assumption is that if you're providing a digital solution and if you're branding it's a digital twin	9
Digital tools	Digital Twin	I think Digital twin is a great opportunity, they have not reached their potential yet, we could do simulations, we could optimize production, and automating the wind turbines a bit more, they are a bit automated already, but they need more automation. It's a huge potential	10
Digital tools	Scada	I think there have been Scada systems today which is belonging to the operational technologies domain you have maybe teach the twins monitoring and dashboards which has been mostly in the IT domain, and you may see that there are solutions that will work across these two domains and then you need to make sure that they have human oversights	1

Digital tools	Scada	We are testing several digital tools. Everything for advanced Scada systems to our own test benches and we have different systems that we are testing out.	2
Digital tools	Scada	Right now, if you look at a predictive maintenance point of view most of the data comes from SCADA, and there are sensors there are vibrion and temp, this is the most important data from what is used at the moment	5
Digital tools	Scada	I think huge one here every supplier has their own system of their own set of sensors and instruments that's all well and good as I mentioned maintenance and operation of this you need to integrate into and look at it in the bigger picture, so he comes the different types of SCADA	8
Digital tools	Artificial Intelligence	Intelligent digital software that you optimize this turbines to capture us much as possible and have effective digital solutions for you know planning operation and maintenance so that so that you don't go for like just fixed schedule maintenance you go out there based on all the predictions that this part needs to be changed out so you change and maintain the system in the optimal way so to kind of have the turbines producing with a maximum uptime as possible so marine operations optimization of that whole digital and composing solution that's going to be a key	1
Digital tools	Artificial Intelligence	Artificial competence can enable good and timely decisions.	3
Digital tools	Artificial Intelligence	I think everybody is following data, so collecting more data and using AI and tech where we can. and knowledge management is something I see as lacking in the industry if 50% of the changes can happen when you change only 20%. Having the ideology towards not the big data but towards the quality data, and this is how you manage knowledge.	5

Digital tools	Artificial Intelligence	I think the industry is moving has already moved and it's probably moving even further towards completely automated control systems, and you know terms of operations and maintenance with as little human interaction with these systems	9
Digital tools	Artificial Intelligence	AI and machine learning are key, I'm a bit unsure how much it's in use now. But this will help us, it would optimize the solution for a problem, it's hard for us as human to define the problem so that the machine can solve it, we need to define it. I mentioned martials and corrosion, could we have some tools to detect and analyze it. Or if you have a CCTV camera you could see the equipment, get a heat map, and identify corrosion or other issues or needed maintenance, then you could plan a bit ahead on this.	10

Priority theme #3 Industry 5.0

Table 4: Readiness & Utilization

Priority theme #	Second order themes	Concepts and example quote	Interview#
Industry 5.0	Readiness	That I am not that familiar with the latest buzz word 5.0. I think 4.0 is already capturing an AI told me and whatnot so that we are still striving towards, but I think other nice comment as well that maybe it's about the human aspect still being important and of course that's humans are still going to be very important for the for a long time still. So having solutions that can supplement and complement each other in a good way without compromising what we've been talking about as well it's going to be a key	1

Industry 5.0	Readiness	I don't think we are there yet. It's a combination, that the business has been mature if ugh for it, and the technology might not have been ready for it. On the digital ide we are still struggling on how to utilize it. It's a fight between ambitions and kind of sky is the limit talks and want you actual need.	2
Industry 5.0	Readiness	I hear that there is already some countries having that type of approach in which even if you have a different operatorship you have access and then you can see and you can predict bird migrations and things like that you can better plan for the right wind farms and also it goes into the operations phase so yeah I see something on that on the 5.0.	7
Industry 5.2	Readiness	I think connected systems and intelligent systems on top of that it's one thing to connect assets another thing to make sense of all the different data and link it to you know the reality of the decisions that need to be made and that's not always the easiest and it's also can be subjective depending on where you sit in the chain	9
Industry 5.0	Utilization	I think yeah having IOT and connected wind farms a term that has come to emerge so have different wind farms connected to each other and even the only one they've heard those start perhaps is going to be the ownership of the windfarms and so it's to have a kind of a platform that can join all the data and manage all the connectivity of the wind farms and also so yeah there is as many connected to each other	7
Industry 5.0	Utilization	I think the industry is moving has already moved and it's probably moving even further towards completely automated control systems, and you know terms of operations and maintenance as little human interaction with these with these systems as possible	8

Industry 5.0	Utilization	I think it will be an enabler you know it's the ability to um not just capture but also process and contextualize lots of disparate datasets in a very short space of time all the different tools that fall under that 5.0 piece	9

Priority theme #4 Multidimensional success criteria

Table 5: Scale, Operation Uptime, Data collaboration, knowledge & transfer

Priority theme #	Second order themes	Concepts and example quote	Interview#
Success criteria	Scale	Offshore wind farms of course they want to make money at the end of the day so how can we maximize profitability	1
Success criteria	Scale	We need to look at a bit high energy prices, and we can ensure that we can build out the volumes needed specialty in Europa. The merchant part of selling the energy there are potential upsides there we can utilize better in the future.	2
Success criteria	Scale	You can't grow an industry from scratch that fast without a lot of growing pains and so the biggest one is supply chain at the moment you know record number of projects being announced and being awarded and there's just simply not enough of anything to deliver them	8
Success criteria	Scale	I think it would be with all these different floating structures and combinations of turbines and floaters it will be extremely valuable to have you know sensors and so on that could monitor the behavior of the turbine much of the stress that it's underneath and then kind of from analysis from that data then link the performance of the turbine to some of this stress conditions	9
Success criteria	Scale	Need more steady projects to build the industry	10
Success criteria	Operation uptime	No occurs this is all connected, you know it doesn't matter if you are excused the wind farm and it can't operate for the years its planned to operate, then the running cost will be tough to get it to be profitable. You need to optimize the operations of it so that the system doesn't go down during operation.	1
Success criteria	Operation uptime	They need to move when its wind and have a high uptime to produce, and a system that can do condition-based monitoring.	3

Success criteria	Operation uptime	I think they need to run 245/7 that will important there need to be no break down. Currently the big ones are actually losing money on the delivery, and they are making during the operation from when the contract is done inflation will be high.	5
Success criteria	Operation uptime	Its uptime for the turbine, that's the main measurement.	6
Success criteria	Operation uptime	I guess the capacity you know capacity factor so basically how effectively the turbine is generating energy as a function of you know it's operating life cycle to keeping the turbine operational keeping it generating wind start generating energy from the wind as much as possible	8
Success criteria	Operation uptime	Reducing time spent on waiting on weather during maintenance. For floating wind, could we tug the turbines back too sure for maintenance? More simulations	10
Success criteria	Data collaboration	large turbine manufacturers such as Vestas and Siemens carmesa and so forth they really try to protect this business and protected data and you know they want to almost kind of rent these turbines out to you and then take full control of the data and maybe even optimization and maintenance of that part alone specifically so that they think they will very protective. 2. I guess if they don't want to play along but this remains to be seen how this turns out, but you know data needs to be shared if they're going to if you're going to be able to do this will do the multi-dimensional optimization you can't just optimize for producing the most the time and that it's even more complex developed.	1
Success criteria	Data collaboration	This is needed	2
Success criteria	Data collaboration	I'm a bit critical about the level of cooperation, they are competing on many levels, they are taking them into the operator side. We need them to shear more accurse the industry, but I don't see any collaboration today. They are so commercial and selling more like cars/unites.	3
Success criteria	Data collaboration	You need to have access to all data even if you don't see it as relevant, you need the history of the data as well. And then you can make sure in time that you can use it when methods improve, and you have better algorithms, better ways of working and can utilize it more and when the industry matures more making sure you have access to the historical data.	4

Success criteria	Data collaboration	I don't think there is much collaboration in the market today. I think there needs to be some more joint group say more wind farms are being built and getting closer to each other. This sort of for like creating a group more like a combined consortium that can work with us, and I think that has to be kind of pushed through from the innovation parts.	7
Success criteria	Data collaboration	I think maybe we need some specific applications to be able to enter and penetrate the market, but I think the where the real value is to integrate together and in order to pull this up, I think we need some big partnerships it will be a lot of competition around this 2. there is a shift because now we see that warranty time first generators and not that will push them to figure out how to do maintenance and continue operational this and I hope that voters will push them into a more integrated system when the warranty is expired	8
Success criteria	Data collaboration	Not too much collaboration	10
Success criteria	Knowledge & competence	It's obviously and offshore wind farm needs to be operated, it's very few that have experience in doing that. To operate it is important.	2
Success criteria	Knowledge & competence	It needs to strike a balance and you increase the complexity, so that you need to balance that you have a robust system, we have seen this in oil and gas, it's becoming too complex due to lack of competence it needs to be balanced and robust.	3
Success criteria	Knowledge & competence	1. The main area we are focusing on offshore wind 450 GW is the target in 2050. But you also need the skill set of the students, so we aim to make the students ready for that. There is also education and responsibility how we live life. 2. I see as lacking in the industry if 50% of the changes can happen when you change only 20%. Having the ideology towards not the big data but towards the quality data, and this is how you manage knowledge.	5
Success criteria	Knowledge & competence	1. I think there is one, and this is a known issue. People is a big bottle neck at the moment the industry is grooving fast. 2. So if you can train persons with VR or simulators, to be ready sooner with the task offshore this will be good.	6

Success criteria	Knowledge & competence	floating thing being becoming a more commercialized technology still there are different concepts and different things being done in the market, so I think once those kinds of barriers start to be I think they need to be more realistic, and that people start to understand better what that means	7
Success criteria	Knowledge & competence	for the foundations it covers skilled people	8
Success criteria	Knowledge & competence	Need to increase this, not only on a company level but on a industry level.	10

Priority theme #5 Operational excellence

Table 6: Operational Challenges

Priority theme #5	Second order themes	Concepts and example quote	Interview#
Operational challenges	Cost	The industry is profitable today, but there is room for improvements. Operational optimization needed, with current high-power prices the wind industry is getting more profitable	1
Operational challenges	Cost	We can today produce a KWh at a price of 5 Euro cent an hour, so the price is low, but the industry is perhaps struggling more with profitability, the price is a bit too low.	2
Operational challenges	Cost	If you are going to create an industry that is leaning on an industry offshore, you need a steady stream of projects. We need that to create a healthy industry and hold the cost down	3

Operational challenges	Cost	Extremely high costs involved	4
Operational challenges	Cost	I think in operational the wind tech onshore there is not a lot of issues, the cost offshore is 10-20 times more, the water wind you have offshore is also driving the cost	5
Operational challenges	Cost	Showing that the offshore wind can be profitable over time. To make an offshore wind industry more profitable during operation require higher efficiency	8
Operational challenges	Cost	Waiting on weather during operation and maintenance is a big cost driver	10
Operational challenges	Complexity	There are too many complexities, like harbors and you'll need ships, and you need more people, and you need the weather to be on your side. Everything in addition to rules so it's so much more complex right and you need all these things to play together and then you can have lots of providers and actors and such kind of things it's you get a lot of different solutions even harder to standardize	4
Operational challenges	Complexity	It’s still early phase in the industry and you need to combine the weather, temperature, maintenance, Scada all as a hole. To pull it out.	6
Operational challenges	Complexity	Um it seems to be quite easy to get the wind farm going. I think we will get more challenges in the maintenance part of this, and we need more instrumentation and digital applications to help with the maintenance part of this I think everything boils down to maximize the energy output	7

Operational challenges	Complexity	If there's only one vessel in the world that can install turbines at 50 megawatts I'm not sure as a developer you really want to be waiting in line for that vessel and so I think I think all of that stuff comes into play and it's a technology it's an optimization game again not necessarily pushing the technological limits of how big a turbine can be it links to how effectively things can actually be delivered	9
Operational challenges	Complexity	Some of the challenges today is the lack of good communication, procedures, and responsibilities in the industry. Regulations from the government is lacking and we as a developer and operator have to set the regulations for our self. This is also cost driving since there is uncertainty.	10
Operational challenges	Silos	We want to help bridge the silos and make the data more accessible for the owner of the wind farms.	1
Operational challenges	Silos	Seems like the windmills and parks operate in siloes lack of access to all the data from the turbine.	2
Operational challenges	Silos	From theory to practice and there is a lot of different parts and vendors that need to work together to get it to work.	4
Operational challenges	Silos	And nobody of the vendors want to open the silos, the industry is not shearing information today. Today they operate in siloes, they want to create an internal edge.	5
Operational challenges	Silos	Through the value chain there is a lot of silos throughout the value change and it’s hard to follow from order production to implementation. So, parts are communicating but it’s not streamed lined.	6

Operational challenges	Silos	They to go together and work with the with the market and the industry player to find the best and the most economical ways to secure infrastructure that everyone can utilize to bring the most power most efficient to the end	8
Operational challenges	Silos	I've not been witnessed to data collaboration between vendors um I think something that's very interesting is um we have encountered a pain point a real friction point between the developers and the Orient so developers who want to you know validate their layouts their designs with key engineering data parameters and simulation results from for a given technology the OEM's hold that data and they do not share it it's basically considered IP. OEMS protecting their liability	9
Operational challenges	Silos	Lack of data and knowledge sharing in the industry, room for improvements	10
Operational challenges	Infrastructure	I think, its important, that you have a market strategy that is aligned with the real market, so where will you feed this power into the system. And how will you handle this into the system. A. Staten is responsible for this, so they need to regulate the power in. B. Establish business framework for sale of the power, and take into account	3
Operational challenges	Infrastructure	the supply chain will also be an issue, so planning is important. My words are coming based on my maintenance point of view.	5

Operational challenges	Infrastructure	definitely the industrial part of it and the bigger with parts all the infrastructure. I think that's the biggest challenge now solutions to overcome it uh I'm obviously going to say digitalization in the design phase because that's where we have the best interest and I do think you know reducing time	8
Operational challenges	Infrastructure	I think there's two elements one is obviously asset integrity management and how do you know mooring lines failure but mooring lines going to be extremely costly if these you know if turbine and foundation upend have an easy thing to fix so uh that that's going to be very big	9

Table 7: Operational Opportunities

Priority theme #5	Second order themes	Concepts and example quote	Interview#
Operational opportunities	Grid integration	Integration and optimalisation needed, we are not able to open for all the planned offshore wind to the grid today. You need also to have a grid that can take its electricity.	1
Operational opportunities	Grid integration	It’s also a potential that we will have a lot of energy coming in from offshore and the grid integration is definitely going to be a problem and will be the biggest challenge going forward.	2
Operational opportunities	Grid integration	They need to move when its wind and have a high uptime to produce, and a system that can do condition-based monitoring. Getting the data to do this is important and have enough data to optimize the power system to optimize this system. I don’t think today’s strategy for the onshore grid is able to handle this.	3

Operational opportunities	Grid integration	Yes, there is definitely a lack of a proper digital twin, I want to sell this to Equinor, it is often a multi displayers, most people are looking at it, seeing performance, and looking at the met ocean condition, the cabling, the grid the access, how far for shore should it be?	5
Operational opportunities	Grid integration	You have some issues in wind to, like the grid, not the same stability, but there are more advantages.	6
Operational opportunities	Grid integration	it's connecting this to the grid on the different locations in order to make it yeah sound and profitable, so I think that's one of the key challenges...I think it's to have good grid connection and to have infrastructure that can take in actual the offshore wind farm into the grids because sometimes some locations perhaps that's not going to be possible and then you're going to be very remote	7
Operational opportunities	Grid integration	We could use last power from the grid to produce hydrogen offshore given that we have the infrastructure, and all that little bit more up there is what kind of taxes and the extra stuff we would need to pay the grid owners to do that and that could easily capsize.	8
Operational opportunities	Grid integration	There are some challenges with the grid integration, the cost of the cabling is also high.	10
Operational opportunities	Data based decision	Big potential and use of integrated digital twins	1
Operational opportunities	Data based decision	Be able to kind of create value to the lifecycle of the of the windmill or park in a way I was saying integration making sure that data flows and that's decisions are based on actually facts you get from the data. Optimization based on data. But it takes time to get there.	4

Operational opportunities	Data based decision	Be able to use technology to enhance operational operations particularly when we're going to go into more remote locations. Technology as enabler.	7
Operational opportunities	Data based decision	We need to look at the whole farm and several farms in the digital system, we need to really work on the efficiency part of this it's quite different from the oil and gas.	8
Operational opportunities	Data based decision	I think any solution that is looking at farm scale digital is going to be the first step you can cut yeah contextualizing those different subsystems and kind of alluding just maybe some of the synergies there of you know well the whole system actually isn't working very well because the boring line configuration isn't right or what it would happen in that stuff just pulled it out there	9
Operational opportunities	Data based decision	Adding in automation and AI is also a big potential. and we are not leveraging the full potential here today.	10