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THESIS TITLE

OFFSHORE WIND ENERGY IMPLEMENTATIONS OF EUROPEAN UNION STATES IN NORTH SEA

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UMUR

OFFSHORE WİND ENERGY
IMPLEMENTATİONS OF EUROPEAN UNİON
STATES İN NORTH SEA

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TAAHHÜTNAME

Bu tezin Manisa Celal Bayar Üniversitesi Lisansüstü Eğitim Enstitüsü Siyaset Bilimi ve Uluslararası İlişkiler Ana Bilim Dalında akademik ve etik kurallara uygun olarak yazıldığını ve kullanılan tüm literatür bilgilerinin referans gösterilerek tezde yer aldığını, tamamen kendi çalışmam olduğunu, her alıntıya kaynak gösterdiğimi, tezin yazımında akademik ve etik kurallara aykırı herhangi bir yapay zeka ve program kullanmadığımı beyan ederim.

İmza

Damla UMUR

ÖZET

KUZEY DENİZİ'NDE AVRUPA BİRLEŞİK DEVLETLERİNİN DENİZ ENERJİ UYGULAMALARI
Yüksek Lisans Tezi

Damla UMUR
Manisa Celal Bayar Üniversitesi
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Danışman: Prof. Dr. Hüseyin Kutay Aytuğ

Bu çalışma, Avrupa Birliği'nin ve bu birliğe üye belirli devletlerin deniz üstü (offshore) rüzgar enerjisi politikalarına odaklanmaktadır. Tezin ilk bölümünde enerji ve yenilenebilir enerji hakkında genel bilgiler verilmekte, ardından rüzgar enerjisinin avantajları ve dezavantajları ele alınmaktadır. Bu bölümde ayrıca deniz üstü rüzgar enerjisine de değinilmektedir. İkinci bölümde, Avrupa Birliği'nde deniz üstü rüzgar enerjisinin tarihsel arka planı incelenmektedir. AB'nin enerji politikalarının analizine ek olarak, Avrupa'da rüzgar enerjisi ve deniz üstü rüzgar enerjisinin gelişimi önemli dönüm noktaları çerçevesinde ele alınmaktadır. Ayrıca, Güney Kuzey Denizi'nde gerçekleştirilen bazı başarılı projelere de bu bölümde yer verilmektedir. Bu kısımda Almanya ve Hollanda'nın deniz üstü rüzgar enerjisindeki durumu ve geleceğe yönelik hedefleri de vurgulanmaktadır. Son ve üçüncü bölümde ise, Avrupa Birliği'nin deniz üstü rüzgar enerjisi alanında karşılaştığı zorluklar ve bu sorunlara yönelik önerilen çözümler özetlenmektedir.

Anahtar Kelimeler: Açık Deniz Rüzgar Enerjisi, Avrupa, Kuzey Denizi, Nerherlands, Almanya

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ABSTRACT

OFFSHORE WIND ENERGY IMPLEMENTATIONS OF EUROPEAN UNION STATES IN NORTH SEA
Master's Thesis

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This study focuses on the offshore wind energy policies of the European Union and the specific member states identified within this union. The first part of this thesis provides general information about energy and renewable energy, followed by a discussion of the advantages and disadvantages of wind energy. Offshore wind energy is also addressed in this section. In the second part, the historical background of offshore wind energy in the European Union is examined. Along with an analysis of the EU's energy policies, the development of wind energy and offshore wind energy in Europe is analyzed based on significant milestones. Furthermore, several successful projects conducted in the southern North Sea are highlighted. This section also emphasizes the final situation and future goals of Germany and the Netherlands in offshore wind energy. In the final and third section, the challenges faced by the European Union regarding offshore wind energy and proposed solutions to these issues are summarized.

Keywords: Offshore Wind Energy, Europe, North Sea, Nerherlands, Germany

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This study includes the studies carried out by the countries in the North Sea in the field of offshore wind energy. I would like to express my sincere gratitude to my esteemed advisor Prof. Dr. Hüseyin Kutay Aytuğ for guiding and supporting me in the realization of this thesis. I would like to sincerely thank everyone who provided academic, moral and technical support while preparing this thesis.

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INDEX OF SYMBOLS AND ABBREVIATIONS

Abbreviation	Explanation
AIA	Advance Informed Agreement
COP	Coefficient of Performance
EAP	Environmental Action Programme
EGD	European Green Deal
EIA	Environmental Impact Assessment
EU ETS	European Union Emission Trading Scheme
E.U	European Union
EWEA	European Wind Energy Association
GW	Gigawatt
GWEC	Global Wind Energy Council
IRENA	International Renewable Energy Agency
KW	Kilowatt
LMO	Living Modified Organism
MW	Megawatt
NSEC	North Seas Energy Cooperation
SET-Plan	EU Strategic Energy Technology Plan
TEN-E	Trans-European Networks for Energy
Tpwind	European Technology Platform for Wind Energy
UK	United Kingdom

Abbreviation	Explanation
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change
UNRISD	United Nations Research Institute for Social Development
WAPA	Western Area Power Administration
WWEA	World Wind Energy Association

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INTRODUCTION

The urgent need to combat climate change and reduce reliance on fossil fuels has accelerated the global shift towards renewable energy. Among these, offshore wind energy stands out as a key solution, especially within the European Union's (EU) strategy for energy independence, emission reduction, and carbon neutrality. The North Sea, with its shallow waters and strong wind potential, has become a strategic hub for offshore wind deployment. Germany and the Netherlands, both North Sea states, have emerged as leaders in this field through their ambitious policies, investments, and regulatory frameworks.

This thesis explores the development and implementation of offshore wind energy in the EU, focusing on Germany and the Netherlands as case studies. It aims to understand how national-level strategies align with broader EU goals, and how institutional and political environments shape energy transition outcomes. Rather than offering a comparative analysis, the study provides a political examination of policy creation, implementation, and coordination in each country.

Offshore wind energy offers numerous advantages over onshore wind, such as higher efficiency, reduced land competition, and lower visual impact. Despite its slow initial growth, the sector has expanded significantly in the past decade due to falling costs, technological advances, and increased political will. The North Sea's operational capacity reached 28 GW by 2022, with further potential through innovations like floating turbines and marine biofuels.

Germany and the Netherlands exemplify successful integration of EU energy directives into national action, achieving notable progress in grid development, investment attraction, and stakeholder coordination. However, the sector still faces challenges such as permitting delays, high costs, and legal uncertainties. Addressing these requires political solutions, including better regulatory alignment and enhanced cross-border cooperation.

Ultimately, this thesis contributes to the academic discourse on EU energy policy by highlighting how political and institutional dynamics influence offshore wind development. Understanding these factors is essential for ensuring a coherent, effective, and legitimate energy transition across Europe.

CHAPTER ONE

WIND ENERGY AND OFFSHORE WIND ENERGY

A thorough overview of energy and renewable energy sources is provided in this part, with a focus on how they contribute to sustainable development. It also examines the offshore uses of wind energy, one of the most well-known renewable energy sources. It starts by outlining the basic ideas of wind energy production, along with its benefits and drawbacks in comparison to other energy sources. After that, the topic turns to offshore wind energy, emphasizing its increasing importance in the world's energy transitions. Important elements are looked at, including economic viability, environmental effects, and technical developments. The part also examines how offshore wind farms differ from onshore wind farms, highlighting the potential of offshore wind power to satisfy future energy demands.

1.1. Energy, Renewable Energy

Energy is the capacity for action or transformation. It can take many different forms, including motion, heat, light, and electricity. Our everyday activities, such as operating machinery and cars, heating our houses, and charging our gadgets, depend on energy (Snyder, Kaiser, 2009: 45).

There are two primary forms of energy: non-renewable and renewable. Nuclear energy and fossil fuels like coal, oil, and natural gas are examples of non-renewable energy sources. Sunlight, wind, water (hydropower), geothermal heat, and biomass are examples of renewable energy sources. To suit human demands, these sources offer energy in a variety of forms (Snyder, Kaiser, 2009: 46).

Energy is essential to contemporary living. It supports vital services like healthcare and education and drives industry, transportation, and communication networks. Everyday operations and economic growth would halt in the absence of energy. It is also essential for raising living standards and developing technologies Musial, Ram, 2010: 3).

To meet our daily needs, we use energy in a variety of ways. Our homes run on energy, which also provides heating, cooling, and lighting. It powers vehicles such as automobiles, buses, trains, and aircraft. Energy is used in industries to run machinery and produce items. Additionally, it facilitates the operation of computers, phones, and the internet by supporting communication technologies (Musial, Ram, 2010: 3).

Renewable energy comes from natural sources like sunshine, wind, water, and geothermal heat that naturally replenish themselves over time. Renewable energy sources are more sustainable for long-term use than fossil fuels since they never run out (Musial, Ram, 2010: 4).

Solar energy, which comes from the sun; wind energy, which is produced by wind turbines; hydropower, which uses the energy of flowing water; geothermal energy, which is derived from the heat of the Earth's interior; and biomass, which comes from organic materials like waste and plants, are the main sources of renewable energy. These resources offer environmentally responsible and sustainable substitutes for conventional fossil fuels (Musial, Ram, 2010: 4).

Reducing pollution and fighting climate change require renewable energy. It helps protect the environment by offering a more sustainable and clean substitute for fossil fuels. By lessening reliance on finite and imported energy resources, it also advances energy security (Musial, Ram, 2010: 4).

There are numerous applications for renewable energy. Electricity for homes and businesses is produced by solar panels. Grids use the electricity generated by wind turbines. Electricity is produced by hydropower plants using flowing water. Heat and biofuels are produced from biomass. Buildings can be heated and cooled using geothermal systems, which also generate electricity (Musial, Ram, 2010: 5).

The availability and environmental impact of renewable and non-renewable energy sources are the primary distinctions between them. Renewable energy sources cause no harm to the environment and are naturally renewed over time. Fossil fuels and other non-renewable resources are limited and contribute to climate change by releasing greenhouse gases when they are consumed. Future energy demands can be met more sustainably and cleanly with renewable energy (Musial, Ram, 2010: 5).

1.2. Advantages and Disadvantages of Wind Energy

Wind energy is one type of renewable energy. Compared to many other energy sources, wind energy generating generally has fewer negative environmental effects (EIA, 2023).

Globally, wind power has grown at an astounding rate in recent decades. By the end of 2020, wind energy will have an astounding installed capacity of 743 gigawatts (GW), providing about 6.1% of the world's electricity needs, according to the Global Wind Energy Council. What is the cause of this remarkable growth? Let's examine the environmental advantages of wind energy and why it is such a desirable choice: Firstly, wind energy is renewable and clean. Wind energy's renewability is one of its biggest benefits. Wind power relies on an endless resource—the wind—as opposed to fossil fuels, which run out over time. Energy output is steady and sustainable as long as the wind blows. Furthermore, wind energy is pure, generating neither hazardous byproducts nor greenhouse gas emissions, which makes it an important tool in the fight against climate change and the reduction of carbon footprints (Energy5, 2024).

Secondly, wind energy is abundant and widely available. Considering that wind exists almost everywhere on Earth, wind energy has enormous potential. The potential for wind power worldwide is estimated by the International Renewable Energy Agency (IRENA) to be 500 TW, which is several times more than the present global energy consumption levels. Remote communities and offshore places can reduce their reliance on fossil fuel-based power grids and get access to sustainable energy when wind conditions are right (Energy5, 2024).

The third characteristic of wind power is mitigating water and air pollution. Conventional energy sources, such as natural gas and coal, have long been linked to negative environmental effects. On the other hand, wind energy offers a solution because it drastically lowers air pollution and water usage. Wind turbines completely eliminate the requirement for water, protecting the declining supply of water that traditional power plants require for cooling operations. Moreover, the lack of combustion involved in the production of wind energy guarantees the decrease of dangerous pollutants like sulfur dioxide, nitrogen oxide, and particulate matter, improving community respiratory health and the quality of the air (Energy5, 2024).

Lastly, low lifecycle carbon footprint is important issue. Wind energy has a minimal carbon impact throughout its lifecycle, according to numerous studies. The carbon emissions of wind power are far lower than those of other energy sources, such as coal and natural gas. Wind energy systems emit four to forty-six times less greenhouse gas per unit of electricity generated than coal-fired power plants, according to a study done by the National Renewable Energy Laboratory of the US Department of Energy. The importance of wind energy in slowing down climate change and safeguarding our world for future generations is highlighted by this discrepancy (Energy5, 2024).

The benefits of wind energy divided into two groups: community benefits and environmental benefits. Apart from offering a reasonably safe and cost-effective energy source and contributing to the fight against global warming, wind energy projects have the potential to yield tangible advantages for local communities. Individuals or collectives within the community can purchase one or more wind turbines for themselves. A turbine may occasionally be purchased as a component of a larger commercial wind farm development, which lessens the overall financial burden of the design and building phases. The money raised by their project benefits the community, which can be used to establish a cooperative or community fund or to provide cash to the participants. This can use the funds to finance community-wide initiatives like insulating current homes or enhancing neighborhood parks and public spaces. Using a similar strategy, local governments can fund their own wind energy projects in order to create revenue that can be allocated to other priorities in the budget or used to fund other energy-saving and renewable energy initiatives. Large-scale project developers frequently provide a community fund, with a suitable organization in place to oversee the money's use and distribution. For the first six years of operation, the government has proposed to let towns keep the business rates paid by commercial wind farms that receive planning clearance in their region. Bigger wind turbines can improve the value of land use by giving the landowners who own the land they are built on a small income while preserving the area around the turbines for other uses, like farming. Locals in the supply chain can also find work and business possibilities in regions of the nation where major onshore or offshore wind energy development is projected (Local Government Association, 2023).

If we focus on environmental benefits, carbon emissions are not released during wind energy generation. Carbon emissions from power plants that use fossil fuels can be replaced by electricity produced by wind energy, which can lower overall emissions. It is also possible to reimburse the energy consumed in the production and installation of wind turbines quite rapidly. This can happen as quickly as six or eight months for a large wind turbine on a favorable site. It is an extremely clean energy source since, when in use, it produces no waste or releases any pollution (Local Government Association, 2023).

The intermittent nature and unreliability of wind energy are among its main drawbacks. Wind is a variable resource since it does not blow continuously and its intensity can vary greatly over time and between different places. This implies that wind turbines are unable to provide a steady flow of electricity, particularly when there is little or no wind. Because of this, wind power systems frequently need backup from traditional energy sources like coal or natural gas, or they need to be combined with energy storage technologies like batteries, which are currently costly and have a limited capacity, in order to provide a steady and dependable electricity supply. The entire cost and difficulty of incorporating wind energy into current power systems are raised by this intermittency, which also threatens grid stability (Local Government Association, 2023).

The hefty upfront expenses of wind energy are still another major drawback. Significant upfront costs are associated with the creation of wind generating projects, including the production of wind turbines, transportation to frequently remote locations, site preparation, installation, and grid interconnection. Furthermore, because of the harsh marine environment, offshore wind farms are considerably more costly to construct and maintain than onshore ones, despite the fact that they are frequently more efficient due to stronger and more reliable winds. Entry barriers may result from these high capital costs, particularly for developing nations or areas with little financial resources. Furthermore, even if wind energy has long-term environmental and economic benefits, it can be challenging to defend the initial costs in the absence of adequate government incentives, subsidies, or private investment (Local Government Association, 2023).

The noise and aesthetic impact of wind turbines are frequently criticized, which can result in strong opposition from the local population. Even while contemporary turbines are more silent than their predecessors, they nevertheless produce aerodynamic and mechanical noise, especially in severe winds. People who live near wind farms may find this continuous low-frequency noise upsetting, particularly in peaceful rural settings. Furthermore, many people find the tall tower structures and big, whirling blades to be physically obtrusive, disturbing the scenic views and natural surroundings. The "Not In My Backyard" (NIMBY) problem, in which people oppose the construction of wind farms close to their houses but support renewable energy in theory, is mostly caused by this aesthetic concern. Such opposition may lead to project delays, higher planning expenses, or even the cancelation of planned installations (Local Government Association, 2023).

Although wind energy emits fewer pollutants than other forms of electricity, it can have adverse effects on wildlife, especially bats and birds. Because of accidents with the revolving blades, wind turbines—particularly those situated in ecologically sensitive areas or along migratory routes—have been linked to higher fatality rates. The flight patterns and activities of some species, like bats and raptors, make them especially vulnerable. Wind farms have the potential to cause habitat displacement in addition to direct impacts, making species avoid locations they once used for migrating, feeding, or breeding. Significant environmental issues are raised by these effects, which call for cautious site selection, regular monitoring, and environmental impact assessments. Although mitigation strategies like better turbine design or curtailment during periods of high migration might lessen these consequences, they may also make operations more complicated and expensive (Local Government Association, 2023).

Large tracts of land are necessary for wind farms, especially onshore installations, to function effectively because turbine spacing must be sufficient to avoid aerodynamic interference. Even while each turbine has a relatively tiny physical footprint, a wind farm may need a sizable amount of land overall, particularly when access roads, maintenance facilities, and safety zones are taken into consideration. Competition from other land-based pursuits including forestry, urbanization, agriculture, and nature preservation may result from this widespread land use. Wind farms occasionally have the potential to alter conventional land use patterns, decrease the amount of farmland that is available, or have an adverse effect on the ecological value and beauty of natural landscapes. To reduce disputes and guarantee sustainable land management, balancing wind energy growth with current land uses frequently calls for meticulous spatial planning, stakeholder participation, and occasionally legislative intervention (Local Government Association, 2023).

Given that wind farms are frequently located in isolated or rural locations with the best wind resources but distant from the urban and industrial hubs where the greatest demand for power exists, one significant obstacle to wind energy is the requirement for substantial transmission infrastructure. New high-voltage transmission lines must be built in order to transport the generated power to end customers, which can be expensive and time-consuming. In addition to making wind energy projects more expensive overall, the construction of this infrastructure presents environmental issues because transmission corridors have the potential to disturb ecosystems, necessitate the clearing of land, and have an impact on nearby communities. In many instances, normally feasible wind farms have not been able to go online due to delays in grid expansion. In order to ensure timely and sustainable infrastructure development, energy developers, grid operators, and governments must coordinate their plans in order to integrate wind energy into the electricity grid effectively (Local Government Association, 2023).

Even though wind energy is renewable and emits no emissions when in use, the materials used to make wind turbines present geopolitical and environmental risks. Rare earth elements like neodymium, dysprosium, and other important metals are frequently needed for parts like generators, magnets, and blades. These elements are mostly mined in a small number of nations. Significant environmental damage, including as habitat destruction, soil and water pollution, and the production of toxic waste, can arise from the extraction and processing of these commodities. In addition, over dependence on a small number of supplier nations, particularly those with unpredictable political or regulatory landscapes, makes supply chains vulnerable and raises questions regarding energy security and sustainability in the long run. These problems become more urgent as the demand for wind turbines rises globally, underscoring the need for better recycling techniques, substitute materials, and more moral sourcing procedures in the renewable energy sector (Local Government Association, 2023).

1.3. As an Alternative to Fossil Fuels: Offshore Wind Energy

Utilizing the wind power generated on the high seas, where there are no obstructions to prevent it from traveling at a faster and more steady speed than on land, offshore wind energy provides a clean, renewable energy source. Mega-structures are erected, sitting on the seabed and outfitted with the newest technological advancements, in order to maximize the use of this resource (Iberdrola, 2023).

Since offshore wind creates power without burning fuel or emitting carbon dioxide, it is good for the environment. Offshore wind is so far out at sea that it is rarely perceptible from the coast and completely silent. Compared to land, the wind is more powerful, steady, and tame at sea. This implies that more power may be produced with more consistency. Larger towers and blades can be transported by boat more easily than by car, which facilitates the construction of larger wind turbines that produce more electricity. Large numbers of turbines can be built in the vast expanse of the water, avoiding trade lanes and environmentally delicate regions. The majority of Americans reside close to the coast. Nearby, offshore wind can generate the substantial amounts of energy required (Orsted, 2022).

Numerous global places are acknowledged for possessing significant potential for producing offshore wind energy. Among these crucial areas are: One of the most advanced areas for offshore wind power is the North Sea, especially off the coasts of nations like the Netherlands, Germany, Denmark, Norway, and the United Kingdom. It's the perfect place for offshore wind farms because of the strong winds and relatively shallow waters. The Baltic Sea, which is surrounded by Sweden, Denmark, Germany, Poland, and Finland, offers a great deal of opportunity for the development of offshore wind energy. To take advantage of the wind resources in the area, these nations are actively investigating offshore wind projects. East Asian nations, such as China, South Korea, and Japan, are making more and more investments in offshore wind energy. This region's expanding energy needs and highly populated coastal areas make offshore wind an attractive renewable energy source. There is a lot of room for offshore wind development along the US east coast, especially in states like Massachusetts, New York, New Jersey, and Virginia. Initiatives are in place to support the region's renewable energy targets and take advantage of the region's considerable wind resources. Other northern European nations, like Sweden, Norway, and Belgium, are looking into offshore wind power possibilities in addition to the North Sea. Due to their long coasts and powerful winds, these nations provide offshore wind as a feasible renewable energy source. Coastal nations such as Portugal and Spain are attempting to utilize offshore wind energy in order to diversify their energy sources and lessen their dependency on fossil fuels. Countries like Greece and Italy have the potential to create offshore wind farms in the Mediterranean Sea. With multiple projects in progress, Taiwan has become a major player in Southeast Asia's offshore wind energy market. As part of their goals for renewable energy, other Southeast Asian nations like Vietnam and Thailand are also thinking about including offshore wind (Lange, Focken , 2006: 6).

Currently the largest offshore wind farm in the world, Hornsea Wind Farm is situated in the North Sea off the coast of Yorkshire. There are several phases to it, the two most noticeable being Hornsea One and Hornsea Two. The combined capacity of Hornsea Wind Farm when it is fully operational will exceed 6 gigawatts (GW). Before Hornsea overtook London Array, it was the largest offshore wind farm in the world. It is situated in the Thames Estuary and has a 630 megawatt (MW) capacity. One of the biggest offshore wind farms in the world is called Walney Extension, and it is located off the coast of Cumbria in the Irish Sea. It is capable of 659 MW in total. An important offshore wind energy project with multiple phases is the Borssele Wind Farm, which is situated in the North Sea. It will have a total capacity of about 1.5 GW when it is fully operating. With a 576 MW capacity, Gwynt y Môr is one of the biggest offshore wind farms in operation in the world, and it is situated off the coast of North Wales (Lange, Focken , 2006: 6).

The offshore wind power business is dominated by a number of companies. Among the biggest businesses engaged in the development, building, and operation of offshore wind power are: The largest offshore wind developer in the world is a Danish energy business called Orsted. In both Europe and the US, Orsted has constructed and run a number of offshore wind farms. One of the top producers of wind turbines, including offshore turbines, is Siemens Gamesa. Globally, Siemens Gamesa is a significant supplier of wind turbines for offshore wind farms. Equinor is a Norwegian energy corporation that has made significant investments in the development of offshore wind power. In addition to building new projects in the United States, Equinor is the operator of multiple offshore wind farms located in Europe. Portuguese renewable energy developer EDP Renewables is now working on offshore wind generating projects in both Europe and the US. Swedish energy firm Vattenfall is involved in the development of offshore wind power around Europe. In the North and Baltic Seas, Vattenfall manages a number of offshore wind farms. GE Renewable Energy is a top producer of offshore wind turbines among its other models. Wind turbines for offshore wind farms are mostly supplied by GE Renewable Energy. A Chinese state-owned corporation, China General Nuclear Power Group is making significant investments in the development of offshore wind power in China and other countries (EKT Interactive, 2021).

CHAPTER TWO

RENEWABLE ENERGY AND WIND ENERGY IN EUROPE

Europe has become a global pioneer in the shift to sustainable energy systems in recent decades. Significant progress in the production of renewable energy has been fueled by the continent's strong commitment to lowering greenhouse gas emissions and lessening the effects of climate change. Europe's advantageous geographic and climatic features have made wind energy one of the most important renewable energy sources. A thorough examination of the region's energy policy, the larger renewable energy scene, and the particular development trajectory of wind energy is necessary to comprehend this shift. These aspects will be thoroughly examined in the sections that follow, providing a thorough summary of Europe's advancements in renewable energy and the crucial role that wind power will play in its energy future.

2.1. Energy Policies of Europe

Three guiding concepts form the basis of EU energy strategy. These are competitiveness, supply security, and sustainability (Ministry of Foreign Affairs, 2024). The implemented policies are grouped into seven key categories: renewable energy, energy efficiency and conservation, internal energy markets, energy supply security, environmental preservation, nuclear energy, and research and development. The presentation of the pertinent policies and an explanation of their purpose come first for each category, followed by an introduction that covers significant turning points in its development (Kanellakis, Martinopoulos , 2013: 1020).

The EU is a global leader in renewable energy technology research and implementation. However, according to a report published in 2021, the EU needs to further enhance its global competitiveness. Under the European Green Deal, renewable energy is a key component of the clean energy transition (European Commission, 2024).

Raising energy efficiency targets is crucial for Europe's energy transition. Efficient energy use reduces energy bills, decreases the EU's dependency on external resources, protects the environment, improves quality of life, and contributes to sustainable economic growth. To achieve these benefits, efficiency must be improved throughout the entire energy supply chain, from production to consumption (European Commission, 2024).

The European energy market is non-discriminatory, flexible, customer-focused, and competitive. It focuses on consumer protection, market access, transparency, regulation, interconnections, and supply security. The goal is to ensure a functional market with fair access, strong consumer protection, and sufficient interconnection and generation capacity (European Parliament, 2024).

Energy supply security is a recurring theme in national, European, and global energy strategies. In November 2000, the European Commission released a green paper titled "Towards a European Strategy on Energy Supply Security". The European Parliament and the Council emphasized the importance of reducing the risks associated with dependency. Since then, energy supply has been threatened by terrorist attacks, storms, accidents, blackouts, conflicts, and rising fuel prices. Hurricane Katrina in 2005 further complicated energy supply security, affecting not only oil production but also natural gas, transportation, refineries, and electricity infrastructure, impacting the entire energy system (Chevalier , 2006: 1).

The EU's broader resource efficiency goal, which includes the efficient use of all natural resources and the maintenance of strict environmental protection requirements, will include the implementation of the energy efficiency measures. The 2008 European Council and Parliament enacted the energy and climate change policy. This is a crucial first step toward the eventual objective of lowering global emissions by at least 50% below 1990 levels by 2050 when compared to levels of 2005 (Carvalho , 2012: 20).

Nuclear energy produces over 26% of the electricity generated in the European Union and is a low-carbon substitute for fossil fuels. But nuclear energy has grown quite contentious in the wake of the Fukushima tragedy in 2011 and the Chernobyl accident in 1986. EU regulation aims to ensure that nuclear waste is managed and disposed of securely, while Member States retain the autonomy to decide whether to incorporate nuclear power in their energy mix. EU policies are based on Articles 40–52 (investment, joint ventures and supplies) and 92–99 (nuclear single market) of the Treaty establishing the European Atomic Energy Community (Euratom Treaty) (European Parliament, 2024).

Since its inception, EU policy for research and technical development (RTD) has been a significant area of European legislation. A European framework program for research was added in the 1980s to further expand this policy. The majority of EU research funding in 2014 fell under the purview of Horizon 2020, a program that ensured the EU's competitiveness on the world stage and ran from 2014 to 2020. The current EU research and innovation program, Horizon Europe, was introduced in 2021 and is set to run from 2021 to 2027 (European Parliament, 2024).

2.2. Renewable Energy in Europe

Interest in renewable energy sources was spurred by the oil crisis of the 1970s, which compelled European nations to reevaluate their energy security. Hydropower was the most popular renewable energy source in Europe at the time. Water power was widely used to create energy in hilly countries like Austria, Switzerland, and Norway. The idea of renewable energy had not yet fully taken root at the policy level, despite the fact that hydropower was starting to be recognized as a viable substitute for fossil fuels (The Sustainable Agency, 2008).

As environmental concerns gained more attention in the 1980s, several European nations boosted their research expenditures on renewable energy. Using its subterranean resources, Iceland rose to prominence in the generation of geothermal energy during this time. Similarly, by using geothermal resources in the Tuscany region, Italy became one of the first countries in Europe to do so. However, fossil fuels continued to play a major role in this decade (The Sustainable Agency, 2008).

The European Union started to organize its environmental policies in the 1990s, and it was at this time that the first renewable energy targets began to take shape. Wind energy was prominent in this scenario. Germany and Spain quickly increased the usage of onshore wind turbines, while Denmark became a pioneer in this field. Simultaneously, the exploitation of agricultural waste led to the spread of biomass and bioenergy. During these years, the first experimental plants were set up to turn agricultural leftovers and forest products into energy (Schoenherr, 2025, 4).

Investments in renewable energy were boosted in the early 2000s when the European Union issued its 20-20-20 targets, which called for a 20% decrease in greenhouse gas emissions, a 20% share of renewable energy, and a 20% increase in energy efficiency by 2020. Solar energy grew significantly during this time, particularly in Southern European nations like Greece, Italy, and Spain. Small-scale solar systems and household production grew in popularity as photovoltaic panel prices started to drop. Offshore wind energy projects were started at the same time, especially in nations like Denmark, Germany, the Netherlands, and the United Kingdom that border the North Sea. Europe is now among the world leaders in wind energy thanks to these initiatives (REN21, 2014).

Europe made great progress in integrating renewable energy sources during this time. Smart grids and energy storage devices were purchased in order to balance the sporadic output of wind and solar power. Germany set an example for the rest of Europe by promoting renewable energy sources through its Energiewende (Energy Transition) strategy, which aimed to phase out nuclear power. The production of biogas and its application in heating systems during these years also led to a more methodical integration of bioenergy. Based on wood waste and forest products, the Nordic nations—especially Sweden and Finland—developed extremely effective systems (Clean Energy Wire, 2020).

The European Union's European Green Deal has made reaching carbon neutrality by 2050 a key component of its renewable energy plans for the years beyond 2020. Projects have been started along the Atlantic, Mediterranean, and Baltic Sea shores, proving that offshore wind energy is no longer limited to the North Sea. The size of solar energy applications has increased dramatically, and many nations are building massive solar parks to satisfy growing demand for clean energy. Meanwhile, emerging technologies like hydrogen energy have become more well-known, making it easier to incorporate electricity generated from renewable sources into a variety of industrial and transportation sectors. The optimization, prediction, and real-time control of energy flows across linked grids are also becoming more and more supported by artificial intelligence, which is another development in the digital management of renewable energy systems (European Commission, 2023).

2.3. Development of Wind Energy

A protracted and dynamic process, the growth of wind energy has been influenced by shifting energy demands, legislative frameworks, and technological developments. It is essential to first look at wind power's historical foundations in order to comprehend its current trends and global context. The historical context not only sheds light on the early applications of wind as a source of energy, but it also establishes the framework for examining the ways in which various nations have embraced and developed wind technologies over time.

2.3.1. Historical Development of Wind Energy

The history of wind power covers a broad range of developments, from the early use of simple devices powered by aerodynamic drag forces to the more complex devices used in the present day, propelled by sophisticated aerodynamic lift forces. The Sistan windmill, a Persian vertical axis windmill designed for grain grinding and water pumping, is the first known historical windmill design. It was driven by aerodynamic drag forces. By 644 A.D., the Sistan windmills were in operation, and they are still in use today. Windmills with a significantly altered design and method of operation first appeared in northern Europe in the 12th century. The early windmills in northern Europe all had horizontal axes, in contrast to the Sistan windmills' vertical axis design. They were employed in a wide range of mechanical operations, such as irrigation, sawmilling lumber, grinding grain, and powering equipment. Before the Industrial Revolution, windmills in Europe had advanced to a very sophisticated state of design (Allamehzadeh , 2016: 3).

Towards the close of the 1800s, wind power became the first source of energy. In Ohio in 1888, Charles Brush created the nation's first instance of employing windmill rotor power to produce electricity. A few years later, Marcellus Jacobs invented contemporary aerodynamic wind turbines and constructed a number of tiny wind turbines with electrical generators. The fact that Jacobs' wind turbines had three blades with actual air-foil designs and resembled contemporary wind turbines was one of their key characteristics. His turbine's battery-storage capability and ability to be connected into a home power system were further features. Poul La Cour constructed more than 100 power generating turbines in the 20–35 KW size range in Denmark. Based on the most recent generation of Danish smock mills, La Cour designed their product. Additionally, German engineers created extremely complex horizontal-axis wind turbines that used bearings at the rotor hub to enable the rotor to "teeter" in response to gusts of wind. In order to achieve light weight and high efficiencies, Professor Ulrich Hutter created a series of advanced medium-sized horizontal-axis wind turbines that included contemporary airfoil-type fiberglass and plastic blades with variable pitch. In 1931, the Russians built the 100KW Balaclava wind generator, a large-power utility wind generator. Large-scale wind turbines would function, as shown by the experimental wind turbine facilities that followed in the US, Denmark, and Germany between 1935 and 1970 (Allamehzadeh , 2016: 4).

Following World War II, European wind turbine development proceeded, primarily with the goal of connecting to the electrical grid. Up until the early 1960s, the 200 kW Gedser Mill wind turbine (Figure 6) in Denmark ran profitably. Its primary characteristic was akin to Poul La Cour's three-bladed, fixed pitch turbines. Regrettably, it was no longer competitive with steam-powered generating plants due to the drop in fossil fuel prices (Allamehzadeh , 2016: 4).

2.3.2. Development of Wind Energy in the World

The distinct physical, political, and economic circumstances of each nation have influenced the rate at which wind energy has developed globally. Some countries have only lately started to investigate the potential of wind, while others have become leaders by making early investments in extensive wind infrastructure. We may learn more about how national strategies, resource availability, and policy decisions affect the expansion of wind energy by looking at specific country situations. The developments in important nations are highlighted in the sections that follow, beginning with the UK, one of the major players in offshore wind energy.

2.3.2.1. United Kingdom

In terms of wind energy, the UK is one of the most prominent nations in Europe. With regard to installed capacity and technological advancements, the nation is particularly strong in offshore wind energy investments. The UK, which is made up of England, Scotland, Wales, and Northern Ireland, is a very good place to invest in wind energy because of its position and strong wind potential (Snyder, Kaiser , 2009: 5).

Since the 2000s, wind energy development in the UK has accelerated due to government backing for renewable energy, which has resulted in the implementation of significant projects. With a goal of 50 GW by 2030, the nation's total wind energy capacity as of 2023 was about 30 GW. Offshore wind farms have emerged as a major force behind this expansion in recent years (Snyder, Kaiser , 2009: 5).

Dogger Bank Wind Farm is one of the biggest projects in this field and will be the biggest offshore wind farm in the world when it is finished. This enormous project, which will be built in three stages and have a 3.6 GW overall capacity, is situated in the North Sea. Dogger Bank will use clean, sustainable wind energy to meet a sizable amount of the UK's energy needs once it is fully operational. By 2026, the project should be finished (Snyder, Kaiser , 2009: 5).

Furthermore, the UK is among the top nations in the world for developing cutting-edge floating wind turbine projects. Compared to traditional fixed-bottom turbines, these turbines, which are made to capture wind energy in deep oceans, provide more versatility and a wider range of uses. Some of the earliest large-scale floating wind energy projects in the world are Kincardine Offshore Wind Farm, off the coast of Scotland, and Hywind Scotland (Jones, Rowley , 2011: 9).

The UK's energy security plan heavily relies on these significant developments in wind generation. The nation has made wind energy a key component of its ambitions to reach net-zero emissions by 2050 in an effort to lessen its reliance on fossil fuels and cut carbon emissions (Jones, Rowley , 2011: 9).

2.3.2.2. Norway

One of the top nations for investments in renewable energy is Norway, which is especially notable for being the first to implement floating wind generating projects in deep waters. Offshore wind energy has a lot of promise thanks to the nation's long coastline and powerful wind currents. Norway is now a world leader in floating wind turbine technology, which makes it possible to generate energy in deep oceans where conventional fixed-bottom turbines are challenging to install (Lindstad, Eskeland , 2016: 99).

Hywind Tampen is among the most important projects in this respect. This project, which supports oil and gas platforms, is the first large-scale floating wind farm in the world. By supplying Norway's North Sea oil fields with renewable energy, Hywind Tampen not only cuts carbon emissions and the use of fossil fuels, but it also serves as an example of how offshore wind energy can be applied to a variety of industries (Lindstad, Eskeland , 2016: 99).

Norway wants to have at least 30 GW of offshore wind energy capacity by 2030, and it is not restricting itself to projects that are already underway. The government is offering substantial incentives for investments in renewable energy, and new projects are being created to achieve this goal. The development of floating wind technology is made possible by Norway's robust engineering and maritime infrastructure, opening the door for future international expansion (Lindstad & Eskeland , 2016: 99).

In addition to improving Norway's energy independence, this approach makes a substantial contribution to Europe's green transition. Norway's leadership in wind energy is reinforced by investments in carbon-free energy production, which also guarantee that the nation will play an even bigger role in the development of renewable energy in the future (Lindstad, Eskeland , 2016: 100).

2.3.2.3. Türkiye

Türkiye has established itself as one of the region's leading nations for the development of renewable energy because to its notable advancements in wind energy in recent years. The nation's installed wind power capacity surpassed 12 GW as of 2023, indicating the industry's explosive growth. Türkiye is aggressively developing its wind energy infrastructure with the ambitious goal of 30 GW by 2035 in order to fulfill rising energy demands and lessen dependency on fossil fuels (Yılmaz, Demirtaş , 2020: 67).

Onshore wind energy projects in the nation have advanced remarkably, especially in the Aegean and Marmara regions where wind conditions are ideal. With some of the biggest wind farms in the country, these areas have emerged as the hubs of Türkiye's wind energy growth. Government laws, incentives, and private sector involvement have all encouraged wind energy investments, which have helped to steadily increase the use of renewable energy sources (Yılmaz, Demirtaş , 2020: 67).

As part of its long-term renewable energy policy, Türkiye has begun investigating offshore wind energy in addition to onshore projects. With the goal of utilizing the nation's long coasts and abundant wind resources to build massive offshore wind farms, feasibility studies for offshore wind projects are presently being conducted. These projects have the potential to greatly increase Türkiye's wind energy capacity and further diversify its energy mix if they are carried out effectively (Yılmaz, Demirtaş , 2020: 68).

Türkiye is well-positioned to emerge as a major force in the global renewable energy market thanks to its well-defined strategy and steadfast dedication to wind energy. The nation's commitment to a sustainable and environmentally friendly future is demonstrated by its focus on increasing wind capacity, incorporating cutting-edge technologies, and investigating offshore wind prospects (Yılmaz, Demirtaş , 2020: 68).

2.3.2.4. China

China is now the world's biggest producer of wind energy, contributing significantly to the global switch to renewable energy. With more than 400 GW of combined onshore and offshore wind energy capacity as of 2023, China is at the forefront of the sector in terms of both large-scale project development and technology developments. The nation's deliberate wind energy investments demonstrate its dedication to cutting carbon emissions and obtaining energy security from renewable sources (Zhao, Liu , 2021: 70).

China has advanced significantly in wind energy, both offshore and onshore. Large-scale onshore wind farms have been established throughout the country's vast inland regions, capitalizing on the reliable and powerful wind conditions found in places like Inner Mongolia, Xinjiang, and Gansu. These massive wind farms help the nation produce more renewable energy and lessen its reliance on coal-fired power plants (Zhao, Liu , 2021: 70).

China is making impressive progress in offshore wind energy in addition to onshore advancements. The nation is building massive offshore wind farms along its vast coastline, especially in provinces like Jiangsu, Guangdong, and Fujian, by utilizing cutting-edge technology. These projects optimize electricity generation in deep oceans by utilizing floating wind technology and state-of-the-art turbine designs (Zhao, Liu , 2021: 70).

China is at the forefront of the global wind energy market thanks to its dedication to innovation and widespread deployment. In the upcoming years, China is expected to increase its wind energy capacity even further through sustained investments in wind infrastructure, technology, and grid integration. Wind energy will continue to be a key component of China's sustainable energy policy as it works toward its 2060 carbon neutrality target, enhancing its position as a leader in the world's renewable energy revolution (Zhao & Liu , 2021: 71).

2.3.2.5. Russia

Russia has been steadily growing its investments in wind energy, even though it entered the market later than other large economies. With about 2 GW of built wind energy capacity as of 2023, the nation has made steady but sluggish progress. Even while wind energy only makes up a small percentage of Russia's total energy mix at the moment, fresh developments show that there is significant interest in increasing the generation of renewable energy (Petrov, Ivanova, 2022: 45).

Russia's enormous geographic potential is one of the main factors affecting the wind energy industry there. Large-scale wind farms could be supported by the robust and steady wind currents found in the Siberian and Far Eastern areas, which have substantial wind energy resources. However, because of logistical constraints, severe weather, and infrastructure issues, project development in these isolated places has been comparatively slow. Notwithstanding these obstacles, the government has started offering incentives to entice investments in the wind farm industry, and a number of new wind farm projects have been started (Petrov, Ivanova, 2022: 45).

Russia has stepped up its wind energy initiatives in recent years, and both domestic and foreign energy businesses are taking part in new projects. In an effort to diversify its energy sources beyond conventional fossil fuels, the nation is progressively incorporating wind power into its energy grid. Although the current capacity is still limited, plans for future expansion and technical developments may enable Russia to fully realize the potential of its wind energy industry (Petrov, Ivanova , 2018: 45).

Russia's attitude to wind energy will be vital in determining its long-term energy policy as the world continues its transition to renewable energy. In the upcoming decades, the nation may play a bigger role in the global wind energy market if it can get past development obstacles and take advantage of its vast wind potential (Petrov, Ivanova , 2018: 45).

2.3.2.6. Japan

As part of its larger shift to renewable energy sources, Japan has been making significant investments in wind energy. In order to effectively harness offshore wind power, Japan has mostly concentrated on floating wind energy projects due to the country's deep coastline waters and limited land availability. Japan is now a pioneer in floating wind technology thanks to this creative strategy, which enables the country to build wind farms in deeper oceans where conventional fixed-bottom turbines are impractical (Tanaka, Saito , 2019: 187).

When Japan put its first large-scale offshore wind farm into operation in 2023, it was a momentous milestone. A significant step toward bolstering the nation's wind energy industry and lowering its reliance on imported fossil fuels was taken with this breakthrough. It is anticipated that offshore wind energy will be essential to Japan's energy transition, boosting energy security and advancing the country's carbon neutrality objectives (Tanaka, Saito , 2019: 187).

Japan has set the lofty goal of having 10 GW of offshore wind energy capacity by 2030. Through regulatory incentives, subsidies, and research projects aimed at developing floating wind turbine technology, the government has been actively supporting new offshore wind projects in order to accomplish this goal. There are currently a number of significant offshore wind farms in the planning and building stages, especially in places with abundant wind resources like Kyushu, Tohoku, and Hokkaido's coastal regions (Tanaka, Saito , 2019: 187).

Japan is establishing itself as a significant player in the global wind energy market with its strategic concentration on floating offshore wind energy. Japan hopes to ensure a more resilient and sustainable energy future by utilizing cutting-edge technologies and increasing offshore wind capacity, which will lessen its need on traditional energy sources and aid in the worldwide fight against climate change (Tanaka, Saito , 2019: 187).

2.3.3. Development of Wind Energy in European Union and Member States

Wind power is becoming a key component of the European Union's energy and climate policies as it positions itself as a global leader in the shift to renewable energy. The growth of wind energy throughout the continent has been greatly influenced by EU-wide policy, financing sources, and cooperative frameworks. Before looking at particular instances from various member states, it is crucial to assess the overall development of wind power in Europe in order to completely understand the EU's role in the growth of wind energy globally.

2.3.3.1. Development of Wind Energy in Europe

The energy crises of the 1970s, especially the oil embargo in 1973, revealed how heavily industrialized countries rely on the importation of fossil fuels, particularly crude oil. The embargo, which was sparked by Middle Eastern geopolitical tensions, caused severe spikes in oil prices, extensive fuel shortages, and economic disruptions in many regions of the world. This incident exposed the strategic vulnerability of an excessive dependence on a single energy source in addition to destabilizing the energy markets. Energy security consequently became a key issue in both domestic and global policymaking (Andersen, Müller, 2022: 74).

Governments and international organizations started reevaluating their long-term energy strategy after the crisis. One of the main themes was the idea of diversifying the energy supply, both geographically and in terms of its sources. The dual objectives of lowering reliance on imports and lowering the risks of future supply disruptions led to a major increase in research and development of alternative energy technology. As a clean, plentiful, and locally accessible resource, wind energy began to be recognized as a potential component of this diversification endeavor. This signalled the start of a paradigm change away from policies that prioritized fossil fuels and toward more sustainable and balanced energy strategies (Andersen, Müller, 2022: 74).

The crisis led to a more thorough reexamination of environmental sustainability in addition to pressing energy-related issues. Renewable energy was increasingly viewed as an ecological necessity as well as an economic and security solution as the use of fossil fuels and the emissions they produce were more directly linked to global environmental problems like air pollution and climate change. As a result, environmental goals were progressively incorporated into energy planning. Global initiatives started to take shape throughout the ensuing decades thanks to international discussions, environmental regulations, and frameworks for policies that promote the growth of clean energy. These initiatives laid the groundwork for the global shift to renewable energy, which includes the widespread expansion of wind power (Andersen, Müller, 2022: 75).

In the 1980s, there were additional attempts to create big wind turbines in Europe. Among them was the UK's Orkney-60 wind turbine, with a capacity of 3 megawatts. Through the European Economic Community's (EEC) Wind Energie Grösse Anlagen (WEGA) program, governments throughout Europe were working together to advance the construction of megawatt-scale wind turbines. The Tjaereborg 2-MW wind turbine in Denmark, the 1-MW Richborough wind turbine in the United Kingdom, the 1.2-MW AWEC-60 wind turbine in Spain, and the 2-MW Gamma wind turbine in Italy are the products of this program. These massive wind turbines, like the Swedish and German initiatives, didn't, however, immediately result in commercialization (Janzing, Oelker , 2019: 215).

The historic report, commonly referred to as the Brundtland Report, was released in 1987 by the United Nations World Commission on Environment and Development. This paper played a key role in introducing the idea of "sustainable development" into the discussion of international policy. "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" is how it defined sustainable development. This definition laid the groundwork for a comprehensive approach to the problems of global development by highlighting the connections between social justice, environmental preservation, and economic progress (Andersen, Müller, 2022: 76).

The Brundtland Report's recommendation for a shift to ecologically friendly energy systems, with a focus on the advancement of renewable energy sources like wind, was one of its main contributions. In order to reduce greenhouse gas emissions and mitigate climate change, the research emphasized the environmental hazards associated with ongoing reliance on fossil fuels and listed clean alternatives like wind power as crucial. The report's promotion of wind energy as a clean, plentiful, and sustainable resource contributed to the development of a worldwide narrative that acknowledged wind power as a long-term answer for attaining energy security and sustainability as well as an environmental need. In the decades that followed, this viewpoint was crucial in promoting global support for the growth of wind energy (Andersen, Müller, 2022: 76).

The 1987 Single European Act served as the legal foundation for EU environmental policy (Balcı , 2006: 116). The goal of the Single Market created a more advantageous economic climate for the free flow of renewable energy technology, such as wind energy, and for boosting investments in this area throughout Europe. The growth of renewable energy projects was made easier by the member states' integration of their energy markets and infrastructure (Andersen, Müller, 2022: 77).

The Fourth Action Program, which spanned six years (1987–1992), was adopted shortly after the Single European Act was ratified. Integrating environmental policy with other policies became a major concern for the first time. The Action Program's objectives were to protect and improve the quality of the environment (particularly in the areas of biotechnology, noise, chemical products, and air and water pollution), protect human health, develop research and activities at the international level, integrate environmental policies with other Community policies, and coordinate and harmonize the various national environmental policies (to be implemented by the proper application of the Treaty norms, the carrying out of the planned actions, the application of appropriate procedures for the information on the environment's conditions) (Vardi, Zeno-Zencovich , 2004: 233-234). The main topics of this action plan were energy efficiency, energy conservation, and a shift toward alternative energy sources in response to the oil crisis (Andersen, Müller, 2022: 77).

The 1992 Rio de Janeiro UN Conference on Environment and Development (UNCED) marked the next significant milestone for global environmental regulation. The Commission on Sustainable Development (CSD) was established during this meeting. Under the auspices of the UN Economic and Social Council (ECOSOC), the CSD was tasked with overseeing the local, national, and global implementation of Agenda 21, developing political alternatives for the aftermath of Rio, and fostering communication and collaboration among governments, the international community, and civil society (Balcı , 2006: 92).

Adoption of ecologically friendly energy sources is encouraged by Agenda 21, an action plan for sustainable development. A framework for lowering greenhouse gas emissions worldwide was established by the UN Framework Convention on Climate Change (UNFCCC), which was ratified at the Rio Summit. In the battle against climate change, renewable energy sources—particularly wind energy—were marketed as fossil fuel substitutes. The preservation of biodiversity was recognized as a primary priority in keeping with the objectives of switching to renewable energy sources and attaining environmental sustainability. It was underlined that the effects of renewable energy projects (like wind energy) on biodiversity should be taken into account when developing them. Promoting the transmission of renewable energy technologies, such wind energy technology, to developing nations was another agreement reached at the meeting. This is a big step in the direction of wind energy's widespread use (Andersen, Müller, 2022: 78).

The new European Union Treaty had a significant impact on the 1992 enactment of Fifth Action Program, which covered the years 1993–2000. This Action Program does, in fact, concentrate on sustainable development, the global aspect of environmental policy, and the increasingly intimate relationship that ought to exist between environmental issues and social and economic advancement, particularly in developing nations. The program identified specific areas that needed priority in collective action, including sustainable management of natural resources, integration of pollution prevention and waste management measures, decrease in non-renewable energy consumption, improved mobility management, enhanced urban environment quality, and more incisive measures in health and security issues (Vardi, Zeno-Zencovich , 2004: 236).

The European Commission released its so-called "Green Paper" on European Contract Law in a communication to the Council and the European Parliament in July 1995. Feedback on the possibilities presented by the Commission for potential future European Community contract law action is requested in this document (Weatherill, 2001, 339). Regarding energy policy, it committed to raising the share of renewable energy (Wind Europe, 2024).

EU White Paper published in 1997. Insisting on "a generalized development of clean products and processes," the White Paper highlights the goal of achieving sustainable development (Hitchens , 1997: 813). By 2010, the proportion of renewable energy in Europe should increase from 6% to 12% (or from 14% to 22% of the electrical supply), according to a White Paper from the EU (Wind Europe). The foundation for European Union policy on renewable energy was established in 1997 with the publication of the White Paper for a Community Strategy and Action Plan Energy for the future: Renewable sources of energy. By 2010, it was suggested that the proportion of renewable energy in the EU's gross energy consumption will double, from 6% to 12%. 2010 also saw the establishment of many technology-specific goals, such as 40 GW of installed wind energy capacity. By the end of 2010, installed capacity for wind energy had surpassed 40 GW, while installed capacity for PV had surpassed 3 GW by a significant margin, standing at 29 GW. The proportion of renewable energy in gross inland energy consumption increased from 4.4% in 1990 to 9.8% in 2010, missing the indicative target of 12% in 2010. The Member States (MS) have made significant progress toward meeting their national indicative targets (Scarlat, Dallemand, 2015, 970-971).

The estimates of CO2 emissions for wind-powered electricity generation can be defined in a variety of ways. They rely on the presumptions made about which fuels are replaced by wind energy (Zervos, 2003, 67). Kyoto Protocol (1997) is very crucial in this point (Andersen, Müller, 2022: 79).

In order to lessen its reliance on foreign energy and minimize the costs to its economy's ability to compete globally, the EU has adopted the Kyoto Protocol as a tool and part of its overall plan (Filippis, Scarano, 2010: 40). The protocol is an essential part of this plan and a mechanism that encourages the use of renewable energy sources, such as wind power, to reduce greenhouse gas emissions and promote energy independence. Among the resources that prove to be invaluable in accomplishing these two goals is wind energy. Through the utilization of wind power, the European Union hopes to improve energy security, diversify its energy sources, and lessen its need on imported fossil fuels. Moreover, wind energy is a financially viable approach to decarbonizing the economy without sacrificing competitiveness internationally. By means of policies and actions that are in line with the Kyoto Protocol, the European Union aims to harness the sustainable potential of wind energy in order to propel economic growth, improve energy resilience, and propel its climate commitments on a regional and global level (Andersen, Müller, 2022: 80).

The Windforce 10 report (1999), released by EWEA, Greenpeace, and the Danish Forum for Energy and Development, demonstrates how wind power might provide 10% of the world's electricity by 2020 (Wind Europe). According to this 10%

global scenario, Europe was expected to install 220 GW of wind power by 2020, while non-European countries were projected to install approximately 1000 GW over the same time frame (Hatziargyriou, Zervos, 2001, 1770). Numerous scientific evaluations compiled in this paper demonstrate how vast and evenly distributed the world's wind resources are over six continents. According to the analysis, there is little chance that the amount of wind available worldwide will ever be a barrier to the use of wind energy for the generation of electricity (Rave, Bierregaard, 1999, 6).

Furthermore, through its Framework Programs, which allocated a sizeable portion of the budget to non-nuclear energy, the European Commission has consistently funded wind power research and development. For example, 2.125 billion euros, excluding nuclear energy, have been set aside for energy, the environment, and sustainable development in the 5th Framework Programme, which has a budget of 14.96 billion euros for the years 1999–2002. Approximately 1 billion euros, of which 36 million euros are for wind energy, have been made available for energy systems that use renewables (Hatziargyriou, Zervos, 2001, 1766).

Europe is home to about 70% of the world's wind turbines, or about 300,000 MW, that are used to generate power. 3500 MW of these were installed in 2000 alone, demonstrating the remarkable rate of development over these years. With two thirds of the global market share, the European wind manufacturing sector is expanding concurrently. These astounding advancements are credited to the European Union's and the national European governments' effective assistance, which followed their pledge to cut greenhouse gas (GHG) emissions. Consequently, wind energy is viewed as a low-impact, economical substitute for other traditional electricity generation methods, offering evident advantages to both the environment and the overall economy (Hatziargyriou, Zervos, 2002, 1765).

The Treaty of Nice, which was signed on February 26, 2001, and which modified the previous Treaties. It becomes operative on February 1st, 2003. The revised second paragraph of Article 175—which replaced the previous paragraph 2—is noteworthy from an environmental perspective since it modifies the precise areas that call for consensual decision-making processes (Vardi, Zeno-Zencovich , 2004: 237).

The main reason why major European environmental groups called the Treaty of Nice a "failure" was because it contained no provisions to further climate, sustainability, and environmental protection policy. In order to streamline decision-making procedures in advance of EU enlargement, the treaty concentrated on institutional reforms within the EU. It did not, however, include sustainable development goals into its framework or address urgent environmental issues. The Treaty of Nice was viewed as a lost chance at a time when environmental and climatic issues were garnering international attention since it failed to commit the EU to more robust environmental policies or set any particular environmental targets. The treaty, according to environmental organizations, ignored sustainable development principles and did not integrate environmental concerns into the main decision-making processes of the EU. Enhancing EU institutions and governance was the treaty's main goal, with little consideration given to how these changes might help or solve environmental issues. The EU had begun to develop a more progressive environmental position, and this was seen as a step backward (Andersen, Müller, 2022: 80).

The Sixth Action Program, which covered a ten-year period beginning on July 22, 2002, was implemented after the Fifth Action Program concluded in 2000. The program's scope emphasizes specific issues while insisting on previously established goals, such as encouraging the inclusion of environmental concerns in all Community policies and helping to achieve sustainable development throughout the present and future expanded Community. Climate change, biodiversity, the environment and human health, natural resources, and waste are among the major environmental objectives that have been established (Vardi, Zeno-Zencovich , 2004: 237).

In order to lessen dependency on fossil fuels and cut carbon emissions, the initiative promoted the development and integration of renewable energy sources, such as wind energy. By promoting technology, the initiative aimed to raise the proportion of renewable energy in the overall energy mix, in line with EU renewable targets. In order to achieve the EU's environmental and energy security objectives, the initiative promoted innovation, research, and investment in clean energy technology (Wind Europe, 2024).

The Cartagena Protocol on Biosafety, an international pact under the Convention on Biological Diversity (CBD), is referred to as the Biosafety Protocol 2003. Adopted in 2000, it became operative on September 11, 2003. The protocol's goal is to guarantee the safe handling, transportation, and use of living modified organisms (LMOs) produced by contemporary biotechnology that can negatively impact the environment, human health, or biodiversity. The precautionary approach, advance informed agreement (AIA), information sharing and transparency, and capacity building are some of the main goals and characteristics. The precautionary principle is emphasized by the precautionary approach, which permits nations to restrict or outright ban the importation of LMOs in the event that there is inadequate scientific proof of their safety. The Advance Informed Agreement (AIA) lays forth protocols to guarantee that nations have the data they need to decide whether to allow LMOs to cross their borders. A Biosafety Clearing-House (BCH) is established through information sharing and transparency to promote the sharing of biosafety-related experiences and information on LMOs. Building capacity helps developing nations acquire the know-how and infrastructure required to put biosafety measures into place (Andersen, Müller, 2022: 80).

The system was introduced in 2005 after the EU ETS Directive was approved in 2003. The first worldwide emissions trading scheme in history is the EU ETS. The fourth phase is now underway (2021-2030). The intermediate goal of a minimum 55% net reduction in greenhouse gas emissions by 2030 was one of several legislative proposals adopted by the European Commission on July 14 , 2021: outlining the EU's plans to become climate neutral by 2050. The package outlines in concrete terms how the Commission plans to meet EU climate targets under the European Green Deal by amending a number of EU climate laws, including the EU ETS, the Effort Sharing Regulation, and laws pertaining to land use and transportation (European Commission, 2024).

COP 11 marked the first Meeting of the Parties to the Kyoto Protocol to discuss matters pertaining to the Protocol after its enforcement started in 2005. At MOP 3, which took place in 2007, the Bali Action Plan was unveiled and discussions were made regarding a framework for mitigating climate change that would stretch beyond 2012. As stated in the Bali Action Plan, the parties hope to reach a legally binding agreement during the Copenhagen summit in two years. Finally, in December 2009, COP 15/MOP 5 took place in Copenhagen. The Copenhagen Accord, which is the post-Kyoto climate pact and is still pending additional discussions, was ultimately agreed by COP 15/MOP 5 in lieu of a legally binding agreement to tackle climate change (Lau, Lee , 2012: 5282).

As part of the attempts to tackle climate change, a variety of renewable energy sources, including wind energy, were explored during COP 15 in Copenhagen. It was noted that shifting away from fossil fuels and lowering CO2 emissions would require wind energy, a tested method of producing electricity devoid of greenhouse gas emissions (Andersen, Müller, 2022: 81).

Although TPWind was introduced in 2006 with strong policy support, the network came together to create the platform through the project UpWind, which was supported by the 6th EU Framework program. This project served as a trial run for creating the network that will eventually become TPWind. 43 partners from the European business and research groups were involved in the initiative. European Wind Associations (EWEA) and the European Academy of Wind Energy (EAWE) were the driving forces behind the UpWind application, and they continue to be important supporters to this day (Ricard, 2015, 12).

The primary industry participants in the TPWind initiative include both major producers of wind turbines and smaller businesses that specialize in aerodynamics. The primary driving is the projection that wind energy will account for 12–14% of the power consumed in the EU by 2020, with a total installed capacity of 180 GW. The goal is to reach 300 GW of installed capacity by 2030. TPWind has stated that it will evaluate the total amount of finance from both public and commercial sources that is available to complete this task (Ricard, 2015, 13).

The European Union's 7th Framework Programme (FP7), which focuses on research, technological development, and demonstration activities, is a tool for implementing the Lisbon Strategy's political goal of making the EU economy the most competitive, dynamic, and knowledge-based economy in the world by 2010. It is intended to be an even more ambitious and inventive continuation of the preceding sixth framework program. The program's duration is set for January 1 , 2007: through December 31, 2013. The five specific programs that make up FP7 are Cooperation, Ideas, People, and Capacities (as well as a fifth program on nuclear research that is not included in this brochure1). FP7 differs from the previous framework program in that it has a new structure, a budget that has been significantly increased, new participation rules, a longer duration (seven years as opposed to four), more flexible funding schemes, and simpler implementation procedures that involve some degree of externalization of administrative tasks (European Commission). Projects to increase wind turbine efficiency, advance offshore wind energy technology, and improve wind energy system integration with the electrical grid were carried out under the auspices of these initiatives. In addition, FP7 sought to meet targets for renewable energy and boost Europe's competitiveness in the world wind energy market. Innovative innovations were developed as a result of the program's strengthening of partnerships in the field of wind energy among research institutes, universities, and industry organizations (Andersen, Müller, 2022: 81).

Adopted in 2008, the EU Strategic Energy Technology Plan (SET-Plan) aims to direct funds for low-carbon technology research and innovation in Europe, thereby expediting the advancement and implementation of these technologies. The development of important energy technologies, such as wind, solar, electrical grids, biofuels, carbon capture and storage, and nuclear fission, was encouraged by the creation of several European Industrial Initiatives (Scarlat, Dalleman, 2015, 971). In response to the diminishing and dispersed funding of energy research in Europe, the Plan was deemed an essential component of the EU policy portfolio, which was required to combine limited resources in order to meet the energy and climate targets that were set forth in 2007 and beyond. The goal of the SET-Plan was to use extensive demonstration projects to take low-carbon technologies from concepts to the mainstream market. Considering the amount of money required to construct these kinds of projects, coordinated EU action was considered necessary. It's possible that promising technology won't make it to market due to unsuccessful demonstration initiatives. In addition to promoting low-carbon technology development in Europe, the Plan sought to position the EU as a leader in global markets for these technologies (Skjærseth, Eikeland , 2021: 1-2).

With the goal of addressing the issues of combating climate change and securing energy supply, the Energy Act was ratified on November 26 , 2008: and it contains provisions pertaining to importing and storing gas, electricity produced using sustainable resources, transmission of electricity, payments to small-scale, environmentally friendly power producers, the closing of wells and energy installations, handling and getting rid of waste generated when nuclear plants are operating, petroleum-related licenses, access by third parties to pipeline improvements and oil and gas infrastructure, reporting on topics related to energy, the obligations of the Markets Authority for Gas and Electricity, reimbursements for heat produced from renewable sources, power and gas meters, as well as provisions for the safety of electricity, the safety of hardware, software, and data concerning nuclear issues (Croner-i). In this regard, marine wind energy is a pertinent substitute since it is a clean, domestic, renewable energy source. The new generation Policy's three main goals—lowering greenhouse gas emissions, enhancing supply security, and boosting Union competitiveness—can all be significantly aided by maritime wind generation (EUR-Lex, 2024)

In the US and Europe, interest in new wind projects has decreased as a result of the financial crises of 2008 and 2009. However, tensions in the Middle East over politics and the March 2011 Fukushima Daiichi nuclear power plant accident in Japan reignited interest in nuclear and non-nuclear energy sources. More consistently, wind energy was being distributed geographically. Of the world's capacity in 2000, Germany accounted for one-third, followed by Denmark, Spain, and the United States with 14% each. After ten years, Denmark's share of the global market had decreased to less than 2%, and the United States had taken over as the industry leader with 21% of global capacity. China emerged as the nation with the most installed capacity, seemingly out of nowhere. A further 7% came from India. Even the wind industry's underdogs in Europe, like France, Great Britain, and Italy, witnessed tremendous increase in wind capacity; at the end of the decade, each nation accounted for between 3% and 4% of the world's total wind capacity. After 2005, wind energy in Portugal saw a notable increase. After five years, it might generate as much wind energy as Denmark (Jones, Bouamane , 2011: 47).

The Environmental Impact Assessment (EIA) Directive, which has been in effect since 1985, is a primary piece of legislation aimed at safeguarding the natural world. Three amendments to the EIA Directive were made in 1997, 2003, and 2009. The 2003 modifications in particular are significant for wind energy projects since they brought the EIA Directive into compliance with the UNECE Aarhus Convention (UNECE, 1998), which addresses public participation and access to environmental information (Hansen , 2011: 10).

The EU's commitment to change was outlined in the 2007 European Commission proposal, "Energy policy for Europe" (COM(2007) 1 final), and "Limiting Global Climate Change to 2 1C–The way ahead for 2020 and beyond" (COM(2007) 2 final). This contained an obligatory EU aim of 20% renewable energy, including a 10% target for renewable energy for 2020, and an EU commitment to achieve at least a 20% reduction in GHG emissions by 2020 compared to 1990 levels (Scarlat, Dallemand, 2015, 971). The objective was to raise the proportion of wind energy in the generation of electricity and decrease greenhouse gas emissions by 20% in comparison to 1990 levels. Numerous funding options and other forms of assistance were put up to encourage the growth of wind energy plants (Andersen, Müller, 2022: 82).

Staff members of the Transition Team initiated briefing and negotiating with congressional staff members regarding the specifics of the proposed Recovery Act in December 2008. The energy and environment policy group gave a summary of the clean energy package and introduced the four main themes, or priorities, along with the particular policies that went along with them: Efficiency measures include residential weatherization, state block grants, building retrofits, and lowering government energy use. The grid includes the Western Area Power Administration (WAPA) expanding transmission capacity and using smart grid technology. Transportation-related initiatives include investing in public transportation, accelerating the replacement or retrofit of heavy-duty diesel engines, and boosting the production of automobile batteries. Sustainable energy includes carbon capture technology demonstration at coal plants and the promotion of renewable energy including wind through production tax incentives and financial guarantees (Aldy , 2013: 6).

The European Commission's energy plan for the years 2010 to 2020 was outlined in Energy 2020: A strategy for competitive, sustainable, and secure energy (COM(2010) 639). The five main goals of the new energy strategy are to create an energy-efficient Europe, establish an integrated energy market, ensure safety and security, maintain leadership in energy innovation and technology, and bolster external relations (Scarlat, Dalleman, 2015, 971). To meet the 2020 energy and climate change targets, the European Commission set important wind energy targets in 2010. Among these goals were reaching 230 GW of installed wind energy capacity in Europe and

15% wind energy share of overall power generation. The goals also included advancing wind energy technologies, raising turbine efficiency, cutting maintenance expenses, and resolving the technical difficulties associated with offshore wind energy projects. To encourage investment in wind energy projects, a number of financial incentives and support systems were also put forth with the intention of bolstering legislative and regulatory backing. In order to address climate change and expedite Europe's transition to renewable energy sources, these aims are essential (Andersen, Müller, 2022: 83).

Rio+20, also known as the United Nations Conference on Sustainable Development, was held in Rio de Janeiro, Brazil, from June 20 to 22 2012 (Sustainable Development, 2022). A draft document has changed through multiple conversations from an original one that collected and aggregated contributions from countries, important civic groups, and international organizations. From June 15–22 , 2012: nearly 20,000 individuals, including journalists, representatives of significant groups, UN employees, and government delegations, gathered at the Rio Convention Center. Governments and significant organizations sponsored side events in a dedicated pavilion, and other rooms were used for open and closed meetings. Businesses, academic institutions, and civil society organizations also staged hundreds of side events, such as the "People's Summit for Social and Environmental Justice," which was hosted in 1992 at the same location as the "Global Forum," a civil society gathering (Andersen, Müller, 2022: 83).

Many observers found the Rio+20's outcome to be disappointingly modest, particularly those from civil society organizations. Many people thought the final declaration, "The Future We Want," which was 53 pages long and contained 283 words, was a poor and uninspired text. Indeed, it was called "The Future We Don't Want" by NGOs (Sanchez, Croal , 2012: 47).

There is disagreement on a number of important topics, including the "green economy," which is a fundamental idea at this conference. When comparing the comparatively upbeat viewpoint and recommendations of UNEP (2011) with those put forth in UNRISD (2012), which demands careful consideration of its social dimensions, it becomes clear that not only is its meaning not universally accepted, but also that many CSOs and even UN bodies do not share its reasoning (Sanchez, Croal , 2012: 48).

The Rio+20 result statement restates earlier pledges, as shown in paragraph 99, for instance: As appropriate, we support regional, national, subnational, and local initiatives that advance public involvement, information access, and access to justice in environmental issues. This is a condensed form of Rio Declaration Principle 10. Some of the passages seem really pessimistic. In light of several decades of persistently failed attempts to come to an agreement to reduce greenhouse gas emissions, we reiterate that climate change is one of the biggest issues of our time and voice profound worry that emissions of greenhouse gases continue to climb globally (Sanchez, Croal , 2012: 49).

Impact assessment is only mentioned once in the outcome document, under the "Oceans and Seas" subsection (which is a subheading of V. A. Thematic areas and cross-sectoral issues): Additionally, we pledge to strengthen efforts to shield delicate marine ecosystems from serious negative effects, especially by making good use of impact assessments (paragraph 168). The acknowledgement of the significance of technology assessment is a related topic, as stated in the section on "Means of Implementation": We acknowledge the significance of enhancing national, regional, and international capacities in research and technology assessment, particularly in light of the potential deployment and rapid development of new technologies that may also have unanticipated negative effects, particularly on biodiversity and health, or other unanticipated consequences (paragraph 275) (Sanchez, Croal , 2012: 49).

The Global Wind Energy Council's (GWEC) 10th annual global report, "Global Wind Report 2014," contains significant information about developments in the wind energy sector. In 2014, Europe reached a market growth of 5%. Germany set a new record with approximately 5,300 MW of installations. Thus, Germany became the third country, after China and the USA, to achieve installations exceeding 5,000 MW in a single year. The United Kingdom, Sweden, and France had a good year in 2014, while Poland and Turkey were also among the countries that had a positive year (Yeni Enerji, 2015)

GWEC's 2020 report states that in order to meet global climate targets, wind energy capacity needs to be increased by at least 180 GW annually over the next decade. The sector set a record in 2020 with 93 GW of new capacity installations, but it is emphasized that this current pace is insufficient to reach the net-zero emissions goal. The report highlights that governments need to implement swift and effective policies by removing bureaucratic barriers, increasing infrastructure investments, and making energy markets suitable for renewable energy (Yeni Enerji, 2015).

With the introduction of the EU Energy Roadmap 2050, legally enforceable renewable energy targets for 2030 may be established by 2014 (Wind Europe). The European Council decided on the headline targets for 2030 in October 2014, which included an indicative aim of 27% energy efficiency, a binding EU-wide target of at least 27% renewables, and domestic GHG reductions of at least 40%. We address three key issues that come up in the context of establishing a renewable target for 2030 that is being discussed in the political sphere, based on a thorough modeling analysis of the European electricity sector: (i) In accordance with a long-term decarbonization route through 2050, what is the cost-effective RES-E share for 2030? (ii) What financial consequences result from setting RES-E shares higher than the one that is most cost-effective? (iii) What implications does the European level formulation of the RE objective (instead of the Member State level, as of 2020) have for the distributive question (Knopf, Nahmmacher, Schmid, 2015, 18-19).

It is intended to enhance wind energy production capacity through the upgrade of electrical transmission and distribution infrastructure, which will make the integration of wind energy sources easier. Support for research and development (R&D) has been given to develop wind energy technology, which has made it possible to produce wind turbines that are more economical and efficient. In particular, laws that facilitate investments in this sector have been developed, and the building of offshore wind farms has been encouraged (Andersen, Müller, 2022: 84).

The SAVE Program is the main focus of the EU's non-technological activities regarding energy efficiency. Within the framework of this program, the EU ensures efficient energy use through policy measures, pilot activities, and local/regional energy management. The program promotes frugality and efficiency in energy consumption within the industry, commerce, and transportation sectors in the EU. Under the SAVE Program, the EU has spent 170 million Euros by the year 2006 (İncekara , 2019: 303).

The COOPENER Program promotes the efficient use of energy and the provision of energy from renewable sources internationally. The EU spent 17 million Euros on the COOPENER Program, covering the years 2003-2006 (İncekara , 2019: 303). This Key Action's (Coopener) immediate goal is to bolster local capacity in the areas of energy policy and regulations in order to support national, local, or regional energy policy makers and regulators in their efforts to establish market conditions that will encourage the supply of energy services, which can be utilized to reduce poverty in developing nations' peri-urban, urban, and rural areas. For example, providing sustainable power for lighting, communications, water pumping, and wealth-creating machinery, as well as sustainable heat for cooking and building heating and cooling, can make it more appealing and easier for local actors, including the private sector, to mobilize investments in the provision of sustainable energy services for health, education, housing, and wealth-creating activities for the energy poor (Fonseca , 2004: 39).

SYNERGY is a cooperation program managed by the Directorate-General for Energy and Transport of the European Commission. The program provides funding to shape and implement cooperation activities with non-EU countries to ensure that energy policy benefits the participants. Unlike other EU programs, the SYNERGY program addresses the external dimension of the EU's energy policy. The support provided under the SYNERGY program has generally not been less than 250,000 Euros per project. SYNERGY has been integrated into the "Intelligent Energy for Europe" program (İncekara , 2019: 303).

The European Union has set the '20-20-20 Targets' to foster economic development in 2008. This plan aims for a 20% reduction in greenhouse gas emissions, a 20% increase in energy efficiency, and a 20% increase in the share of renewable energy (Çetin , 2021: 211). To ensure energy supply diversity and security and to achieve the "20-20-20" energy targets (which include energy efficiency, clean use of fossil fuels, and the promotion of cogeneration powered by renewable sources, among others), the EU is developing various energy programs. Additionally, in recent years, many strategies and projects have been developed within the framework of the Trans-European Energy Network. In line with these targets, wind energy has played an important role, leading to a rapid increase in wind energy projects in EU countries (İncekara , 2019: 311).

The European Commission approved the "A 2030 framework for climate and energy policies" green paper on March 27, 2013. This document initiated a public consultation wherein Member States, other EU institutions, and stakeholders were able to provide their opinions on the kind, scope, and character of possible energy and climate targets for 2030, as well as on other significant facets of EU energy policy for the following fifteen years. The Commission considered these opinions as it continued to work on developing more detailed recommendations for the 2030 framework, which were presented at the end of 2013. The aim of the undertaking was to contribute creative, rigorously scientific policy analysis on specific topics to the discussion of the post-2020 energy and climate policy framework instead of tackling every issue in the package, concentrate on a technical or political "choke-point" while maintaining control and flexibility and guaranteeing timely delivery of results (Climate Strategies, 2024)

Energy presently accounts for 75% of the EU's greenhouse gas emissions, making it a crucial component in the objective of the EU becoming climate neutral by 2050. The European Commission has emphasized the necessity of decarbonizing at least six times quicker than anything accomplished internationally, raising the share of clean energy and renewable energy carriers, and enhancing energy efficiency in order to meet this goal. In this environment, the delivery of solutions and system transformations depends critically on research and innovation as well as new and innovative renewable technologies. The Strategic Energy Technology Plan (SET-Plan) oversees energy-related research and innovation activities in the EU. The FPs provide the majority of the financial support for these initiatives. The eighth Framework Programme (FP), known as Horizon 2020 (H2020), replaced the seventh Framework Programme (FP7) and had a budget of EUR 79 billion. It was implemented from 2014 to 2020 (Calvo-Gallardo, Arranz, 2022: 5).

All of the current EU financing for research and innovation, including the European Institute of Innovation and Technology, the Competitiveness and Innovation Framework Programme's innovation-related activities, and the Research FP, were combined into H2020. It focuses on the diverse societal issues that European citizens must deal with. In addition to the variations in administrative and financial issues, H2020 differs from FP7 in three important areas: (1) H2020 prioritizes impact-oriented research above knowledge-oriented research; (2) it is more business-oriented than academic-oriented; and (3) it aspires to expand rather than deepen knowledge. To put it briefly, H2020 is all about connecting research to the market and society, as well as industry and innovation (Calvo-Gallardo, Arranz, 2022: 5).

As part of its commitment to building a low-carbon economy, the European Union's flagship research and innovation initiative, Horizon 2020, has given wind energy a prominent priority. Substantial financing was provided by the program to assist in the development of cutting-edge wind energy technology, such as grid integration, energy storage, and offshore wind farms. Innovation is critical to lowering prices, increasing efficiency, and boosting wind energy's sustainability, as highlighted by Horizon 2020. In order to meet the EU's targets for renewable energy and accelerate technological advancements, industry, research institutions, and public stakeholders were encouraged to collaborate on projects. These projects focused primarily on lowering greenhouse gas emissions and raising the proportion of wind energy in the energy mix (Andersen, Müller, 2022: 85).

The European Union (EU) created the 7th Environment Action Programme (7th EAP) as a broad framework to direct environmental policy between 2013 and 2020. The initiative, "Living well, within the limits of our planet," outlined important goals and priorities to influence the EU's sustainability and environmental protection strategy. Despite its formal termination, its goals and tenets still shape present-day EU environmental policy and initiatives (Andersen, Müller, 2022: 85).

The EU has committed to stepping up its efforts through this program to preserve our natural capital, promote low-carbon, resource-efficient growth and innovation, and protect people's health and well-being—all while honoring the Earth's natural boundaries. It is a shared approach that ought to direct future actions by the Member States and EU institutions, who are jointly accountable for carrying it out and achieving its top priorities. It outlines three main goals: a) to preserve, maintain, and improve the Union's natural capital; b) to transform the Union into a competitive, green, and resource-efficient low-carbon economy; and c) to protect Union residents from environmental stresses and threats to their health and well-being (Deselnicu, Militaru , 2018: 1).

The shift to a low-carbon energy system was given top priority in the 7th EAP in order to lessen reliance on fossil fuels and cut greenhouse gas emissions. This goal was thought to include increasing the use of carbon-free renewable energy sources. By increasing resource efficiency, the program sought to lessen the EU economy's environmental impact. One important energy source that has arisen to support this goal and contribute to sustainable energy production is wind energy. The 7th EAP encouraged the transition to renewable and environmentally friendly energy in keeping with the objective of protecting natural resources and guaranteeing ecosystem resilience. Since wind energy generates energy without using natural resources, it was thought to be a technique that helps achieve this objective. Increasing the use of renewable energy sources, including wind, was intended to improve energy security and the EU's energy independence. In the battle against climate change, it also significantly contributed to the reduction of greenhouse gas emissions (Andersen, Müller, 2022: 86).

In order to drastically decrease the dangers and effects of climate change and limit global warming in accordance with the Paris Agreement (2) (UNFCCC 2015), we must quickly shift our production and consumption habits and completely overhaul our energy system. Increasing the use of renewable energy sources (RES) is crucial to slowing down climate change and bringing about this shift. As Europe's long-term energy demand remains stable or declines, a greater proportion of renewable energy sources is needed to displace non-renewable resources, particularly fossil fuels, in the production of heat, transportation, and power supply. This process lowers greenhouse gas (GHG) emissions in all areas of the economy. Thus, renewables play a crucial role in fulfilling the decarbonization priority of the European Energy Union, fulfilling the EU's climate obligations under the Paris Agreement, and facilitating the shift towards a low-carbon, resource-efficient, and competitive EU economy and society by 2050 (European Environment Agency , 2019: 5).

The European Green Deal (EGD) is the EU's plan for the green transition mandated by the Paris Climate Agreement. The EU's new growth plan, known as the EGD, was unveiled on December 11 , 2019: by President of the European Commission Ursula von der Leyen. Its goal is to make Europe the first continent in the world to be carbon neutral by 2050, with net zero greenhouse gas emissions (Republic of Türkiye Ministry of Foreign Affairs). A few main goals have been the foundation of EU energy policy in recent years: environmental and climate protection, competitive economics, and energy security. Policy and economic decision-makers concurred that the European Green Deal must be implemented in this situation. The implementation of this plan ought to guarantee both rapid technical advancement and high environmental quality (Simionescu, Păuna , 2020: 3).

The European Green Deal plays a crucial role in accelerating the development of wind energy in line with the EU's goal of becoming carbon neutral by 2050. This deal increases investments in renewable energy by providing funding for wind energy projects and encourages the modernization of energy grids. Additionally, it develops strategies to boost offshore wind energy potential, with major projects planned in regions like the North Sea and the Atlantic. As the wind energy sector grows, the Green Deal aims to increase green jobs and a skilled workforce. Simultaneously, it supports the expansion of wind energy while considering environmental sustainability and biodiversity protection measures (Andersen, Müller, 2022: 87).

The Global Wind Energy Council (GWEC) and the International Renewable Energy Agency (IRENA) conducted a recent study on the past thirty years of wind energy policy worldwide. They found that three factors were essential to a successful policy: A clear support scheme design; a political commitment over the long term; and enough compensation to allow for reasonable investor profit (Kitzing, Morthorst , 2021: 36).

While there is evidence that wind energy may develop under standard market economic frameworks, such as those that use tax credits in the United States or other fiscal incentives, deployment is frequently aided by having a steady compensation plan and an obvious and efficient price system. These institutions, however, are not always adequate [1]; wind energy policy, for example, is frequently most successful when it is supported by political pledges from the government and articulated through national or state-level targets. Setting goals is crucial for increasing public awareness and providing investors with unambiguous, long-term signals [1]. It is essential that goals are translated into specific policy frameworks and combined with an efficient permission-issuing procedure, an effective administrative system, and the rule of law and openness (Kitzing, Morthorst , 2021: 36).

Permissions and siting processes that are well-designed minimize expenses and risks, improve returns on investment, and lessen the possibility of clashes with communities and local government. Anecdotally, an open and laissez-faire regulatory environment has encouraged wind projects in Texas, a global leader with over 33 GW of installed wind power. Wind energy deployment in the state has been facilitated for more than 20 years by a robust power market, a culture of energy generation, and supporting policies and investments in transmission building. In addition, cutting requirements and developing national standards throughout the permission process—as Germany, for instance, did in the early years of technology deployment—can lower project development costs and encourage additional players to enter the market (Kitzing, Morthorst , 2021: 37).

Accessibility to the electrical grid is a crucial component of a framework that effectively facilitates the implementation of wind power. Today, wind energy gets priority access to the grid in 10 of the twelve markets that were evaluated for the IRENA/GWEC study. Regulation authorities and management may become overloaded with project applications if well-thought-out grid-connection protocols are not accompanied with policies for the distribution of transmission system capacity, as has happened in China. Early experiences in a number of markets have demonstrated that system integration which consists of several interconnected aspects—remains a crucial component for project development. These aspects include the efficient processing of requests for grid connections and the prompt assignment of grid connection points, authorization to connect to the grid, and guaranteeing the availability of enough grid capacity to efficiently inject power from the wind park into the system. Early and proactive planning is necessary to guarantee grid access over longer time periods in order to accomplish the latter (Kitzing, Morthorst , 2021: 37).

Local community awareness and involvement is another critical component of success. For instance, legislators created laws to guarantee that nearby communities benefited materially from local wind farms in Denmark, Germany, Greece, and Scotland [1]. In Denmark and Germany, early technological development began with encouraging nearby farmers to generate their own electricity. This strategy helped to establish a fledgling sector prior to 1980 and laid the groundwork for the current wind industry (Kitzing, Morthorst , 2021: 37).

Numerous instances of societal factors causing wind project delays or failures have been reported within the last three decades. While there are several factors at play [13], the primary ones have been identified as low levels of public understanding of the technology, community hostility to wind projects, and lack of public participation [1]. For additional information on social concerns and wind farm planning, see Chapter 5. When wind farms are being developed, the most effective regulations encourage "win-win" ideas for all stakeholders, including the local industry and the community's population (Kitzing, Morthorst , 2021: 37).

A common aspect of wind energy policy is the growth of the home sector. Governments work to increase local manufacturing capacity in order to optimize benefits to the community, but they also do so in order to guarantee the availability of equipment at fair rates and to create prospective export markets for technology. Large, consistent domestic demand as well as expansion prospects are necessary for the establishment of successful local supply chains. These factors guarantee a long-term market for locally skilled labor, components, and equipment. Long-term goals can help achieve success by indicating future market volumes (Kitzing, Morthorst , 2021: 37).

In the Communication titled "Measuring progress towards the attainment of the Programme's 2030 and 2050 priority objectives," a monitoring framework was introduced in July 2022 with the goal of creating a measuring tool for the EU 8th EAP advancements and objectives. Furthermore, the EU's 8th EAP evaluates a number of intermediate stages using a network of 26 interrelated variables, such as living circumstances, biodiversity, and climate change. Additionally, specific references to the following indicators, targets, and sources are included in the EAP: (1) CC mitigation and adaptation; (2) free environment, pollution, and health impact; (3) biodiversity and health; (4) energy encounters; (5) "eco-innovation" and sustainability; and (6) "environmental wellbeing." The "mid-term review" is another handy way to frame the EAP. Additionally, it establishes the essential standards in compliance with Article 4's legislative provisions, which permit the phases of monitoring and reporting (Olimid, Olimid, 2022: 93-94).

Reaching carbon neutrality by 2050 is one of the main goals of the 8th EAP. The EU places a high priority on expanding renewable energy sources, such wind power, which are crucial for a low-carbon energy system, in order to meet this goal. The necessity of greatly expanding the EU's capacity for renewable energy is emphasized in the 8th EAP. One of the most developed and extensively used renewable energy sources in Europe, wind energy is essential to this growth. The 8th EAP intends to improve the energy security of the EU by encouraging wind energy and other renewables, thereby decreasing reliance on fossil fuels, especially those supplied from outside the EU. This objective is supported by wind energy as a home energy source. By managing wind turbines' end-of-life phases and recycling materials utilized in wind technology, the program promotes a circular economy. This strategy makes ensuring that wind energy is sustainable during its whole lifecycle, not only while it is in use. The 8th EAP promotes the mobilization of public and private investments in wind farms and other renewable energy infrastructure in order to decrease greenhouse gas emissions and hasten the shift to renewable energy sources. Wind farms and other renewable energy projects must be created in a way that preserves biodiversity and doesn't disturb ecosystems, according to the program. This entails giving careful thought to new wind installations' placement and effects on the environment (Andersen, Müller, 2022: 88).

2.3.3.2. Development of Wind Energy in Member States

2.3.3.2.1.Greece

Innovative applications of renewable energy have been a tradition on Kythnos island since the 1980s (Katsaprakakis, Proka, 2022: 25). In 1982, The Greek island of Kythnos welcomes the first wind farm in Europe, consisting of five 20 kW turbines (Wind Europe). By offering incentives to the local community to take part in the energy transition through the establishment of energy communities, the social acceptance of RES projects was encouraged. A more sophisticated energy management system encouraged the use of renewable energy. Regulatory obstacles, such as the requirement for a framework for spatial planning pertaining to renewable energy sources and the margins imposed for their penetration in non-interconnected systems, are prevalent, just like in other Greek non-interconnected islands (Katsaprakakis, Proka, 2022: 25).

Throughout the 1990s, Greece progressively increased its wind energy capacity after the groundbreaking wind farm on Kythnos. The Greek government started actively promoting wind energy during this time by establishing preliminary policy frameworks and licensing processes. A number of medium-sized wind farms were set up in mainland areas including the Peloponnese and Thrace. Thrace's "Boreas"—strong, reliable northern winds—made the region especially appealing for the development of wind power, and early wind turbines were established close to Alexandroupoli and Komotini. Installations were mostly located in the southern and eastern coastal regions of the Peloponnese, where excellent wind conditions and a lower population density made project approval easier. However, because of little investment interest and bureaucratic obstacles, growth was remained comparatively slow (Karamanos, Pavlopoulos, 2002, 54).

An important turning point for renewable energy occurred in the early 2000s when Greece joined the EU energy market and complied with European regulations. The implementation of Law 2773/1999 and the ensuing feed-in tariffs under Law 3468/2006 offered financial incentives for investments in wind energy. Particularly in regions with high wind potential like Evia, Lakonia, and Crete, these modifications resulted in a notable increase in installed wind capacity. Due to the island's rugged landscape and powerful Meltemi winds, Evia has seen a number of large-scale wind projects, including the Marmari and Karystos wind farms, which combined have an installed capacity of over 100 MW, making the area a leader in wind energy in the country. The rocky coastline of Lakonia, in the southeast Peloponnese, has seen the construction of wind farms, including projects close to Monemvasia and Asopos, adding to the region's capacity of more than 70 MW. In contrast, wind farms were built mostly in the central and eastern regions of Crete, including the Lassithi Plateau and Anogeia. Notable installations like the Aposelemis wind park made a substantial contribution to the island's energy mix even though it was not yet connected (Tsani, 2015, 587).

The wind energy industry was impacted by the 2009 financial crisis in two ways. It promoted a move toward more affordable and sustainable energy systems, but it also decreased governmental assistance and postponed several projects. Public spending on energy infrastructure fell, and the inability to obtain funding caused several planned wind projects to be delayed or scaled back. The crisis did, however, also serve as a spur for legislative changes meant to streamline licensing processes and lessen administrative workloads. Greece kept adding additional wind installations in spite of financial limitations because of the momentum already in place and the participation of the private sector. In areas where grid capacity permitted integration, such as Central Greece and Western Macedonia, independent power producers (IPPs) were essential to maintaining development. Additionally, at this time, foreign direct investment and European structural funds offered vital financial support that kept investors interested and stabilized the industry (Tsani, 2015, 587).

The Greek wind industry saw a resurgence in growth after 2014. The use of competitive bidding procedures (auctions) and revised licensing legislation significantly enhanced the regulatory environment. These adjustments improved the sector's openness, cut expenses, and drew in more aggressive investors. Significant infrastructural advancements included the creation of the Independent Power Transmission Operator (IPTO) and plans to connect the islands to the mainland grid. In particular, the Cyclades Interconnection project allowed for a higher penetration of renewable energy sources in islands that were not connected. Wind farms became increasingly feasible in places like Western Macedonia, Central Greece, and offshore regions. High-capacity wind parks, including those close to Livadia and Fthiotida, have grown in Central Greece thanks to the region's robust grid infrastructure and ideal wind conditions. Formerly a lignite-based energy region, Western Macedonia started to move toward renewable energy, and new wind farms helped to diversify the energy mix. Through site mapping, environmental assessments, and initial stakeholder discussions, preliminary studies and pilot initiatives also started investigating the offshore wind potential in the Aegean and Ionian Seas, laying the foundation for future maritime installations (Kaldellis, Zafirakis , 2017: 70).

As part of its National Energy and Climate Plan (NECP), Greece has set a goal to accelerate its renewable energy ambitions in the 2020s, with a particular emphasis on wind energy. Additionally, offshore wind potential is being investigated, especially in the Aegean Sea. The government has identified a number of attractive maritime zones for offshore wind development, such as the Dodecanese islands, the Northern Aegean region near Alexandroupoli, and the regions west and south of Crete, where the wind and water depth are perfect for floating wind technologies. With the help of regulatory initiatives to expedite the permitting and environmental assessment procedures, certain locations have been given priority for upcoming auctions and development. Initial partnerships have been formed with foreign developers and energy companies, with an emphasis on investment planning, technology transfer, and feasibility studies. Energy communities, like the ones backed on Kythnos, are still important for encouraging decentralization and local participation. With offshore wind rapidly progressing from the planning to pre-development stages and poised to become a crucial component of the nation's energy transition in the years to come, Greece has established itself as a regional leader in wind power in Southeastern Europe as of the mid-2020s (Avgeri, Karanikolas,2023: 67).

2.3.3.2.2.Sweden

The first wind turbines were installed in Sweden in the late 1970s and early 1980s, marking the beginning of the country's wind energy growth. Small in size, these early turbines were primarily intended for demonstration and experimentation. One of the first noteworthy installations was located on Gotland Island, where excellent wind conditions made it an ideal place to evaluate the viability of wind power (Ackermann, Söder, 2002, 68).

The WTS-75 wind turbine, located close to Nasudden on Gotland's southwest coast, was a particularly noteworthy landmark. Kamewa was the manufacturer of the second megawatt wind turbine constructed in Sweden. With a rotor height of 75 meters and a hub height of 77 meters, the turbine had a 2 megawatt installed capacity. From 1984 to 1990, it was in operation, generating electricity and acting as a vital resource for research and development (Ackermann, Söder, 2002, 69).

With assistance from the Swedish firm Kvaerner and the German utility Preussen Elektra, an upgraded nacelle was erected on the same tower in 1993 as part of a German-Swedish research collaboration. The two businesses individually funded the $34 million project, which helped foster global cooperation in the development of wind energy. Before a gearbox problem forced its decommissioning in 2006, the modified turbine eventually achieved a global record for wind electricity generation (Janzing & Oelker , 2019: 215).

Understanding the technical feasibility of wind power in Sweden's particular geographic and climatic conditions was the main goal of these early initiatives, which were spearheaded by academic institutions, research facilities, and state energy organizations. Despite their small scale, these pilot initiatives played a vital role in increasing public awareness of renewable energy and developing local knowledge. Sweden's long-term commitment to sustainable energy solutions was significantly shaped by the knowledge acquired during this formative time (Midttun, Koefoed, 2003, 56).

Sweden developed a supportive policy and regulatory framework in the 1990s, marking significant progress in formalizing its commitment to renewable energy. The Swedish government started implementing explicit policies to support wind energy as environmental consciousness increased and the need to diversify the country's energy mix became more pressing. These included long-term plans to incorporate renewables into the electricity system, investment incentives, and targeted finance schemes.

During this time, a more organized strategy to increase wind energy output nationwide replaced small-scale experimental endeavors (Midttun, Koefoed, 2003, 56).

Research and development activities pertaining to wind power increased significantly in the 1990s, coinciding with changes in policy. Energy businesses, academic institutions, and government agencies worked together on demonstration projects aimed at advancing grid infrastructure and wind turbine technology. These programs improved wind turbines' technical performance and dependability while simultaneously fostering institutional strength and popular acceptance. The first larger-scale and economically feasible wind turbines thus started to appear during this decade, paving the way for Sweden's subsequent explosive growth in wind energy (Midttun, Koefoed, 2003, 57).

Due in large part to the implementation of the green certificate system in 2003, Sweden's wind energy industry underwent a sea change in the 2000s. This market-based support system gave renewable energy providers financial incentives, increasing the economic appeal of wind generating projects. Electricity providers were required to buy a specific percentage of their power from renewable sources under the scheme, which increased demand for green certificates and promoted investment in clean energy technologies. The framework provided by the policy was solid and transparent, which was crucial in encouraging participation in wind energy from the public and private sectors (Eriksson , 2008: 90).

The number of onshore wind turbine installations in Sweden increased significantly during the course of the decade as a result of this favorable policy environment. The building of wind farms grew particularly quickly in the southern and western regions of the nation, which enjoy reliable and powerful wind resources. Additionally, throughout the 2000s, turbine efficiency and size increased, resulting in lower costs per megawatt-hour and increased energy generation. This expansion established Sweden as a new leader in renewable energy in Europe and greatly increased the share of wind energy in Sweden's overall electricity mix (Eriksson , 2008: 90).

During this time, a number of noteworthy wind farms were built, demonstrating the impetus the green certificate system generated. The Näsudden wind farm on Gotland Island was one of the most well-known projects; it grew throughout the 2000s and is now one of Sweden's biggest and most researched wind power locations. The Lillgrund offshore wind farm, situated in the Öresund Strait close to Malmö, was another noteworthy development. With 48 turbines and a 110 MW total capacity, Lillgrund was the largest offshore wind farm in Sweden when it was put into service in 2007. It is also a significant project in the history of wind energy in Scandinavia (Eriksson , 2008: 91).

The Markbygden Wind Farm in northern Sweden, which started construction in the late 2000s and would grow to become one of the biggest land-based wind energy complexes in Europe, was one of the other significant onshore wind farms. By creating jobs, investing in infrastructure, and involving local stakeholders, these initiatives not only significantly increased the national grid's capacity but also promoted area economic growth. Together, they proved wind energy's feasibility and scalability in Sweden and reaffirmed the green certificate system's effectiveness in promoting the use of renewable energy (Wolsink , 2020: 45).

The wind energy industry in Sweden grew significantly in the 2010s, making the nation one of Europe's top producers of wind power. Deeper integration with the European energy markets facilitated this expansion by promoting regional cooperation on renewable energy initiatives and facilitating more effective cross-border electricity commerce. Sweden gained access to more investment flows, better market transparency, and better policy coordination by taking part in the Nord Pool power market and larger EU climate frameworks (Wolsink , 2020: 45).

Simultaneously, wind turbine technology advanced quickly, increasing output and efficiency. Even in regions with modest wind, newer turbines with longer blades, taller towers, and more advanced control systems enabled higher capacity installations and better performance. Additionally, as grid integration technology advanced, intermittent wind power could be more reliably and adaptably integrated into the country's electrical grid. The decade saw an increase in interest in offshore wind energy, even if onshore wind remained the most common type. Projects such as the 2013 commissioning of the Kårehamn offshore wind farm in the Baltic Sea marked the start of Sweden's offshore wind adventure and showed the nation's desire to diversify its renewable energy sources (Wolsink , 2020: 46).

Sweden's wind energy industry has grown significantly throughout the 2020s, and in late 2024, wind power surpassed nuclear energy as the primary source of electricity. Wind energy became the main source of power generation in that year, contributing 35% of the country's electrical output in December (Wolsink , 2020: 46).

The growth of offshore wind farms has run into challenges in spite of these advancements. Applications for 13 offshore wind turbines in the Baltic Sea were denied by the Swedish government in November 2024, citing military worries about possible effects on the country's defensive capabilities. Among these worries was the potential for wind farms to obstruct missile detection and interception. Leaders in the sector, like Mads Nipper, CEO of Ørsted, have stated confidence in resolving these defense-related concerns by utilizing lessons learned from previous Baltic Sea initiatives (Wolsink , 2020: 46).

Numerous massive offshore wind projects are being developed in response to the rising demand for renewable energy. For example, Eolus Vind has applied for the Najaderna offshore wind project in Uppsala County, which is situated off the coast of Tierp and has a maximum capacity of 1.7 GW. Furthermore, Ørsted is requesting permission for four offshore wind parks with a combined 15 GW of capacity. Despite the difficulties in developing offshore wind, Sweden is committed to growing its renewable energy infrastructure, as seen by these initiatives (Wolsink , 2020: 47).

2.3.3.2.3.Denmark

In 1978, Denmark's first modern wind turbine was built close to the town of Tvind, marking a major advancement in the country's onshore wind energy development throughout the 1970s. The Tvind turbine, a massive, community-driven project constructed by a team of educators and students, represented the grassroots character of Denmark's early wind energy movement. Around this time, a number of local organizations and cooperatives nationwide started funding small- and medium-sized wind projects, frequently motivated by worries about environmental sustainability and energy independence (Larsen, Kristensen,2023: 97).

The Danish government started to offer institutional and financial assistance for wind energy development in response to the public's increasing interest in renewable energy. To boost private investment and hasten the rollout of wind power, policies including feed-in tariffs and subsidies for wind turbine installations were implemented. With onshore wind playing a key part in the national strategy, these projects set the groundwork for Denmark's transition to a cleaner energy system (Larsen, Kristensen , 2017: 97).

Denmark's wind energy industry rapidly industrialized in the 1980s and 1990s, especially in onshore wind development. Major Danish wind turbine manufacturers Vestas and Bonus (later acquired by Siemens) rose to prominence at this time, and they were instrumental in increasing turbine output and enhancing technological dependability. In order to improve their durability, efficiency, and compatibility with the national electrical grid, the industry started standardizing turbine designs. These developments made it possible for wind energy to transition from community-based and experimental projects to more scalable and commercially viable options (Larsen, Kristensen , 2017: 98).

To facilitate future growth, the Danish government and academic institutions made investments in creating advanced mapping and planning tools for wind resources. The National Wind Atlas, which was published in the 1980s and offered comprehensive data on wind patterns nationwide, was one of the most important results of this endeavor. It assisted in determining the best sites for onshore wind farms. Wind energy installations consequently started to proliferate throughout rural regions, greatly boosting local development and strengthening Denmark's standing as a world leader in wind energy technology (Larsen, Kristensen , 2017: 98).

With a more organized legislative and regulatory framework in the 1990s and early 2000s, Denmark reaffirmed its commitment to onshore wind energy. The Electricity Supply Act's passage in 1999, which created a legislative framework for wind power integration into the country's energy grid, was a significant turning point. This act streamlined the permitting procedures for new onshore wind projects and established more precise criteria and support systems for renewable energy, particularly wind. Reducing administrative obstacles and promoting a quicker rollout of sustainable energy solutions were the objectives (Larsen, Kristensen , 2017: 99).

The government implemented market-based tools including quota systems and green certificates to encourage energy producers to invest in renewable energy sources and further boost wind energy. In order to ensure more public participation and local approval, municipalities and local communities were also given more roles in the planning and implementation of wind projects. In order to improve the overall productivity and aesthetic integration of onshore wind farms in the landscape, Denmark also started providing incentives for repowering, or the replacement of older, smaller wind turbines with newer, more efficient models, during this time.

Denmark's onshore wind industry entered a technologically mature period between the 2000s and 2010s, characterized by significant advancements in turbine efficiency, size, and design. Wind turbines grew taller, stronger, and able to produce a lot more electricity with fewer units. Repowering, or replacing aging turbines with fewer but significantly larger and more efficient models, became a strategic change during this time. In addition to increasing energy output, this lessened the visual congestion caused by the older wind farms that are dispersed throughout the countryside (Larsen, Kristensen , 2017: 99).

Public worries about noise, visual encroachment, and turbine proximity to residential areas increased as onshore wind farms proliferated. Denmark responded by enacting stricter siting laws to guarantee greater planning and reduce adverse effects on nearby towns. New technological difficulties were also brought about by the incorporation of wind energy into the national grid, particularly with regard to intermittency and stability. In order to overcome challenges, Denmark made investments in smart grid technologies and grid management advancements, enabling wind power to be included into the nation's energy mix in a more flexible and dependable manner (Larsen, Kristensen , 2017: 99).

Due in major part to growing land use issues and public opposition, Denmark's onshore wind installation speed slowed between 2010 and 2020. Finding appropriate and socially acceptable locations for new turbines got increasingly challenging as the amount of available land decreased and competition from other land users increased. A more careful approach to project development resulted from worries about noise, visual impact, and proximity to residential areas. These problems led to a change in emphasis from growing new installations to increasing the effectiveness of already-existing ones (Larsen, Kristensen , 2017: 99).

Repowering emerged as the primary tactic for preserving and increasing onshore wind capacity during this time. In order to generate more electricity in a less amount of space, fewer, bigger, and more efficient turbines eventually replaced older ones. This strategy assisted in striking a balance between social, environmental, and energy production objectives. The assumption that modernizing existing infrastructure was a more acceptable course of action was reinforced by policies and support systems that continued to favor repowering over greenfield development (Larsen & Kristensen , 2017: 99).

Increasing societal acceptance and community involvement has been increasingly important to the Danish wind industry from 2020. Along with benefit-sharing programs that enable local governments and individuals to directly gain economically from adjacent wind turbines, new regulatory procedures have promoted increased transparency in project design. By making sure that communities feel more valued and participated in the decision-making process, these actions seek to increase trust and decrease resistance (Larsen, Kristensen , 2017: 99).

Onshore wind's incorporation into the country's energy infrastructure has also been aided by ongoing technological advancement. Wind energy infrastructure is becoming more and more integrated with digitalization and smart grid technologies, which allow for improved forecasting, real-time monitoring, and more adaptable electricity supply management. These developments have improved wind power's dependability and stabilized the grid, especially as its proportion of the electrical mix has increased (Larsen, Kristensen , 2017: 99).

2.3.3.2.4.Netherlands

The Netherlands' first onshore wind turbine was installed in the late 1970s, marking the beginning of the country's current wind energy development. A 30 kW experimental turbine that was installed in 1976 close to the North Holland village of Callantsoog is among the oldest known installations. It was created mainly as a research model to examine wind conditions, mechanical dependability, and energy output by a team of engineers and researchers. During this time, conventional windmills gave way to more contemporary turbines that produced power. Small-scale and experimental in character, the early projects were frequently carried out by local inventors interested in renewable energy alternatives as well as universities and research institutions. Understanding turbine performance, design, and the viability of incorporating wind energy into the national electrical grid were all aided by these early deployments (Vries, Bakker , 2021: 69).

The Dutch government started to offer limited assistance for research and development related to renewable energy in the 1980s. Pilot projects and public money made it easier to build prototype wind turbines in different parts of the nation. Even though these early programs produced little, they were extremely important in raising public awareness and technical expertise. The foundation for the large-scale wind energy development that would occur in the ensuing decades was established by the lessons acquired from these modest endeavors (Vries, Bakker , 2021: 69).

Through national energy policy, the Netherlands started to take more methodical and planned measures toward the growth of wind energy in the 1990s. As part of the nation's long-term energy transition objectives, these policies have placed an increasing emphasis on the value of renewable energy sources. To promote investment in wind generation, the Dutch government implemented a number of incentive programs, chief among them feed-in tariffs and subsidies. Through the guarantee of a set price for power supplied to the grid from renewable sources, these financial instruments sought to increase the economic viability of wind energy (Vries, Baker , 2021: 69).

Significant efforts were undertaken to update and extend the electrical grid infrastructure in order to handle the increasing proportion of wind power, concurrent with the development of new policies. In order to guarantee the dependable integration of wind energy into the national system, regional grid operators started working on technical enhancements. In addition, a number of early commercial onshore wind farms were built throughout this decade, marking the shift from tiny experimental projects to larger, more coordinated operations. Wind farms constructed in regions like Flevoland and North Holland, whose flat terrain and good wind conditions made them the perfect places, are notable examples. These projects, which were usually created by private investors or local cooperatives, frequently included groups of medium-sized turbines with capacities between 200 and 500 kW. Even yet, their rather small capacity by today's standards was a major advancement in proving wind energy's scalability and viability. These preparatory measures were essential in setting the stage for the Netherlands' eventual larger-scale wind energy deployment in the ensuing decades (Vries, Bakker , 2021: 70).

The Netherlands' onshore wind energy capacity increased significantly in the 2000s. Both the public and commercial sectors stepped up efforts to scale up wind power generation, building on the groundwork established in the 1990s. Several provinces saw the development of new wind farms, with Flevoland, Groningen, and Zeeland standing out as crucial areas because of their open spaces and ideal wind conditions. As wind energy started to contribute more significantly to the nation's electricity mix, installed onshore capacity increased substantially over this decade (Vries, Bakker , 2021: 70).

Significant technical developments in wind turbine design enabled this expansion. In addition to being larger and more efficient, turbines were able to provide greater outputs at lower wind speeds. Tower heights and rotor diameters expanded, enhancing overall performance and increasing the economic appeal of wind energy. The sector's maturity was also aided by collaborative innovation among engineering firms, energy companies, and research organizations, as well as public-private collaborations. Together, these initiatives paved the way for even more ambitious advancements in the years to come by establishing onshore wind as a dependable and scalable energy source (Vries, Bakker , 2021: 70).

As part of larger plans for the energy transition and climate change, the Netherlands reaffirmed its commitment to onshore wind energy between 2010 and 2020. Existing onshore wind farms were expanded and repowered during this time due to more aggressive renewable energy objectives imposed by national and regional governments. Modern, high-capacity turbines replaced older, less effective ones, improving land-use efficiency and energy output. Large-scale repowering initiatives like Windpark Noordoostpolder, for instance, helped modernize the province of Flevoland's wind landscape by substituting a lower number of turbines with a more powerful one. Because integrating wind farms into rural and semi-urban areas requires careful balancing of environmental, economic, and social issues, this decade also saw a greater emphasis on spatial design and public consultation (Vries, Bakker , 2021: 70).

The 2013 Dutch Energy Agreement (Energieakkoord), which set forth specific objectives for wind energy generation and stakeholder interaction, was the most significant modification to policy frameworks to encourage this development. During this period, local energy cooperatives rose to prominence, encouraging citizen ownership and boosting support for wind projects. A prominent illustration is Windpark Nijmegen-Betuwe, a neighborhood-based project in which locals jointly invested and profited directly from wind energy profits. Innovation in technology continued to be a major force behind development, with improvements in digital monitoring systems, predictive maintenance tools, and turbine materials leading to increased dependability and lower operating costs. A more decentralized and egalitarian approach to wind energy development is shown in the growing prevalence of cooperation between towns, energy cooperatives, and private investors. Even when the country's focus shifted to offshore and other renewable technologies, these initiatives made sure that onshore wind continued to play a vital part in the Dutch energy mix (Vries, Bakker , 2021: 71).

The Netherlands strengthened its climate goals in the 2020s in accordance with the Paris Agreement and the European Green Deal, giving onshore wind and other renewable energy sources more importance. Adopted in 2019 and put into effect throughout the first part of the 2020s, the Dutch Climate Agreement (Klimaatakkoord) established specific goals for wind energy generation and sought to cut greenhouse gas emissions by 49% by 2030. Onshore wind remained a key component of this structure, with municipalities and regional governments in charge of distributing land and assisting in the creation of new wind projects (Vries, Baker , 2021: 72).

The increasing participation of local stakeholders and communities in wind farm ownership and planning has been one of the period's defining characteristics. Participatory models were promoted by new rules and best practices, allowing local people to directly profit from wind energy projects and co-invest in them. These methods enhanced the social sustainability of energy transitions while also increasing public acceptance. To further address environmental and community concerns, project planning also incorporated continuous advancements in turbine design, noise reduction, and visual impact mitigation. All of these initiatives worked together to guarantee that onshore wind energy would continue to be a crucial component of the Netherlands' shift to a low-carbon economy (Vries, Bakker , 2021: 72).

The Netherlands has emerged as one of Europe's frontrunners in wind energy development as of the mid-2020s. With the help of policy frameworks that prioritize decentralization, regional coordination, and community involvement, onshore wind capacity is still increasing steadily. With high-capacity turbines outfitted with predictive maintenance and real-time monitoring systems, wind farms are becoming more technologically sophisticated. These developments have improved operational effectiveness while lessening their effects on the environment and the environment. In order to maximize land use and enhance visual integration into the landscape, several older wind farms have been repowered with fewer but more potent turbines (Vries, Bakker , 2021: 72).

Notwithstanding these advancements, the Netherlands' wind energy industry continues to face a number of obstacles. Grid congestion has grown to be a serious problem, especially in places where renewable energy is widely used. This calls for immediate investments in smart grid technologies and transmission infrastructure. Because the need for land for renewable energy conflicts with housing, agriculture, and environmental preservation, spatial planning is still difficult. Furthermore, some local populations are still worried about how wind turbines may affect the ecology and aesthetics, which emphasizes the necessity of inclusive planning procedures and open communication. In the upcoming years, these elements will still influence how onshore wind energy develops (Vries, Bakker , 2021: 72).

2.3.3.2.5.Germany

When a few experimental wind turbine installations were started in the late 1970s, Germany's interest in wind energy was sparked. The Growian (Große Windkraftanlage) project's construction in 1983 was one of the first significant turning points. This massive prototype was created as a government-funded research project to evaluate wind energy's possibilities on an industrial scale. It is situated close to Kaiser-Wilhelm-Koog in northern Germany. Even though the Growian turbine was eventually deactivated after only a few years due to technical and financial issues, it was a major step in showcasing Germany's dedication to investigating alternate energy sources (Lesny, 2022: 90).

The majority of wind energy projects at this early stage were still modest and experimental, frequently being completed by independent engineers or universities. Wind power lacked the financial incentives and public awareness required for broad adoption, and government assistance was scant. Notwithstanding these limitations, by offering insightful scientific information and igniting interest in the potential of wind as a renewable energy source, this first stage set the stage for further developments (Lesny, 2022: 90).

The implementation of the Electricity Feed-in Act (Stromeinspeisungsgesetz) in 1991 was a major factor in the 1990s wind energy development revolution in Germany. By requiring utilities to buy power produced from renewable sources at set, advantageous rates, this ground-breaking law essentially ensured wind energy providers a steady income. Germany's rapid growth in the renewable energy sector was made possible by this strategy, which also offered the much-needed financial incentive to encourage investment in wind power (Lesny, 2022: 90).

This led to a steady increase in the number of onshore wind farms, especially in the windy northern parts of the country like Lower Saxony and Schleswig-Holstein. The rise of cooperative and citizen-owned wind energy projects was another characteristic that set this age apart. To guarantee that the financial gains stayed in the area, local communities banded together to finance, build, and run wind turbines. This strategy promoted a decentralized energy landscape that would later become a defining feature of Germany's transition to renewable energy sources and helped to increase public support for wind energy (Lesny, 2022: 90).

A significant surge in the development of wind energy in Germany began in 2000 with the implementation of the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG). The previous Electricity Feed-in Act was superseded by this law, which also greatly improved renewable energy assistance systems. It secured priority grid access for renewable electricity and fixed feed-in tariffs for wind generation for 20 years. Due to the long-term investment assurance these regulations provided, wind energy projects quickly expanded throughout the nation (Lesny, 2022: 90).

The German wind industry also experienced notable industrial expansion and technological innovation in the 2000s. Domestic manufacturers such as Enercon, Siemens, and Nordex became global participants, leading to employment development and export prospects. But as more wind farms were constructed, issues with land use and the environment began to arise. Public discussions and project delays were occasionally caused by concerns about noise, landscape impact, and biodiversity. Despite this, the decade is often regarded as Germany's wind power golden age, marked by robust policy backing, technological innovation, and a significant stride toward energy transformation (Lesny, 2022: 91).

Germany's onshore wind energy industry grew steadily throughout the 2010s, but a number of new issues caused the expansion to stagnate. The growing opposition from local populations, particularly in populated or picturesque locations, was one of the main problems. Concerns over noise, shadow flicker, and the visual impact of enormous wind turbines led to rising opposition and more frequent legal conflicts. Permitting procedures consequently got more intricate and time-consuming, which slowed the approval of new projects (Lesny, 2022: 91).

At the same time, infrastructure limitations were revealed as wind energy's increasing percentage of the national grid was integrated. The country's north was home to a large number of high-capacity wind farms, while the south was home to important industrial and urban demand areas. This discrepancy made it clear that the transmission network needed to be expanded and upgraded. The effective transportation of wind-generated electricity was hampered by delays in the construction of new power lines and grid connections, which also sparked worries about the stability and intermittency of the grid. Throughout the decade, onshore wind continued to be a crucial component of Germany's renewable energy policy in spite of these challenges (Lesny, 2022: 91).

Germany's commitment to a sustainable energy future was accelerated in 2011 following the Fukushima nuclear accident when it made the bold decision to phase out nuclear power completely. This ruling bolstered the nation's Energiewende, or Energy Transition, a long-term plan to move away from nuclear and fossil fuels and toward renewable energy. Wind energy swiftly became a key component of this change, accounting for an increasing portion of Germany's electricity production from both onshore and offshore wind (Lesny, 2022: 91).

Germany installed unprecedented amounts of wind capacity over the decade, and by the end of the 2010s, wind energy was the nation's main source of electricity. But as the decade came to an end, this impetus started to diminish. There was a discernible drop in new installations as a result of regulatory changes, more difficult permission procedures, and growing public opposition to new onshore projects. Notwithstanding these obstacles, wind energy continued to be a key component of Germany's plan to phase out coal by 2038 and fulfill its climate obligations under the Paris Agreement (Lesny, 2022: 92).

Significant structural and technological changes have occurred in Germany's onshore wind energy industry since 2020. The increasing emphasis on repowering—the process of swapping out outdated, inefficient wind turbines for more contemporary, higher-capacity models—has been one of the major themes. In addition to increasing energy output, this method helps with land-use issues because it requires fewer turbines to produce more electricity. Repowering has emerged as a crucial tactic, especially in areas where the first wind farms were put in during the 1990s and 2000s (Lesny, 2022: 92).

As increasing proportions of wind generation continue to enter the electrical mix, Germany has been working to enhance grid integration and system flexibility. Additionally, the nation is promoting wind energy's role in sector coupling, particularly through investments in wind-to-X technologies and green hydrogen production. By transforming excess wind energy into transportable and storable forms, these developments hope to promote energy consumption outside of the power industry. Germany continues to be a driving force behind renewable energy policy in the EU, actively assisting in the implementation of the EU Green Deal and promoting the adoption of comparable clean energy frameworks by other EU members (Lesny, 2022: 93).

CHAPTER THREE

OFFSHORE WIND ENERGY IN EUROPE

With its enormous potential for large-scale, sustainable electricity generation, offshore wind energy has emerged as a key component of Europe's renewable energy plan. European coastal regions, especially those in the North Sea, have offered favorable conditions for the growth of offshore wind farms due to their abundance of marine resources and strong, reliable wind conditions. In addition to helping the European Union achieve its decarbonization objectives, this energy source improves energy security and fosters economic expansion by fostering job creation and technological advancement. The ensuing sections will look at the general growth of offshore wind power, particular developments in the Southern North Sea region, and the present situation and potential future among EU member states in order to provide a better understanding of its evolution and relevance in Europe.

3.1. Development of Offshore Wind Energy in Europe

The size of the operation, the depth of the sea, the distance from shore, and evolving technology all have a significant impact on the design, construction, and management of an offshore wind farm. Although operations are currently shifting farther from shore and into deeper seas, the small-scale, shallow-water, near-shore developments of the 1990s and early 2000s were mostly based on onshore technologies and build concepts (MacAskill, Mitchell , 2013: 375).

While the early offshore initiatives in the 1990s were small-scale and meant to gain expertise with certain issues (such as building, environmental conditions, and maintenance), the projects of 2000s are much larger and more commercially focused. In Germany, for instance, planned offshore wind parks typically have 80 turbines totaling 400 MW in capacity. Twenty-three offshore wind farms were up and running in Europe's North and Baltic Seas by the end of 2007. With 1100 MW of total generation capacity, they made up 3% of the installed capacity in Denmark, the UK, Germany, the Netherlands, Sweden, and Ireland. 2008 saw a more than 30% rise in offshore generation capacity in Europe, reaching a total of 1470 MW (Markard, Petersen , 2009: 22).

Set off the Danish coast in Lolland, the Vindeby Offshore Wind Farm became the world's first offshore wind farm in 1991 when it began supplying power to the grid. After that initial trial, offshore wind energy has grown into a multimillion dollar industry and a significant contributor to the production of renewable energy globally. The class of offshore wind turbines (OWT) that are now (as of October 2014) in the prototyping stage have unit sizes ranging from 450 kW at Vindeby to 7.5 MW (Strach-Sonsalla, Stammler , 2016: 5).

Five years after the United Nations Conference on Environment and Development was held in Rio de Janeiro, Brazil, in 1992, the Rio +5 Forum was held in New York from March 13–19, 1997. Local governments, non-governmental organizations, national sustainable development boards, representatives of the private sector, scientific research organizations, financial institution representatives, and educational organizations participated in the event, which was supported by the UNDP. The Forum's overarching goal is to shift SG from "agenda" to "implementation," which is defined as uniting the participant group. The Forum focuses on management systems as part of its plan to apply SG locally, nationally, and internationally. Transferring cultural, historical, and spiritual knowledge and experiences to the Forum is the goal of each participant's unique experience (Bozlağan, 2005, 1024).

The heads of state convened at the United Nations-hosted Millennium Summit in September 2000 to deliberate on a wide range of issues encompassing both environmental and development problems. Following the meeting, a number of global objectives known as the Millennium Development Goals were established, along with the Millennium Declaration, which emphasized freedom, equality, solidarity, tolerance, respect, and shared responsibility as the fundamental principles guiding international relations in the twenty-first century. These include eliminating the spread of AIDS, ensuring universal primary school education, cutting the percentage of people without access to safe drinking water in half, and halving poverty by 2015 (Quental, Lourenco , 2011: 21).

Six key functions were identified at the Johannesburg Conference (2002). These include establishing global agendas, encouraging "joined-up" thinking on development and the environment, promoting shared values, offering national and local governments worldwide leadership, enhancing institutional capacity, and legitimizing global governance by broadening its scope (Andersen, Müller, 2022: 230).

The goal of the summit was to lessen reliance on fossil fuels while increasing the use of renewable resources in the energy industry. It placed a strong emphasis on financing, technology transfer, and international collaboration to help developing nations make the switch to renewable energy. The creation of economical and sustainable energy solutions for the billions of people without access to energy worldwide was another demand made during the summit. In addition to highlighting the energy component of sustainable development, the Johannesburg Summit set the stage for future years to see a rise in interest in renewable energy sources such offshore wind generation (Andersen, Müller, 2022: 230).

The biggest offshore wind farms were built in the early 2000s, particularly the offshore wind farm Middelgrunden in Copenhagen and Horns Rev in Denmark. The 20 turbines that make up the 40 MW rated power Middelgrunden Wind Farm are each 2 MW in size. When the farm was established in 2000, it was the biggest offshore wind farm in the world. A cooperative with 8,650 members and the Copenhagen Utility jointly own the farm. Over 3% of the power utilized in Copenhagen comes from the farm. 3.5 kilometers east of the Copenhagen harbor, on a natural reef, is where the wind farm is located. For over 200 years, the reef has served as a disposal location for toxic garbage and harbor sludge. Consideration has been given to the environment, and feasibility studies have been conducted (Sørensen, Hansen, Larsen, 2002, 1).

In 1997, the Danish Action Plan for Offshore Wind Farms identified the Horns Rev area as one of five viable areas for the installation of offshore wind farms in the future. The 160 MW Horns Rev Offshore Wind Farm was built in 2002 (Leonhard, Pedersen , 2006: 5). Denmark's move to renewable energy has been greatly aided by Horns Rev. It has assisted the nation in lessening its reliance on fossil fuels and lowering carbon emissions. The wind farm has also generated employment possibilities and stimulated local infrastructural investment. Horns Rev is located close to the village of Blåvandshuk, around 14–20 kilometers off Denmark's west coast. It gains from the North Sea's steady, powerful winds (IEA). Situated approximately 14 kilometers offshore from Denmark, Horns Rev 1 is made up of 80 wind turbines positioned between 6 and 14 meters below the surface. This meets the needs of 150,000

Danish families, or over 2% of the country's yearly electricity consumption (GS Seacon, 2024).

The UK's first significant offshore wind farm is called North Hoyle which has been built in 2003. It is made up of thirty wind turbine generators, each with a maximum output of two megawatts. Thus, with a total installed capacity of 60 MW, around 40 000 households' worth of electricity are produced annually. An annual output of roughly 160 000 tons of carbon dioxide is neutralized by the wind farm (Carter, 2015, 21). The UK's offshore wind farm industry has flourished since North Hoyle's success. It proved that offshore wind could be a dependable and expandable source of renewable energy, both practically and potentially. The UK's attempts to cut carbon emissions and achieve its goals for renewable energy have benefited greatly from North Hoyle's contributions. The wind farm lessens the environmental effects of conventional energy sources by replacing power produced from fossil fuels. The initiative has additionally boosted regional economic growth and produced job possibilities (ICE, 2023).

European countries have begun to implement supportive policies to promote offshore wind development in early 2010s. These policies include renewable energy targets, decarbonization tariffs for wind energy and grid connection incentives. These policies, designed to increase the use of renewable energy sources, especially encourage the development of offshore wind energy projects. The presence of a large wind potential in the seas in the coastal regions of Europe has led countries to increase energy production in these areas. As a result, the offshore wind energy industry is growing rapidly and is becoming an important resource to meet Europe's energy needs. These policies also support sustainable development by accelerating the transition to a green economy (Andersen, Müller, 2022: 231).

Directive 2001/77/EC is followed in the establishment of the 2010 goals at the national level. In order to encourage the advancement and uptake of renewable energy sources, this directive specifies precise renewable energy goals for every EU member state. The directive encourages nations to put laws and policies into place that support the expansion of renewable energy production inside their borders by establishing these goals. These national goals act as checkpoints to track advancement toward the EU's overall goals for renewable energy. They also offer a framework for evaluating the success of each member state's efforts to move toward a more ecologically friendly and sustainable energy system (Möst, Fitchner, 2010: 2898).

This regulation emphasized the importance of offshore wind energy in relation to the EU's larger growth of renewable energy sources. Member states aided in the mitigation of climate change by diversifying their energy sources, lowering their dependency on fossil fuels, and reducing greenhouse gas emissions by utilizing wind power. The directive provided establishing specific targets and offering a framework for member states to foster its development through supportive policies, incentives, and investment measures (Andersen, Müller, 2022: 232).

The fight against climate change became a new component of the 2007 Lisbon Treaty, which also decided to establish an energy policy for the entire Union. This established a clear connection between energy and environmental policies. In order to improve energy security and sustainability, the EU adopted a more comprehensive energy policy with the Lisbon Treaty. The EU's energy policy encourages member states to concentrate on initiatives like offshore wind generation and boost their output of renewable energy (Gabnai , 2021: 66). Through specialized laws like the 2009 EU Renewable generation Directive, the European Commission and EU member states further established policies encouraging offshore wind generation after the Lisbon Treaty (Andersen, Müller, 2022: 233).

As demonstrated by Directive 2009/28/EC, the European Union has set a significant objective to increase the share of energy generated from renewable resources. This directive sets legally-binding goals for the development of renewable energy in each of the member states through 2020 (Borawski, Borawska , 2020: 698).

The Renewable Energy Directive 2009/28/EC suggested the establishment of cooperation mechanisms between member states particularly relevant to offshore wind energy, in addition to setting binding targets for renewable energy generation. These mechanisms consist of cooperative projects, joint or coordinated funding schemes, and statistical transfers. The development of offshore wind energy projects in the European Union is intended to be facilitated by these institutions, which promote cooperation among member states through the pooling of resources and expertise (deCastro, Salvador , 2019: 57).

The 2020 Climate and Energy Package, which was introduced in 2009, included new legislation that would enable the achievement of the 2020 energy and climate change targets. The package set a 20% renewable energy objective for the entire EU (Gabnai , 2021: 66). Member states are encouraged by this goal to diversify their energy supplies and make investments in renewable energy sources, such as offshore wind generation. To specify how they will meet their goals for the production of renewable energy, member nations had to create National Renewable Energy Action Plans. It was believed that including offshore wind energy projects into these plans was crucial to achieving the targets for renewable energy. Additionally, the package included subsidies and incentives to assist renewable energy projects, especially expensive and large-scale ones like offshore wind energy. In order to lessen reliance on fossil fuels, the package urged member nations to cut carbon emissions and promote a quicker switch to renewable energy. In this light, offshore wind energy projects are considered a significant way to reduce carbon emissions. The package also backs the Trans-European Networks for Energy (TEN-E) policy, which encourages the development of energy infrastructure across international borders and contains measures to make it easier for offshore wind energy projects to be integrated into electricity networks (Andersen, Müller, 2022: 234).

The problem of connecting to the grid needs special consideration. In this way, a lack of incentive and drive on the part of grid firms to link wind farms to the grid has resulted in the abandonment of numerous wind farm projects. Grid operators are required by the Renewable Energy Law (as revised in 2009) to buy all produced renewable energy in order to prevent this. Additionally, the act creates "the Renewable Energy Fund," whose purpose is to reimburse grid operators for the additional expenses associated with acquiring energy from renewable sources (deCastro, Salvador , 2019: 63).

The large shifts in the corporate structure of wind energy emerged in years between 2000-2011. This shifting structure has two main motivators. The first factor was government policy, which included requirements for local manufacture in many situations in Europe and Asia and in some cases encouraged local enterprises. The second factor was the industry's expansion in size as a result of the commercial manufacture of bigger, more effective wind turbines brought about by technological advancement. The scale of developments for commercial wind farms increased.

Although solitary or small wind farms up to 5 MW accounted for three-quarters of wind turbine sales in 1995, by 2002 commercial and utility owned wind farms accounted for roughly 65 percent of sales. Because of the more favorable wind conditions that exist offshore, an offshore market has also evolved as a significant growing industry. Due to these changes, the industry became far more capital-intensive, which promoted mergers or the entrance of larger, better-capitalized companies. Furthermore, even if capital intensity increased, the hazards remained. Specifically, the US market continued to be unstable (Jones, Bauamane , 2011: 52).

During the years of the 2008-2009 economic crisis, the developing offshore wind power industry, which was mostly limited to the shores of Sweden, Denmark, the Netherlands, and Britain in addition to a single modest offshore wind farm that was established in China in 2009, required government funding in particular. It was nearly hard to get private sector financing because of the unproven technology. The ten-year story of building a 130-turbine offshore farm in Nantucket Sound off Cape Cod, which started in 2001, attested to the significant delays in regulatory permits caused by concerns about safety, aesthetic impact, tourism, and much more (Jones, Bouamane , 2011: 49).

Despite having completed numerous authorization procedures, the growth of offshore wind energy in Germany has stalled. Permits for 1100 plants in the North Sea with a capacity of around 5000 MW and 240 plants in the Baltic Sea with a capacity of 1200 MW had been issued by the middle of 2007. Germany's offshore wind projects in the North and Baltic Seas are subject to extremely strict technical requirements, in contrast to offshore wind projects that are being implemented worldwide. This is because of the deep oceans (between 20 and 40 meters) and the significant separations from the main land—sometimes well over 20 kilometers. This separation is required since Germany's coastal regions are not suitable for the development of wind energy because they are sensitive, ecologically significant, and classified as nature conservation sites. It is also believed that the amount of compensation payable under the previous EEG is insufficient, which contributes to the present stall in offshore wind development. Therefore, the Progress Report suggests lowering the ultimate rate from 5.95 to 3.5 ct/kWh and raising the compensation rate from the present 8.74 to 11–15 ct/kWh (beginning rate) (Büsgen, Dürrschmidt , 2009: 78).

The Federal Government's draft of the new Act, which was approved on December 5 , 2007: goes into further detail about this. Up until December 31 , 2013: an incentive rate of 14 cents per kWh was suggested to be paid; after that, 12 cents per kWh would be due. With effect from January 1, 2015, it was suggested that the rate of degression for new plants be set at 5% per year (the present rate is 2% per year from 2008). For wind turbines installed through the end of 2015, the new EEG now gives an initial rate of 15 ct/kWh with a final tariff of 3.5 ct/kWh. Starting in 2016, there will be a 5% degression and a reduction in the baseline tariff to 13 ct/kWh (Büsgen, Dürrschmdit , 2009: 79).

According to information provided by EWEA, in 2010, a total of 308 offshore wind turbines with a combined installed capacity of 883 MW were connected to electricity grids across nine different wind farms in five countries in Europe. This represents a 51% increase compared to the previous year. The total investment for these projects amounted to 2.6 billion euros (Yeşil Ekonomi, 2011).

When examined by country, the United Kingdom leads the sector with a total installed capacity of 1,341 MW. This country hosts 40% of the offshore wind turbines installed on the continent. Due to this situation on the island, companies like Gamesa, General Electric, and Siemens are expected to increase their investments in offshore wind turbine production in the UK in 2011. Following the UK in this field are Denmark with 854 MW, the Netherlands with 249 MW, Belgium with 195 MW, Sweden with 164 MW, Germany with 92 MW, Finland with 26 MW, Ireland with 25 MW, and Norway with 2.3 MW. From the perspective of investor companies, the Danish company Dong operates 26% of the total offshore wind farms (Yeşil Ekonomi, 2011).

The European Wind Energy Association (EWEA) predicts that by 2030, the electricity generated from offshore wind will be at the same levels as that generated onshore. EWEA and the World Wind Energy Association (WWEA) are conducting extensive research and studies related to offshore wind energy (Kocatürk, 2015, 6).

The offshore wind industry saw remarkable cost reductions around 2015, driven by advances in turbine technology, streamlined construction methods, and the scaling up of projects to capture economies of scale. Larger, more efficient turbines reduced per-unit energy costs, while improvements in installation techniques and specialized vessels enhanced operational efficiency. Additionally, increased competition in the market, supported by favorable government policies and subsidies, encouraged innovation and price drops. The Walney Extension project in the UK, once the world's largest offshore wind farm, exemplified this transformation. It showcased how scaling up capacity and leveraging cutting-edge technology could make offshore wind a competitive and reliable source of renewable energy. These advancements marked a turning point, solidifying offshore wind's role in the global transition to sustainable energy systems (Andersen, Müller, 2022: 240).

In 18 October 2017, the first floating wind farm in the world, Hywind Scotland, goes online. In a park configuration, five 6 MW turbines are connected to test floating technology (Wind Europe). The turbines are situated between 78 and 129 meters below the surface on floating platforms. It is situated around 25 km off the coast of Peterhead, Scotland. The wind farm's position places it in the marine atmospheric boundary layer (MABL), which is renowned for having varying atmospheric stability conditions all year long (Putri, Obhrai, 2022: 1). Equinor, a Norwegian energy corporation that was once known as Statoil, built this project. An important advancement in offshore wind energy technology is the wind farm. Wind energy can now be used in places where it would be difficult or expensive to deploy conventional fixed turbines in shallow waters thanks to floating turbine technology. Hywind Scotland has an installed capacity of 30 MW, which is sufficient to power about 20,000 houses. Despite challenging marine conditions, the farm has shown exceptional performance, with higher capacity factors than other offshore wind farms. When compared to traditional wind turbines, floating wind turbines have been found to be more robust and have greater capacity factors. The Hywind Scotland project has established a precedent for similar projects in other nations and demonstrated the feasibility of floating wind farms in the field of renewable energy (Andersen, Müller, 2022: 241).

Situated in the North Sea off the east coast of England, Hornsea One is one of the biggest offshore wind farms in the world. Ørsted, a Danish energy business, created the concept. With a total installed capacity of 1.2 gigawatts (GW), Hornsea One can power about one million households. Although planning and construction for Hornsea One started in 2016, it was completely operational in 2020. The wind farm is situated about 120 kilometers offshore and has 174 turbines. Offshore wind energy is now a more affordable choice due in large part to the project's size and excellent efficiency. Large-scale initiatives like these help the UK reach its goal of 40 GW of offshore wind energy by 2030 and support its decarbonization objectives (Andersen & Müller, 2022: 241).

Hornsea Two is the biggest offshore wind farm in the United Kingdom. With a 1.3 gigawatt (GW) capacity, Hornsea Two, which was also built by Ørsted, can power about 1.4 million households. Situated next to Hornsea One, Hornsea Two went into full operation in 2022 (Mainstream Renewable Power, 2023).

One innovative project that has significantly advanced floating turbine technology is Scotland's Kincardine Offshore Wind Farm (2021). The world's largest operational floating wind farm is situated in water depths of 60 to 80 meters, approximately 15 kilometers off the Aberdeenshire coast. Five Vestas V164-9.5 MW turbines and one V80-2 MW turbine make up the project. They are all mounted on Principle Power-designed WindFloat semi-submersible platforms. Because of their stability in deeper waters, these platforms provide new opportunities for offshore wind harvesting. Utilizing the largest capacity wind turbines ever set up on floating platforms is one of the Kincardine project's major accomplishments, demonstrating the potential for floating wind technology to be used on an industrial scale. The initiative is an essential step in reaching net-zero energy targets and can power about 35,000 homes in Scotland each year (Andersen, Müller, 2022: 242).

Reaching at least 60 GW of offshore wind capacity by 2030 and 300 GW by 2050 are the objectives of the EU's Offshore Renewable Energy Strategy, which was released in November 2020. Given that the EU's offshore wind capacity was just 16 GW by the end of 2022: WindEurope claims that these goals indicate a significant amount of change for the industry at a never-before-seen pace. The EU and its member states will need to support grid infrastructure development, cross-border maritime spatial planning, and, last but not least, sound permitting and Power Purchase Agreement (PPA) procedures in order to achieve these lofty goals (Libon , 2024: 8).

The EU's Fit-for-55 package (2021) seeks to cut greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels in order to meet the goals of the Paris Climate Change Agreement. By utilizing the full potential of Europe's waters, from the Atlantic to the Mediterranean, and from the North Sea and Baltic to the Black Sea, offshore wind will emerge as the EU's top source of electricity (Libon , 2024: 8).

In Sharm el-Sheikh, Egypt, COP27 (2022) focused on global climate change solutions, with a special emphasis on putting the Paris Agreement into practice and strengthening international cooperation. The topics of discussion at this meeting included climate financing, adaptation, and quickening the world's transition to renewable energy (IRENA, 2022). GOWA was introduced at COP27 by the Global Wind Energy Council (GWEC), the International Renewable Energy Agency (IRENA), and Denmark with the goal of expanding offshore wind capacity globally. In an effort to promote offshore wind deployment and innovation, nine more nations joined the alliance, including the United States, United Kingdom, Germany, and Japan. By 2030, 380 GW of offshore wind capacity worldwide is the short-term goal. In order to achieve climate goals and guarantee energy security, the long-term goal is 2,000 GW by 2050. In order to promote offshore wind and facilitate financing solutions to reduce investment risk and speed up adoption in emerging areas, GOWA promised to develop policy frameworks. In order to phase out fossil fuels and reach the 1.5°C global temperature target, offshore wind was acknowledged as being crucial. In order to expedite project approvals and infrastructure construction, the alliance placed a strong emphasis on information exchange, community involvement, and utilizing industry expertise (Energy Global, 2022).

The EU introduced the REPowerEU action plan in May 2022 with the goal of enhancing Europe's energy security and reducing its need on Russian fossil resources long before 2030. By 2030, the European Union demanded an extra 30 GW of offshore wind power. This goal is in addition to the offshore wind targets (60 GW by 2030) that were previously set in the Offshore Renewable Energy Strategy. The EU's Offshore Wind Energy Strategy now sets a goal of 90 GW by 2030 and 300 GW by 2050. By 2050, the EU, along with the UK and Norway, may have up to 450 GW of offshore wind power operational (Libon , 2024: 8).

In May 2022: Belgium, Denmark, Germany, and the Netherlands made a collective commitment in the Esbjerg Declaration to the REPowerEU call to install at least 65 GW of offshore wind power capacity by 2030 and 150 GW by 2050. The four EU member states have set a shared goal of half of the 300 GW of total EU capacity by 2050 with this 150 GW commitment, as stated in the EU Offshore Renewable Energy Strategy published in November 2020. The expansion of the world's first energy island to its full potential capacity of 10 GW by 2040 at the latest is one of the first stages in the four nations' statement on realizing and furthering plans for energy islands in the North Sea (Libon , 2024: 8).

The European Commission and the North Seas Energy Cooperation (NSEC) members—Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, and Sweden—agreed in Dublin in September 2022 to achieve a minimum of 260 GW of offshore wind capacity by 2050. The NSEC members have also decided to increase offshore wind power in the North Sea region by 193 GW by 2040 and 76 GW by 2030. This agreement, while not legally enforceable, emphasizes the will to work together to meet over 85% of the EU's overall goal of achieving 300 GW by 2050. In order to achieve this goal, the NSEC members will work closely together to improve area and network planning coordination, create a tightly connected (hybrid) offshore network, and expedite national and EU approval processes (Libon , 2024: 9).

As previously said, these European aspirations suggest a significant shift in the sector's scope at a never-before-seen pace. Only 16 GW of offshore wind capacity had been deployed in the EU by the end of 2022: and just 1 GW of new offshore wind power had been added in the previous year. In contrast, the EU must develop 31 GW year on average until 2030 in order to reach the REPowerEU renewable energy targets (Libon , 2024: 9).

On December 13, 2023, the 28th "Conference of Parties," or more often known as the COP summit, came to a close in Dubai, United Arab Emirates. Countries from all around the world can discuss, review, and make decisions necessary to fulfill the objectives of the United Nations Framework Convention on Climate Change (UNFCCC) at COP summits. Global leaders and organizations gather there to talk about the tactics being used or ought to be used to reach the objectives of the goals established by earlier COP conferences, particularly the Paris Agreement. The Paris Agreement, a legally binding international agreement ratified by 196 nations and adopted at COP21, aims to keep the rise in global average temperatures below 2°C over pre-industrial levels and work toward keeping it below 1.5°C. One According to the UN Secretary General, record-breaking temperatures were recorded throughout 2023, signaling the start of "the era of global boiling" and "the end of global warming." Furthermore, the conflicts between Israel and Palestine and Russia and Ukraine have had a significant impact on both the environment and human life. As a result, COP28 became one of the most important summits for nations to come together and carry out the decisions needed to meet the goals set over the years at the local level (Arora , 2024: 1).

The decisions made at COP28 include requiring offshore wind developers who have been granted licenses and government subsidies to invest in research and development in order to ensure the highest possible learning outcomes and value creation, providing industry predictability through yearly announcements of areas to be developed for offshore wind, and strengthening and continuing the North Seas Energy Cooperation (NSEC) on the development of offshore wind and offshore energy grids. The development of the onshore and offshore power grid and power system to ensure the efficient integration of offshore wind and other renewable energy sources, hydrogen, and hydropower in a way that respects nature and promotes coexistence with other users of the area is also part of this event, as is the requirement that pertinent measurement data be gathered and made available for additional R&D under specific conditions (Rokke, Ski , 2024: 30).

Five more nations, including France, Ireland, Luxembourg, Norway, and the United Kingdom, joined the "Esbjerg" coalition in April 2023. The combined goal was raised to 120 GW of offshore wind by 2030 in the North Sea and at least 300 GW by 2050 when the now-expanded coalition of nine nations co-signed the new Ostend Declaration, building on the Esbjerg declaration (Libon , 2024: 9).

The international development of an interconnected North Sea electrical grid was initiated in April 2023 by the UK's National Grid and the Dutch transmission system operator, TenneT. They revealed a first-of-its-kind offshore wind farm-connected cross-border power network. By connecting a Dutch 2 GW offshore wind farm to both nations via undersea interconnectors, the multipurpose interconnector known as "LionLink" will increase energy security and independence in Europe. Therefore, any excess wind-generated electricity can be immediately distributed to areas experiencing a power outage, and vice versa (Libon , 2024: 9).

The Hollandse Kust Zuid (HKZ) wind farm in the Netherlands is the first offshore wind farm constructed without government assistance. This ground-breaking project, created by Vattenfall, was finished in 2023 after reaching financial close in 2019 (Wind Europe). Even among decarbonization solutions, offshore wind energy was much more costly than conventional power. Rapid cost reductions in the technology have recently occurred, and these have been extensively covered in media and consulting studies. Some have even speculated that offshore wind without subsidies has already been accomplished. In contrast to rising capital costs during previous phases of development, the speed of offshore wind cost reductions has advanced more quickly than was generally expected, much like the quick cost reductions in energy storage (Jansen, Staffel, Kitzing , 2020: 2).

3.2. Development of Offshore Wind Energy in Southern North Sea

The founding member states had not yet considered the necessity or significance of developing a community-level environmental strategy in the 1950s, when the Treaty of Rome was being created and amended. However, the necessity to begin community cooperation has been motivated by the rapid industrialization and economic expansion, as well as the resulting increases in pollution and energy consumption. The first formal moment of the European Union's (EU) environmental policy was the October 1972 Paris summit, where prime ministers and heads of state agreed to develop an environmental policy at the community level. Consequently, action programs were initiated and the standard environmental regulations were developed. The objectives and foundations of the common environmental policy began to take shape in 1983 with the third action program, following the first (1973) and second (1977) action programs of moderate effect. When a still valid notion, this policy emphasized the need of taking proactive measures to prevent harm rather than responding to it when it arises. The need of stepping in early and removing the causes rather than concentrating on the outcomes and symptoms is its main takeaway (Gabnai , 2021: 66).

Wind energy in the North Sea developed in the next years as a result of the Paris Summit's emphasis on environmental awareness and energy independence, even though it did not establish specific laws aimed at wind energy. A major item on the agenda was the security of the energy supply, especially in light of the oil crisis. The summit's emphasis on the necessity of nations diversifying their energy sources in this respect subsequently fueled initiatives toward renewable energy, such as wind power, throughout the 1980s and beyond (Andersen, Müller, 2022: 250).

The Stockholm Conference and Limits of Growth study held in the same year are also important. The Limits to Growth (1972) study was distinctive because it was the first to examine the future of humanity and issues like the sustainability of resource consumption and population growth using computer technology and the scientific method. This perception of disaster appeared to be confirmed by incidents like the oil crisis of 1973. Some people exaggerated the risks of a worldwide disaster. However, it was also necessary to draw the world's attention to the problem of long-term sustainable life on a small planet. The Limits to Growth contributed more to this than any other single study (Meadows, Randers, Behrens, 2022: 1).

Stockholm (1972) served as a first assessment of the worldwide effects of human activity on the environment and an effort to establish a fundamentally shared perspective on how to tackle the problem of protecting and improving the human environment. Because of this, the Stockholm Declaration primarily promotes general environmental policy goals and objectives as opposed to specific normative stances. But after Stockholm, there was a significant rise in both international environmental lawmaking and public awareness of environmental issues. International environmental activism gradually shifted its attention from transboundary and global commons issues to cross-sectoral and media-specific regulation as well as the integration of development and economic factors in environmental decision-making (Handl , 2012: 1).

Developing nations were cautious in 1972 due to the North's environmental worries. From Stockholm's emphasis on environment and development to the development of the three pillars of sustainable development—economic and social development and environmental protection—to the 17 interconnected Sustainable Development Goals, the past 50 years have demonstrated the value of intergovernmental cooperation in tackling intricately linked global issues (Chasek, 2022: 2).

To date, three conferences have been organized under the direction of the Habitat institutional structure. The Human Settlements Conference (Habitat I) in Vancouver, Canada, in 1976 was the first. The second was the Human Settlements Conference in Istanbul, Turkey, in 1996 (Habitat II). The third was Habitat III, a conference on housing and sustainable urban development held in Quito, Ecuador in 2016. Official UN sources state that the growing urban population and the obvious problems that came with it were the main drivers of the Habitat conferences, especially at the times when they were conducted. These were ascribed to migration from rural to urban regions and higher rates of healthy births. Participants concentrated on defining state responsibilities for monitoring local, regional, and national settlement plans and addressing settlement-related issues as part of a global conference aimed at addressing the challenges of meeting people's basic needs and expectations in a way that respects human dignity. Improving the quality of life and urban settlements, especially in rural regions, was initially determined to be the main goal of the conference, which addressed the present issues and future of human settlements. The emphasis was on creating workable answers to the problems our cities face. The objective of turning cities into inclusive engines of social and economic development was highlighted within this framework. The conference's declaration, which was allegedly influenced by the conclusions of the 1972 Stockholm Environment Conference, listed general principles in 19 headings. These underlined how important it is to address the current problems with human settlements, especially in developing nations. The proclamation emphasized that achieving and enhancing basic necessities, including work, food, housing, clean water, and health, was a necessary condition for a high quality of life. It acknowledged land as one of the essential components of human settlements, referred to economic development as a tool for raising living standards, and underlined that environmental values are a shared human legacy that must be protected by the entire international community (Korkut, Öner, 2022: 463).

The UN General Assembly voted to hold the Habitat II Conference in Istanbul and create a global action plan with the themes "Adequate Shelter for All" and "Sustainable Settlements in an Urbanizing World" at its meeting on December 22, 1992. The process that followed sought to address issues pertaining to human living conditions on a worldwide scale, stop detrimental trends, and establish the prerequisites for raising living standards based on sustainability. Establishing core values and pledges to direct national and international efforts over the first quarter of the next century was the main goal of the conference. It stressed cooperation with international, national, and local stakeholders on "adequate housing for all" and "viable human settlements in a changing world," in addition to laying out a worldwide action plan. The pledges established during Habitat I were also reiterated during the summit. In addition to highlighting cities as the primary drivers of global growth, the conference, which drew 3,000 delegates from 171 nations and 2,500 civil society organizations, also highlighted the opportunities presented by urbanization. Habitat II offered a global viewpoint, citing the maintenance of improvements in living conditions for current and future generations as a primary objective of global civilizations. It placed a strong emphasis on gender equality, financial support for human settlements, capacity-building and participation, suitable human settlements for everyone, and a dedication to global collaboration. In order to encourage development and guarantee sustainable settlements in a world growing more urbanized, national leaders at the summit established an action plan that envisioned enough housing for everyone. They also underlined how important it is for communities and urban settings at all scales to remain viable and adjust to societal advancement (Korkut, Öner, 2022: 464).

The New Urban Agenda (NUA), which aims to revitalize global commitment to sustainable urbanization, was approved by 197 countries during the Habitat III Housing and Sustainable Urban Development Conference, which took place in Quito, Ecuador, from October 17–20, 2016. On December 23 , 2016: the UN General Assembly endorsed the NUA, the main product of the Habitat III Conference. In order to explore suitable policies that embrace urbanization while bridging the physical divide between urban and rural communities, the Quito Conference sought to bring together a variety of actors. Nevertheless, the rulings were not legally binding. The conference offered a chance to discuss the planning and management issues facing all settlements, as it was one of the first UN global summits after the 2030 Agenda for Sustainable Development (SDGs) and the Paris Agreement on Climate Change. The New Urban Agenda (NUA) viewpoint, which focuses on accomplishing important global development and climate change principles, was also formed by it. In order to create resilient urban settlements, the potential and worth of cities were given top priority in the document providing suggestions at the urban scale, together with the prerequisites for a sustainable future. The primary product of the Habitat III Conference, the New Urban Agenda (NUA), was primarily concerned with attaining sustainable urban development with the objectives of reducing poverty, boosting urban prosperity, and creating ecologically resilient cities. It underlined that although urban poverty, inequality, and climate-related problems are somewhat common, cities are the best places to deal with them. A paradigm shift grounded on urban science, the

New Urban Agenda (NUA) lays out guidelines and criteria for city planning, development, management, and enhancement. It has been created as a guide for all those who live in metropolitan regions around the world, including civil society organizations, the corporate sector, and players at different levels of government (Korkut, Öner, 2022: 465).

Following the Paris Summit, a number of significant events related to the environmental policy took place (noting the years of their signing). Environmental policy was being reconciled after the 1990s. The 1992 Maastricht Treaty expanded the European Parliament's authority. Since the subsidiarity principle was strengthened, the EU has played a significant role both locally and internationally. The concept of sustainable development was added to environmental concerns by the Amsterdam Treaty in 1997 (Balcı , 2006: 86). In 1992, The Maastricht Treaty, also known as the "Treaty about the European Union," expanded the purview of environmental policy and established the idea of environmentally conscious sustainable development as a tenet (Gabnai , 2021: 66).

Important and creative advancements in energy-related issues were made possible by the Maastricht Treaty. The European Union was given the power to establish energy policy with the Maastricht Treaty. As a result, the EU was able to improve member state collaboration on resource diversification and energy supply security. A cooperative atmosphere for wind energy projects in the Southern North Sea countries was fostered by the legislative framework's encouragement of investments in renewable energy sources. Additionally, the Maastricht Treaty increased the financial resources available to organizations such as the European Investment Bank (EIB). The growth of wind energy projects in the countries of the Southern North Sea was expedited by the EIB's increased involvement in lending and financing wind energy projects (Andersen, Müller, 2022: 250).

An important turning point that reinforced the European Union's (EU) energy and environmental policies was the 1997 Amsterdam Treaty. Another key tenet of the Amsterdam Treaty (1997) is that environmental needs and consequences must be considered when developing policies and deciding how to proceed (Gabnai , 2021: 66).

Sustainable development was made a central goal of the EU by the Amsterdam Treaty. This idea promoted investment in ecologically friendly renewable energy sources like wind energy by elevating their significance. As a result, the countries of the Southern North Sea now have a stronger policy basis for wind energy projects. Furthermore, the Amsterdam Treaty established more stringent guidelines for assessing the environmental impact of significant infrastructure projects by improving Environmental Impact Assessment (EIA) standards. These guidelines encouraged wind energy projects to be planned in an environmentally responsible manner and increased the amount of time that environmental considerations were given during project approval procedures (Andersen, Müller, 2022: 250).

The Commission unveiled its Agenda 2000 report in July 1997, outlining the EU's goals for the twenty-first century with regard to policy change, enlargement, and the EU's financial system. Regarding enlargement specifically, Agenda 2000 stipulated that the EU would keep creating a favorable atmosphere for enlargement by increasing funding for the CEECs. Additionally, by keeping an eye on the Accession Partnerships—which include the Europe Agreements and other multi-national initiatives—the EU would keep supporting the CEECs (Katz, 2003, 231).

The report emphasized Europe's enormous offshore wind energy potential, particularly in areas like the North and Baltic Seas. The development of offshore wind farms and more investment in these sectors were stressed in this context. The offshore wind energy industry expanded as a result of this proposal, especially in nations like Denmark, Germany, and the United Kingdom (Andersen, Müller, 2022: 251).

The world's first offshore wind turbines were designed in an environment made possible by the North Sea. Shallow water and a great wind regime can be found in its southern region. The development of this sector has been steadily aided by public initiatives in the five nations with the greatest locations: Belgium, Denmark, Germany, the Netherlands, and the United Kingdom. European industrial companies have been able to protect this market for their goods and services, often at the expense of a high degree of concentration. For example, two manufacturers account for 84% of installed turbines. With the potential to be very large, the acquired know-how positions European stakeholders for success in the global offshore market. Supportive policies for offshore wind throughout the North Sea have changed over time, partially due to the influence of the European Commission. They have shifted to using tender calls and competitive processes (Angeli , 2018: 1).

Combined with rising technological skill, this approach has resulted to a tremendous decline in declared costs. The North Sea has many prospects for expansion due to offshore wind's increased competitiveness, but these are hampered by the costs and challenges of bolstering the power transmission network, which is necessary for the evacuation of generated electric current. The experience of growing this industry in the Nord Sea is undoubtedly something that countries hoping to develop offshore wind energy can benefit from (Angeli , 2018: 1).

Since the 1990s, there has been a greater push to utilize offshore wind resources for the production of utility-scale power. At the focus of this early offshore wind development was Northern Europe. High population concentrations have limited the amount of land available onshore, which has spurred wind energy companies to search the water for appropriate locations. In addition to growing concern about the environmental effects of using fossil fuels, wind energy became more competitive due to an increase in worldwide energy consumption. A large portion of the technological refinement for the design and operation of wind turbines in shallow waters took place in the North Sea and the nearby Baltic Sea (Aubault, Roddier , 2013: 122).

The July 7 London bombings ultimately overshadowed the efforts of France, the United Kingdom, Germany, Sweden, Finland, Denmark, and Italy to prioritize environmental issues at the G8 summit at Gleneagles in July 2005. The Gleaneagles' Meeting serves as a foundation for highlighting the significance of environmental challenges facing European nations (Balcı , 2006: 100).

The G8 meeting promoted innovation and technological advancement in the energy industry. Wind energy technology advanced as a result of this concentration, increasing their cost-effectiveness and efficiency. These technological advancements helped the nations of the southern North Sea, allowing for the construction of bigger and more effective wind farms. The significance of public-private cooperation in sustainable energy initiatives was also emphasized at the conference. By adopting this cooperative paradigm, the nations of the Southern North Sea were able to successfully steer private sector investments toward wind energy. Projects in the area were implemented more quickly thanks to this collaboration (Andersen, Müller, 2022: 253).

Ten European nations and the European Commission launched the North Sea Countries Offshore Grid Initiative on December 7 , 2009: with the aim of fostering regional collaboration to facilitate the development of the offshore grid in accordance with the objectives of the EU's Third Energy Package. Consequently, "in favor of increased cooperation and renewed commitment" to guarantee "a sustainable, secure, and affordable energy supply in the North Seas countries," the North Seas Energy Cooperation was signed on June 6, 2016. Following this political declaration, the United Kingdom, Belgium, Germany, Denmark, and the Netherlands have consolidated their long-term strategies. These five nations serve as pioneer markets and as the hub for diffusion and innovation in offshore wind generation (Gordon , 2020: 1).

The European Green Deal, which "emphasizes the importance of offshore wind in meeting the EU's 2030 and 2050 climate and energy objectives," has gained strength as a result of the NESC's action. Notably, the NSEC decided on an indicative installed capacity of at least 70GW by 2030 based on national planning of Member States during the June 2019 Ministerial Conference in Esbjerg, Denmark. At 65.8GW, the majority of this aim is accounted for by the leading group, which includes BE, DE, DK, NL, and UK. The European aim has risen to more than 80GW in response to recent statements made by the governments of Germany and the United Kingdom. Lastly, the EC has claimed that by 2050, at least 230GW will be needed, and roughly 450GW will be needed to supply 30% of Europe's electricity consumption, even though the 22GW of offshore wind already deployed in the NESC "covers on average 1.5% of Europe's annual electricity demand" (Gordon , 2020: 1).

Technology Innovation for the Local Scale, Optimum Integration of Battery Energy Storage, or Project TILOS, creates strategies to meet the targets of the European Agenda 2020, which include generating 20% of energy from renewable sources and cutting greenhouse gas emissions by 80–95% by the year 2050. Although there is a lot of potential for boosting the generation of renewable energy on European islands, many of them in Southern Europe have little or no grid connectivity to the mainland. In this situation, produced renewable energy needs to be limited because it cannot be easily exported to the mainland (Andersen, Müller, 2022: 254).

TILOS is a project under European Horizon 2020 that aims to finance innovation and research inside the EU between 2014 and 2020. Three topics are covered in the EU Framework Program H2020: outstanding science, business leadership, and societal issues. The TILOS project was ranked third in the subtopic of secure, clean, and efficient energy under the section on social challenges. Local / small-scale storage-LCE-08-2014: this four-year project, which started in February 2015, will cost a total of 13.74 million euros with an 11 million euro European funding (Andersen, Müller, 2022: 254).

As an innovation initiative, the primary goal of the TILOS project is to optimize the utilization of clean (renewable) energy sources to meet the island of Tilos's electricity requirements. The residents of Tilos will benefit from their involvement in this project in terms of environmental preservation, lowering the island's carbon footprint, combating climate change, and creating and promoting sustainable energy models that will lead to greater energy autonomy (Andersen, Müller, 2022: 255).

Within this framework, a novel hybrid system prototype for power generation and storage was built and is currently under construction. It consists of an 800 kW wind turbine, a 160 kW solar park, and a 2.4 MWh/800 kW NaNiCl2 FIMM battery for energy storage. To achieve the highest level of electricity autonomy and balance between intermittent renewable energy sources (RES), such as wind and solar power, electricity output, and electricity demand, a smart micro-grid is also being created to coordinate the system's operations (Andersen, Müller, 2022: 255).

The island regions that are the focus of the TILOS project are locations that are of great priority. In addition to Tilos, the other participating islands are Corsica (France), La Graciosa (Spain), and Pellworm (Germany). The overarching goal is to establish a unique platform that will facilitate the transfer of technological expertise between islands by utilizing the knowledge acquired from the Pellworm smart grid system's operation and by providing fresh, hypothesis-driven research for the creation of comparable systems in other islands (Nivet, Zafirakis , 2017: 1).

The Danish government declared in January 2021 that it would construct the first energy island in the North Sea (Wind Europe). Although the first energy island in history will only be as large as 18 football fields (120,000 square meters), there are plans to increase its size by three times. It will house 200 enormous offshore wind turbines. With a projected cost of 210 billion kroner (£24 billion; €28 billion; $34 billion), it is the largest construction project in Danish history. The artificial island, which is located 80 kilometers (50 miles) out to sea, would be partially privately owned and at least partially held by the state (BBC, 2021). When finished, the project is expected to provide three million households in Europe with renewable energy (Slaymaker , 2024: 1).

3.3. Current Status and Future Prospects of European Union States about Offshore Wind Energy

As part of its larger objectives to attain climate neutrality and guarantee energy security, the European Union has shown a significant commitment to offshore wind generation. In terms of offshore wind infrastructure deployment and future planning, some EU member states have taken the lead. Examining the present situation and plans for the future of these leading countries offers important information about the general direction of offshore wind development in Europe. The Netherlands is a notable example in this regard, having advanced significantly in recent years.

3.3.1. Current Status of Netherlands about Offshore Wind Energy

As of right now, the Netherlands has installed 4.7 GW of offshore wind energy, or roughly 670 turbines (OCEaN, 2024). The nation has increased the development of offshore wind in recent years, emerging as a major force in Europe's shift to renewable energy sources. Reaching this capacity has been made possible by large wind farms like Borssele and Hollandse Kust Zuid, with newer installations becoming more economical and efficient. In order to accommodate the increasing number of turbines, the Dutch government and business sector have worked closely together to streamline the approval process and invest in infrastructure, such as offshore grid connections. This quick development is indicative of the Netherlands' dedication to renewable energy, as offshore wind now provides a sizable amount of the country's electrical needs. Offshore wind is now a major part of the nation's energy mix because to technological developments in turbine installation and design, which have also allowed the nation to maximize its wind resources (Andersen, Müller, 2022: 256).

The Netherlands is currently at the forefront of offshore wind development and installation at a low cost. However, the Dutch had to overcome major obstacles to get to this position. The Netherlands had long recognized the promise that offshore wind offered, just like other nations do. Nevertheless, there were genuinely very few offshore wind turbines operating in the Dutch Economic Zone of the North Sea as of 2019. The onus of project developers included the selection and research of sites as well as the permission process, which came with no assurance that projects would be granted. Project developers had to bear heavy expenses and risks as a result before they could even submit an application for funding. The Dutch Economic Zone of the North Sea had only seen the construction of four offshore wind farms with a total capacity of less than 1 GW by that time, out of 80 initial applications (Libon , 2024: 10).

Offshore wind farms provide a great deal of potential for economic growth. A big local market allows the Dutch offshore and wind sector the chance to continue improving its competence and consequently to reinforce its strong worldwide position. Currently, Dutch businesses account for about 25% of the offshore wind energy sector in all of Europe (government.nl, 2024).

A deeper examination of the relationship between climate change and security is required due to the destabilizing impacts of climate change in already unstable environments, as well as the possibility that climate policies and investments would spark new protests and conflicts. The rivalry for vital raw materials required to realize Europe's green and digital transitions is a further layer on top of the new geopolitics of the (renewable) energy transition. Although they understand how important it is to incorporate the concept of climate security into foreign, defense, and development policy, military personnel, diplomats, and development actors still find it difficult to pull it off. The Netherlands has an interest in taking the lead in advancing the climate security agenda since it is an open economy that depends heavily on global trade and stability (Hollander, Schaik,2023: 1).

Climate security was mentioned in passing and had no bearing on implementation in Dutch foreign, defense, or climate policies until recently. By launching the Planetary Security Initiative in 2015, the Netherlands increased awareness, but this goal was unrelated to its own international climate policies. Even in the area of water climate adaptation, where a second Water, Peace and Security Program is supported, actual policies still lag behind the connection between conflict and security. The limited financial resources and capacity allocated to climate security threats serve as an example of this. This could potentially change as a result of the Dutch international climate strategy (internationale klimaatstrategie, or IKS) that was published in the fall of 2022 as part of a larger set of foreign policy strategies. The IKS paves the way for the integration of pertinent policy domains. The IKS includes "climate and safety" (klimaat en veiligheid in Dutch) as a component of a whole-of-government approach to climate policy, with various Dutch ministries in charge of carrying out the plan. The Africa strategy, the government-wide security strategy, and the natural resources strategy are other pertinent policies concerning climate security (Hollander, Schaik,2023: 2).

The Netherlands launched new projects that support the energy transition in 2024, making notable advancements in the offshore wind energy industry. In order to meet the nation's energy needs and lower carbon emissions, a significant investment in renewable energy is included in the offshore wind turbines constructed this year. These recently constructed offshore wind farms are ideally situated in the North Sea to benefit from reliable and strong wind currents. The Netherlands wants to be carbon-neutral by 2050, and the projects that went online in 2024 have the potential to power tens of thousands of homes. The Netherlands' offshore wind projects also boost the nation's competitiveness in the global energy market as it increases its investments in renewable energy sources in accordance with Europe's energy security and climate change mitigation plans (Andersen, Müller, 2022: 257).

A significant offshore wind farm called Hollandse Kust (noord) is situated off the Dutch coast in the North Sea. One of the large-scale offshore wind farms under development in the Netherlands, this project is expected to cut carbon emissions and meet its targets for renewable energy by 2024. Construction on it started in 2023. The project, which seeks to supply renewable energy to almost one million families yearly, has a capacity of about 700 megawatts (MW). The Hollandse Kust (noord) wind farm benefits from strong wind conditions to enhance energy production. It is situated around 18.5 kilometers offshore in the North Sea. Global energy giant Shell and developer of renewable energy Eneco are working together on the project. This wind farm seeks to improve the sustainability of the Dutch electrical system in addition to producing energy. Innovative technologies with potential uses, such energy storage and hydrogen production, also help the initiative. The Netherlands wants to be carbon neutral by 2050, and a major component of that energy transition will be the Hollandse Kust (noord) project (Andersen, Müller, 2022: 257).

Two sizable offshore wind energy projects called Hollandse Kust (west) Alpha and Beta are situated in the North Sea off the Dutch coast. These initiatives are a result of the nation's attempts to lower carbon emissions and meet its goals for renewable energy. Hollandse Kust (west) Alpha and Beta are located next to the Hollandse Kust (noord) project in the North Sea's Hollandse Kust wind energy sector. The Hollandse Kust (west) Alpha project will be able to produce about 700 megawatts (MW) of energy once it is finished. Approximately 50 kilometers offshore is where this wind farm is situated in the North Sea. The initiative seeks to offer renewable energy to hundreds of thousands of families annually and will make a significant contribution to the Netherlands' objective of being carbon neutral. Shell and Eneco are working together to build the Hollandse Kust (west) Alpha project. Approximately 700 megawatts (MW) is also the energy production capacity of the Hollandse Kust (west) Beta plant. Situated approximately 50 kilometers offshore in the North Sea, the Beta wind farm is close to the Alpha project. Together, the energy firm TotalEnergies and Corio Generation (a GIP company) are developing Hollandse Kust (west) Beta (Andersen, Müller, 2022: 258).

Both initiatives entail the application of cutting-edge technologies in addition to energy production. In addition to wind energy, these initiatives will make use of green hydrogen generation and energy storage technology. These initiatives are further assisted by creative technologies that guarantee grid stability and effectively integrate renewable energy. The Netherlands wants to get 75% of its electricity from renewable sources by 2030, and the Alpha and Beta projects will help the country achieve this target and move toward a carbon-neutral economy (Andersen, Müller, 2022: 258).

The OranjeWind project is situated on the Netherlands' western coast in the Hollandse Kust (west) Wind Farm Zone. This area is located in the North Sea, roughly 53 kilometers offshore from the Dutch coast. With an installed capacity of 700 MW, the OranjeWind project will be able to provide energy to about a million households each year. The Shell and Eneco partnership were victorious in the 2022 tender process for the OranjeWind project. The project is being developed and run in partnership with Shell and Eneco. The tender's sustainability and innovation requirements were given a lot of weight by the Dutch government. OranjeWind is therefore prepared to apply cutting-edge system integration and energy storage technologies. The project's innovative utilization of renewable energy technologies sets it apart. The integration of battery storage technologies and more effective control of energy generation are part of the goals. The objective of this strategy is to improve energy security in spite of variable wind conditions. By 2026, OranjeWind should be up and running. Following the tender procedure, the required licenses were obtained, and the building phase is still in progress. Lessening the project's impact on the environment is its goal. Ecological precautions and creative solutions are being used to safeguard marine life and avoid damaging ecosystems (Andersen, Müller, 2022: 258).

3.3.2. Future Prospects of Netherlands about Offshore Wind Energy

The government projects that by 2030, more than 11 gigawatts (GW) of offshore wind farms will be constructed and connected to the land, according to the 2030 Offshore Wind Energy Roadmap. This accounts for 40% of the Netherlands' present electricity usage (TenneT, 2024). A plan to encourage the development of new offshore wind power in the Netherlands by 2030 has been presented by the Ministry for the Economy and Climate. According to the proposal, 4.5 GW more capacity must be developed by 2023, and 7 GW more capacity must be added between 2024 and 2030 (Climate Policy, 2024). Prime Minister Dick Schoof's new right-wing administration in the Netherlands is sticking to its "ambition" of achieving 50GW of offshore wind power by 2040 (NEA, 2024). The Dutch government unveiled its long-term goal for offshore wind capacity by 2050 in September 2022. By 2050, the government wants to have installed 70 GW of offshore wind power (rechargenews.com, 2024).

By 2023, there must be a minimum of 4.5 GW of offshore wind turbines operating. The Energy Agreement for Sustainable Growth has this promise. 3.3% of the Netherlands' total energy supply will thereafter come from offshore wind turbines. Upholding the offshore wind energy policy is one of the commitments made in both the coalition agreement (2021) and the climate accord (2019). As a result, some 21 GW of offshore wind farms will need to be operational by 2030, which is sufficient to meet 75% of the country's current electricity consumption and 16% of its total energy needs (government.nl, 2024).

According to the Minister, the Netherlands will employ a fluid roadmap that will be revised frequently as soon as new areas are identified.The insights gained from the North Sea Programme's partial revision will be incorporated into the roadmap as an addition.The program will undergo its second iteration in 2025.According to the government, the idea of energy hubs would be put to use after 2030.These offshore hubs may enable offshore hydrogen production in addition to facilitating connections with neighboring North Sea nations.The plan for North Sea energy infrastructure will outline the goals for 2050.The strategy will pinpoint the locations of the energy hubs as well as the infrastructure and capacity requirements (Macquart, Kucukbahar, 2023, 17).

Netherlands' bottom-up methodology was used to create our near-term offshore wind market perspective (2023–2027), which is based on GWEC Market Intelligence's global offshore wind project database, which includes projects that are presently under construction, global auction results, and offshore wind tenders that have been launched worldwide. In addition to the project pipelines already in place, a top-down strategy was employed for the medium-term market perspective (2028–2022), which considers medium– and long-term offshore wind targets at the national and regional levels, as well as current policy. It is very possible that our medium-term forecast will rise even more as existing proclaimed national and regional aims increase, as it reflects these targets. However, there is now a discrepancy between the rate of annual installations and proclaimed targets when it comes to implementation (Williams, Zhao, 2023: 92).

The growth of offshore wind energy is supported by a solid legislative framework in the Netherlands, which is managed through well-defined project planning and timelines found in regularly updated Offshore Wind Energy Roadmaps. The Netherlands Enterprise Agency (RVO.nl) coordinates all site investigations for each wind farm, and the country offers flexible rules and regulations for offshore wind energy development. This method lowers the overall costs of offshore wind projects by giving developers more assurance, boosting investor confidence, and encouraging innovation. The most recent offshore wind tenders without subsidies prioritize qualitative factors like ecological initiatives and system integration in addition to the lowest cost. This intends to minimize environmental effect, maximize societal benefits at acceptable prices, and facilitate the seamless integration of electricity from future offshore wind farms into the energy system. Alternatives for producing green hydrogen from power produced by offshore wind are also being researched (Wind and Water Works, 2024).

As part of the offshore wind energy projects in the Netherlands, a large-scale offshore wind farm called IJmuiden Ver WFS Gamma (Wind Farm Site Gamma) is proposed. High-capacity wind farms will be constructed in the IJmuiden Ver region, which is situated far from the Dutch coast. This region is located about 80 kilometers offshore in the North Sea to the west of the Netherlands. Stronger and more consistent wind conditions will be advantageous for these wind farms, which are intended to be constructed in deep oceans. An important project that contributes to the Netherlands' ambition to raise offshore wind energy capacity by 2030 is IJmuiden Ver WFS Gamma. There will be four distinct wind farms in the IJmuiden Ver zone, with a combined capacity of about 4 GW. WFS Gamma is one of these wind farms.

The IJmuiden Ver wind farm is intended to have a capacity of about 1 GW, and WFS Gamma is anticipated to be on par with these wind farms. It is projected that tenders for this project will be held in 2025, and that they would follow the Netherlands' offshore wind project subsidy-free approach. High-efficiency turbines integrated into the energy system will be part of the project's equipment. The initiative is also taking into consideration ways to produce green hydrogen with offshore wind energy (Andersen, Müller, 2022: 260).

The IJmuiden Ver projects are notable for their environmental sustainability in addition to their ability to produce energy. The projects' effects on the environment and ecosystems are significant evaluating factors in the tenders. An attempt is being made to reduce the effect on marine life and bird migration routes. One of the major initiatives that will be essential to the Netherlands' energy transition and help achieve sustainability and energy security goals is IJmuiden Ver WFS Gamma (Andersen, Müller, 2022: 260).

The Dutch government is planning a large offshore wind farm project in the North Sea called Nederwiek (zuid) WFS I. This project is essential to the Netherlands' energy transition and is part of the country's objective to greatly boost its capacity for renewable energy by 2030. The project, one of many offshore wind energy projects proposed in the area, will be situated in the "Nederwiek Zuid" (Nederwiek South) region. Several gigawatts (GW) of energy could be produced by the Nederwiek (zuid) WFS I project, while the precise amount would depend on the particular project. The Dutch government will put out a tender for the project, which private companies will then develop. It is a big step toward assisting the Netherlands in meeting its obligations under the Paris Agreement and making the switch from fossil fuels to clean energy. Nederwiek (zuid) WFS I is anticipated to go up for tender in the upcoming years, with construction anticipated to start by 2025. The project is planned to be completed in 2030. These kinds of projects are vital to the shift to renewable energy sources and are anticipated to boost jobs and the local economy (Andersen, Müller, 2022: 261).

Another proposed offshore wind farm project in the North Sea is called Nederwiek (noord) WFS II. It is a component of the Netherlands' larger initiatives to develop its infrastructure for renewable energy. This project, which is situated in the "Nederwiek Noord" (Nederwiek North) region, aims to support the nation's aggressive renewable energy targets as stated in its climate and energy transition goals. It is anticipated to have a multi-gigawatt (GW) generation capacity, similar to other projects in the Nederwiek zone, greatly increasing the nation's offshore wind energy production. The Dutch government will commission the project through a competitive procurement process, with private sector companies developing the initiative. Nederwiek (noord) WFS II is anticipated to go through a tendering procedure soon, and construction may start in 2026. This project will finish in 2032 if it goes as planned. Reducing the Netherlands' dependency on fossil fuels and fulfilling the country's goals under the Paris Agreement will be made possible in large part by this wind farm. Nederwiek (noord) WFS II is an integral aspect of the Netherlands' plan to shift to a more sustainable energy system and boost regional economic development, particularly in the offshore wind industry, along with other initiatives of a similar nature (Andersen, Müller, 2022: 262).

Nederwiek (noord) WFS III is a component of the Netherlands' extensive North Sea offshore wind energy development. Located in the "Nederwiek Noord" (Nederwiek North) zone, this project is an essential part of the nation's larger strategy for renewable energy, which aims to meet climate goals and increase the production of clean energy. Anticipated to possess many gigawatts (GW) of electrical generation capability, considerably augmenting the Netherlands' renewable energy infrastructure. Similar to previous Nederwiek series projects, the Dutch government will put out a call for bids for WFS III, which will be built by private enterprises. Nederwiek (noord) WFS III is expected to go to tender in the coming years, and construction is expected to start in 2026. This project will be finished in 2031. This initiative is essential to the Netherlands' attempts to reduce CO2 emissions by switching from fossil fuels to renewable energy sources and to the country's commitment to the Paris Agreement. Nederwiek (noord) WFS III is anticipated to further strengthen the Netherlands' position as a pioneer in the development of offshore wind energy while simultaneously supplying sustainable energy and stimulating local economies through the creation of jobs in the renewable energy sector (Andersen, Müller, 2022: 262).

The Dutch government is planning an offshore wind farm project called Doordewind WFS I as part of its aggressive plans to increase the country's capacity for renewable energy. It is one of many initiatives planned to assist the nation in achieving its sustainability and climate change objectives. It will be situated in the North Sea. With a multi-gigawatt (GW) capacity, Doordewind WFS I is anticipated to provide a substantial contribution to the renewable energy supply of the national grid. The Dutch government will put out a tender for the project, and businesses in the private sector will create it. Offshore wind energy firms will be able to submit competitive proposals through the tender procedure. Doordewind WFS I is anticipated to go to tender in the upcoming years, and construction may begin in 2027. The project is expected to be completed in 2032. The Netherlands' commitment to the Paris Agreement and its objective of switching from fossil fuels to clean, renewable energy sources depend heavily on this project. Doordewind WFS I is a component of a wider portfolio of offshore wind farms that will assist economic growth in the green energy sector and help the Netherlands boost its output of renewable energy and lower its carbon emissions (Andersen, Müller, 2022: 263).

3.3.3. Current Status of Germany about Offshore Wind Energy

Germany had 1,602 offshore wind turbines (OWT) operating as of June 30 , 2024: with a combined capacity of little less than 8.9 GW. In the first half of 2024, 36 of these turbines, totaling 377 MW in capacity, were initially connected to the electrical grid. Over the course of the six-month period, 78 existing turbines also underwent capacity improvements. By the middle of 2024, some of the related wind turbines had already been put up, and new foundations had also been put up (Wind Guard , 2024: 1).

In Germany, offshore wind projects go through a bidding process. In the past, projects have been granted to the lowest market premium offers, and in 2021 and 2022: tenders were held annually. Tenderers can now submit bids for a concession for centrally pre-investigated locations, according to a modification in the system. Other award criteria, like the bidder's decarbonization efforts, are now taken into consideration in addition to the operator's concession payment. The lowest market premium is used to award projects at locations that have not been centrally pre-investigated through an auction process. In the event that multiple bids of €0.00 cents are made, the highest bidder's payment is chosen in a subsequent round, doing away with the previous lottery method (Norton Rose Fulbright, 2023).

According to the draft law, it is typically no longer necessary to conduct a separate assessment of the effects on protected species and wildlife during the building phase. The Federal Maritime and Hydrographic Agency, which is in charge of identifying offshore wind regions, ought to conduct the majority of environmental inspections, which some may view as a conflict of interest. In an attempt to close the country's budget deficit, Chancellor Olaf Scholz's three-party coalition last month also chose to reduce funding allocated for fishing and marine nature conservation, which came from last year's historic offshore wind auctions. This move was a slight to environmentalists. Declaring the creation of hydrogen at sea to be in the "overriding public interest" is one of the early draft proposal's other objectives. As a component of the country's extensive ambitions to promote green gas, that would expedite licensing for electrolyzers close to offshore wind farms. According to a recent industry assessment, hydrogen production, mostly in the North Sea, might grow significantly (Bloomberg, 2024).

In Germany, 29 offshore wind power plants (OWP) were up and running by the middle of 2024. By the end of 2024, two further projects—Gode Wind 3 and Baltic Eagle—should be put into service. In 2023, the foundation installations for the two projects were already finished. Beginning in 2024, the turbines were installed, and many of them have already been put into service. For the Borkum Riffgrund 3 project, the foundations were erected toward the end of 2023, and the first turbines were put in the first half of 2024. May 2024 saw the start of the OWP EnBW He Dreiht's foundation installation. A final investment decision was taken in the spring of 2024 for the Windanker and NC 1-4 projects, in addition to these construction-related activities. By the end of June 2024, additional offshore wind energy projects had an award or claim for grid connection (Wind Guard , 2024: 4).

A large offshore wind farm called Gode Wind 3 is presently being built in the North Sea off the coast of Germany. The wind farm, which is jointly owned by Ørsted and Glennmont Partners, is expected to have a 253 MW capacity. The project is anticipated to be operational in 2024, having started with a final investment decision in 2021. Twenty-three Siemens Gamesa SG 11.0-200 DD turbines, each with a rotor diameter of 200 meters and an 11 MW capacity, will make up the wind farm. The DolWin6 grid link will be used to transmit the electricity produced by these turbines, which will be erected on monopile foundations and transported to the German mainland (NS Energy Business, 2024).

The Baltic Eagle offshore wind farm project is being built in the German state of Rügen, close to the Baltic Sea. It is a collaboration between Masdar and Iberdrola. With a 476 MW overall capacity, the wind farm should be operational by the end of 2024. When Baltic Eagle is finished, it will provide clean electricity to about 475,000 families and cut yearly CO2 emissions by almost one million tons. Installation of the first of 50 Vestas V174-9.5 MW turbines is the project's main objective, and major progress has already been achieved in 2024 with the installation of the first turbines. The Ostwind 2 grid connection will link Germany's electricity system to the Baltic Eagle wind farm (Baltic Wind, 2024).

With a capacity of 913 MW, Borkum Riffgrund 3, which is presently being built off the coast of Lower Saxony, Germany, will be the country's largest offshore wind farm when it is finished. This Ørsted-built offshore wind farm is noteworthy for being the first in Germany to be developed without subsidies, thanks to corporate power purchase agreements (CPPAs) with businesses like Google, Amazon, and BASF. Eighty-three Siemens Gamesa SG 11.0-200 DD turbines, each with an 11 MW capacity, will make up the wind farm. The first turbines were deployed in June 2024, after construction started in 2023. In 2025, full commissioning is anticipated. With Borkum Riffgrund 3, Ørsted's offshore wind capacity in Germany will almost double, contributing significantly to the nation's green energy transition (Ocean Energy Resources, 2024).

OWP EnBW He Dreiht is an offshore wind farm that is being built in the North Sea, 110 kilometers west of Helgoland and 85 kilometers northwest of Borkum. When finished, it will have a 960 MW capacity and will be Germany's largest offshore wind farm. EnBW (Energie Baden-Württemberg AG) is developing the project, which should be operational by the end of 2025. The wind farm will be one of the first commercial installations of the advanced turbine model, Vestas V236-15.0 MW, with 64 turbines that can individually produce 15 MW of power. These turbines have massive monopile foundations that are 70 meters long, 9.2 meters in diameter, and weigh about 1,350 metric tons apiece. The fact that the He Dreiht project is being constructed without official subsidies is one of its main features. Rather, to guarantee a steady flow of income for the project, EnBW has signed long-term power purchase agreements (PPAs) with significant industrial clients like Bosch, Fraport, and Evonik. The Dutch-German grid operator TenneT will oversee an offshore converter station that connects the farm's electricity to the grid (Maritime Executive, 2024).

As a component of their Baltic Hub strategy, Windanker is Iberdrola's third offshore wind farm project in the German Baltic Sea. The project, which is expected to cost about €800 million, is expected to start up in 2026. The 315 MW Windanker project will be made up of 21 Siemens Gamesa wind turbines, each with a 15 MW capacity. Long-term power purchase agreements will be used to sell the generated energy to industrial clients in Germany (PPAs). When the wind farm is fully operational, it will produce enough electricity to power roughly 315,000 households annually, which translates into a yearly reduction of about 500,000 tonnes of CO_2 emissions. The Navantia-Windar cooperation provides key components like monopiles and transition pieces for the construction, which is estimated to produce over 1,200 employment during the process (Offshore Wind, 2024).

The NC 1-4 project is a component of the larger Nordseecluster, an offshore wind farm situated in the North Sea of Germany. This multiphase cluster is intended to make a major contribution to Germany's renewable energy capacity. There are two primary stages to the development of the Nordseecluster: Nordseecluster A and B. Two offshore wind farms make up Nordseecluster A, which has a combined capacity of 660 MW; Nordseecluster B adds another 900 MW, bringing the total capacity to 1.6 GW. It is anticipated that these wind farms will provide 6.5 terawatt-hours of renewable energy per year. Key components of Nordseecluster A are now being built, and complete operations are anticipated by 2027 (Total Energies, 2024).

Off the coast of Heiloland in the North Sea of Germany, the Kaskasi Offshore Wind Farm, also called Kaskasi II (previously Hochsee Testfeld Helgoland), is an offshore wind farm. RWE Renewables is in charge of developing and running the wind power plant project. The wind farm has 38 Siemens Gamesa wind turbines, totaling 342 MW of installed capacity. In order to lessen reliance on fossil fuels and advance sustainable energy, the German Offshore Wind Energy Act includes the Kaskasi II offshore wind farm. By 2045, the act intends to raise offshore wind power's installed capacity to at least 30 gigawatts and at least 70 gigawatts. With around 100 RWE employees and 70 more suppliers working on the project, the offshore wind farm Kaskasi was built in nine months. Beginning commercial operations in December 2022: RWE's sixth wind farm in the German North Sea went into regular operation in March 2023. The Kaskasi offshore wind farm is situated 35 kilometers off the North Sea coast of Germany. The wind farm is roughly 17.4 square kilometers in size, with sea depths varying from 18 to 25 meters. The Kaskasi offshore wind farm is expected to cost about 800 million euros to build. More than 40,000 German houses will receive clean electricity as one of the many project advantages from the Kaskasi offshore wind project. Additionally, the wind turbine's cutting-edge recyclable rotor blades are a step in the right direction toward a sustainable future (Blackridge, 2024).

3.3.4. Future Prospects of Germany about Offshore Wind Energy

It will not be easy to meet the energy needs of Germany, a giant industrial country that gave up nuclear power 10 years ago and will close coal-fired power plants in 2038. Especially if it is taken into account that electric cars are replacing fossil fuel vehicles, the country's energy needs will double in the near future. For this reason, they are working day and night in Germany to build wind energy farms. In order to increase the efficiency of wind turbines, the dimensions are gradually growing and the turbines are being technically improved. The towers are approaching 200 meters, the length of the wings of the corkscrew exceeds 80 meters. It is being made quieter and more environmentally friendly (DW Türkçe, 2024).

The German Offshore Wind Energy Act (German: Windenergie-auf-See-Gesetz or WindSeeG) establishes the political expansion goals for offshore wind energy. According to the directive, the installed capacity of grid-connected offshore wind turbines must be raised to at least 30 GW by 2030, 40 GW by 2035, and 70 GW by 2045. The Federal Maritime and Hydrographic Agency's (German: Bundesamt für Seeschifffahrt und Hydrodrographie, or BSH) current plan calls for installing 50 GW by 2035, above the legally mandated minimum objective of 40 GW (Wind Guard , 2024: 4).

Germany possesses abundant supplies of affordable, high-quality wind energy. Thus, with 63.76 GW of installed wind power capacity overall in 2021, Germany has the greatest installed wind power capacity in the European region. This installed capacity is sufficient to power about 3.4 million of the nation's residences. RWE and BASF announced plans to invest USD 4.9 billion in offshore wind generating projects in May 2021. By 2030, RWE plans to construct a 2 GW offshore wind park as part of the project. The project's goal is to provide electricity to the Ludwigshafen chemical plant owned by BASF. Google agreed in November 2021 to purchase 50 MW of wind energy from an offshore wind farm in the German North Sea that was constructed by the massive Danish energy company Ørsted. The 12-year corporate power purchase agreement (CPPA) will help Google meet its goal of using carbon-free electricity to run all of its data centers by 2030. The Singaporean company Keppel Corporation announced in August 2022 that it will invest USD 314.7 million and a unit for a 50.01 percent share in a specific purpose vehicle (SPV) that controls 50 percent of the German offshore wind farm Borkum Riffgrund 2. Thus, throughout the forecast period, the expansion of the Germany Offshore Wind Energy Market is anticipated to be driven by rising investments and new offshore wind energy projects (Heghe, Sirois , 2024: 1).

Up to 2050, an estimated EUR 15–20 billion will be invested year. Energy cost savings and a decrease in energy imports are the results of these initiatives. Furthermore, German businesses' dominant positions in energy and environmental technology would be strengthened. In addition to achieving the Energiewende goals, new expenditures are required to replenish the nation's aging infrastructure (IRENA, 2023).

The continually rising proportions of renewable energy have already revolutionized the German energy grid. But the next 15 years will show how the Energiewende has far-reaching effects and highlight the solutions Germany needs to achieve its ambitious long-term energy and climate goals. These solutions will set the standard for the worldwide energy shift by incorporating cutting-edge financing and business strategies, as well as new technology advancements in the integration of variable renewable power (IRENA, 2023).

A development path that is transparent to all stakeholders is necessary for the long-term 2050 strategy to be implemented. According to the government's accord, greenhouse gas emissions must be reduced from 1990 levels by 40% by 2020 and by at least 80% by 2050. Though additional work will be needed to meet the Energiewende's long-term greenhouse gas emission targets, Germany is on track to meet its Kyoto Protocol targets (IRENA, 2023).

Germany plans to expand its offshore wind power capacity through a number of significant projects. Nordlicht I, N-9.1 and N-9.2, N-12.1, and O-2.2 are some of the significant projects Germany intends to construct in the upcoming years to increase its offshore wind generation capacity (Andersen, Müller, 2022: 270).

Vattenfall created the massive offshore wind energy project Nordlicht I (previously known as N-7.2) in the North Sea of Germany. In keeping with Germany's renewable energy targets, this project seeks to expand energy production capacity. With a 980 MW installed capacity, Nordlicht I will produce enough renewable energy each year to power about a million German homes (Vattenfall, 2024).

The location of Nordlicht I will be about 85 kilometers north of Borkum Island. The development rights for this project were awarded to Vattenfall in the 2022 auction, giving them the permission to make investments in the region. By 2027, Nordlicht I is anticipated to be finished and start producing electricity. This project, together with Vattenfall's other significant offshore projects in Germany, including the DanTysk and Sandbank wind farms, will support Germany's fossil fuel transition (NS Energy, 2024).

Two sizable offshore wind energy projects, N-9.1 and N-9.2, are situated in the North Sea, roughly 110–115 kilometers northwest of Germany's Borkum Island. Each site, which was created in collaboration between RWE and TotalEnergies, will have a 2 GW capacity, for a total energy production capacity of 4 GW. Between 2031 and 2032, these large projects are expected to be completely operational and generating electricity at their full potential (Energy Industry Review, 2024).

TotalEnergies became a partner after RWE won the development rights for these projects in Germany's most recent offshore wind energy auction. Construction is projected to start in 2029–2030, with final investment choices following environmental licenses in 2027–2028. By 2030, Germany wants to have 30 GW of offshore wind power, and these projects are a part of that ambition (NS Energy, 2024).

TotalEnergies intends to build two sizable offshore wind energy projects in the North and Baltic Seas of Germany: N-12.1 and O-2.2. N-12.1, which was awarded in a German Federal Network Agency auction, is situated in the North Sea, some 170 kilometers offshore, and spans 200 km^2. On the other hand, O-2.2 is located in the Baltic Sea and covers an area of 100 km^2, approximately 40 kilometers from the coast (Bundesregierung, 2024).

These two projects are designed to have a capacity of 2 GW and 1 GW respectively and will generate 3 GW of total energy when completed. The energy produced aims to provide clean electricity to more than 3 million households in Germany. After the completion of the relevant environmental permits and technical analysis, the projects are planned to make an investment decision in 2027 and to be commissioned by 2030. These projects aim to contribute to Germany's energy supply security and support the target of reaching 30 GW of offshore wind power capacity by 2030 (Energy Industry Review, 2024).

CHAPTER FOUR

THE PROBLEMS AND SOLUTIONS FACING EUROPEAN UNION ABOUT OFFSHORE WIND ENERGY

Offshore wind energy in the European Union has a number of obstacles that could prevent its long-term success, despite its bright future and quick growth. Technical constraints, high investment costs, regulatory obstacles, environmental concerns, and grid connectivity issues are some of these difficulties. For offshore wind projects to continue growing and being sustainable, these challenges must be resolved. As a result, a thorough examination of the current issues is required, along with useful suggestions and calculated solutions. Furthermore, other EU member states can learn a lot by analyzing the implementation experiences of top nations like Germany and the Netherlands. These elements will be thoroughly examined in the sections that follow.

4.1. Challenges for Offshore Wind Energy

One of the newest developments in wind energy conversion technology is the offshore wind farm (OWF). Compared to land-based wind resources, these wind resources are more plentiful, powerful, and reliable in terms of their availability. In actuality, stronger wind profiles and larger wind turbine ratings result in noticeably increased energy production (Perveen, Kishor, Mohanty , 2014: 1). However, a number of issues make its creation, use, and long-term viability more difficult. These difficulties fall into one of four categories: social, environmental, economic, or technical (Andersen, Müller, 2022: 280).

The severe sea environment and the intricacy of infrastructure present major technological obstacles for offshore wind energy. Corrosion is accelerated by continuous exposure to seawater, and turbines are further stressed by severe weather events like storms and strong winds. Higher costs result from the need for materials and components to be strong enough to endure these circumstances. Furthermore, maintenance is made more difficult by biofouling, which is the buildup of marine organisms on turbine structures. Due to their remote location, turbines necessitate costly high-voltage subsea cables and substations for power transmission, which adds energy losses and makes grid integration more difficult (Andersen, Müller, 2022: 280).

Additionally, the installation procedure is technically challenging. Depending on the water depth, installing foundations requires specialized vessels, heavy-lift equipment, and careful seabed preparation. Floating wind platforms are necessary in deeper oceans, however this technology is still in its infancy and needs dynamic cables and sophisticated anchoring systems to manage wave and current movement. Another difficulty is getting to offshore turbines for maintenance and repairs since they are difficult to reach in inclement weather. Although they increase complexity and expense, real-time monitoring systems and predictive maintenance technologies are crucial for preventing problems (Andersen, Müller, 2022: 280).

A viable option for deeper oceans is floating offshore wind, although it has its own set of technological challenges. The development of robust flexible cables, effective anchoring methods, and stable floating platforms is still ongoing. Meanwhile, integrating large-scale offshore wind farms into existing grids can strain transmission systems, necessitating infrastructure changes. Innovative materials, better turbine designs, floating technology advancements, and improved grid and storage solutions are all need to meet these difficulties and guarantee dependability and affordability (Andersen, Müller, 2022: 280).

With the potential to drastically cut greenhouse gas emissions and slow down climate change, offshore wind energy is a viable renewable energy source. However, the growth of offshore wind farms brings up significant environmental issues that need to be properly handled in order to guarantee sustainable development and reduce negative effects on wildlife habitats, marine ecosystems, and coastal communities. The necessity to comprehend and lessen the possible environmental effects of offshore wind installations is becoming more widely acknowledged as they continue to expand in offshore and coastal regions worldwide. This involves evaluating how offshore wind turbines affect marine mammals, migratory bird populations, seabed habitats, and marine biodiversity (Gupta , 2024: 4).

Furthermore, the development and maintenance of offshore wind farms may result in habitat fragmentation, noise pollution, and water quality changes, all of which might have a domino effect on marine ecosystems and the species that are linked with them. Subsea cable and equipment installation for offshore wind projects can also change hydrodynamics, disturb sediment, and have an impact on marine life behavior. Given these worries, environmental impact assessments, or EIAs, are essential for assessing the possible environmental consequences of offshore wind development and determining countermeasures. EIAs usually include species surveys, habitat mapping, in-depth analyses of marine ecosystems, and modeling of possible impacts on ecosystems and wildlife (Gupta , 2024: 4).

Moreover, to make sure that offshore wind projects are implemented in a way that strikes a balance between environmental preservation and renewable energy goals, stakeholder participation and collaboration with local people, environmental organizations, and regulatory authorities are crucial. Stakeholder input, scientific knowledge, and local knowledge can all be included into collaborative ways that help identify sensitive areas, reduce conflicts, and improve the ecological sustainability of offshore wind projects. Offshore wind developers can show their dedication to sustainable development and environmental stewardship by proactively addressing environmental concerns and putting in place efficient mitigation strategies. To ensure the long-term viability and success of offshore wind projects, a comprehensive strategy that incorporates biodiversity conservation, environmental protection, and renewable energy goals is needed (Gupta , 2024: 5).

The cost curve for using a technology is one of the elements that affects how rapidly it spreads and gains traction, as is the case with the majority of new technologies. Compared to onshore wind farms, offshore wind energy generation has always been substantially more expensive. However, recent advancements in turbine technology's size and design, combined with production models that are generally more efficient, point to the possibility of closing this gap. However, in recent years, the cost of offshore wind energy has increased instead of decreasing. Rising material costs, especially for steel, and quickly expanding demand relative to supply chain capacity are the causes of this (Green, Vasilakos , 2021: 7).

One of the biggest economic challenges facing the North Sea basin is the shifting landscape of energy production due to the decreased use of fossil fuels. The anticipated decommissioning of current oil and gas infrastructure has sparked a growing interest in its repurposing, though, because it might save society money and work well with newly developed renewable infrastructure. However, a number of variables affect the actual date of decommissioning (COP: cessation of production), primarily pricing and operating expenses, which are followed by cash flow and the amount of investment for new O&G projects. By 2025, over 25% of the current infrastructure is expected to be decommissioned, according to projections (Gusatu, Yamu , 2020: 16).

Public opinion and local resistance are the main causes of the major social issues that offshore wind energy projects frequently encounter. Concerns about the projects' effects on local tourism, fishing, and marine ecosystems may cause coastal communities to oppose them. "NIMBY" (Not In My Backyard) attitudes, in which people favor renewable energy but reject projects close to their own surroundings, might result from the visual impact of turbines on the seascape. Public involvement and awareness are essential for project adoption since misinformation or ignorance about the environmental advantages of offshore wind generation can intensify opposition (Andersen, Müller, 2022: 290).

The loss of traditional sea activities like fishing and leisure is another social issue. For example, fishermen may see offshore wind farms as a threat to their livelihoods since they interfere with fishing grounds and marine environments. Careful stakeholder participation, the development of compensating measures, and open communication regarding the coexistence of wind farms and traditional sea usage are necessary to allay these worries (Andersen, Müller, 2022: 290).

Politically, offshore wind energy frequently faces policy uncertainty and regulatory obstacles. Such projects usually require a drawn-out permitting process that entails navigating numerous levels of local, federal, and international restrictions. Projects may be delayed or even halted by competing interests amongst stakeholders, including energy developers, environmental protection organizations, and maritime authorities. Progress may also be hampered in some nations by political opposition to renewable energy in favor of fossil fuels, particularly if governments are swayed by strong oil and gas lobbying (Andersen, Müller, 2022: 291).

Political conflicts can also arise from the unequal allocation of costs and rewards among areas. While the electricity produced frequently helps far-flung urban centers, coastal areas that are home to offshore wind farms may experience the worst social and environmental effects. This geographic distance has the potential to exacerbate animosity and weaken political backing for offshore wind projects. Governments must enact stable, transparent laws, guarantee a fair distribution of advantages, and encourage cooperation from all parties concerned in order to overcome these obstacles (Andersen, Müller, 2022: 291).

The offshore wind energy business confronts major supply chain issues, particularly as worldwide demand for renewable energy projects grows. The restricted ability to manufacture essential parts like turbines, blades, and foundations is a serious problem. These goods need specific infrastructure for production and transportation because they are big and complicated. The supply chain is further complicated by logistical constraints, such as the shipping of these large components to distant offshore locations. Reaching aggressive deployment goals becomes challenging as lead times lengthen and project costs rise as demand exceeds production capacity (Andersen, Müller, 2022: 291).

The dependence on vital raw materials, such as steel for structural elements and rare earth elements for turbine magnets, presents another difficulty. The supply chain may be disrupted by price volatility and geopolitical risks related to procuring these resources. For instance, during times of worldwide shortages, nations having restricted access to rare earth materials or steel production may experience increased expenses and delays. To reduce these risks, it is crucial to invest in circular economy initiatives like recycling turbine parts, diversify sources, and fortify local supply chains (Andersen, Müller, 2022: 292).

Significant workforce issues, particularly with regard to the availability of specialized personnel, have been brought to light by the offshore wind energy industry's explosive growth. Offshore wind farm construction, installation, and maintenance call for knowledge in engineering, marine operations, and electrical systems—skills that are highly sought after in a variety of industries today. During project implementation, a shortage of properly trained staff may cause delays, higher expenses, and safety issues. Large-scale reskilling programs are also required because many current employees in the energy sector might not have the specialized training required for offshore wind projects (Andersen, Müller, 2022: 292).

The problem is made worse by regional differences in worker preparedness. Skilled personnel may be difficult to find in coastal locations with ongoing offshore wind projects, particularly in isolated or underdeveloped areas. Potential employees may be put off by long commutes and difficult offshore working circumstances, like being exposed to inclement weather. Governments and industry stakeholders must fund specialized training programs, apprenticeships, and efforts to increase the appeal of offshore wind careers in order to overcome these issues. Working together with colleges and technical institutions can also aid in creating a talent pipeline to satisfy the expanding demands of the industry (Andersen, Müller, 2022: 292).

4.2. Recommendations for Offshore Wind Energy

Improving design, encouraging innovation, and honing operating strategies are all necessary to meet the technical obstacles in offshore wind generation. First and foremost, it is critical to create sturdy turbine designs that can endure the severe marine environment, which includes strong winds, corrosion from saltwater, and severe weather. The lifespan of turbines can be considerably increased by advances in material technologies, such as the application of coatings and materials that are resistant to corrosion. Additionally, optimizing energy capture and boosting system performance can be achieved by increasing blade efficiency through advancements in aerodynamics and lightweight materials (Jones, Rowley , 2021: 66).

Attention must also be paid to foundation and installation technologies in order to facilitate more economical and successful offshore operations. Installations in deeper waters and on a variety of seabed conditions can be made easier by advanced foundation designs like floating platforms or gravity-based structures. While specialist vessels and equipment can guarantee effective transit, installation, and maintenance in demanding marine environments, modular and prefabricated components can expedite installation procedures (Jones, Rowley , 2021: 66).

Another crucial issue is enhancing transmission and grid connectivity. Electricity transmission from offshore farms to onshore networks can be made more efficient by upgrading transmission technology, like as high-voltage direct current (HVDC) systems. Reducing energy losses and averting blackouts require the construction of robust and redundant grid infrastructure. Furthermore, encouraging global cooperation on transnational grid connections can aid in managing regional energy surpluses and deficits, thereby advancing a more integrated and balanced energy network (Jones, Rowley , 2021: 66).

Modern technology should be incorporated into operation and maintenance plans in order to save expenses and increase productivity. AI and IoT-powered remote monitoring and predictive maintenance solutions can lessen the need for on-site repairs. While the establishment of port facilities and logistical hubs close to offshore farms can ease ongoing operations, autonomous vehicles and drones can carry out inspection and maintenance duties in difficult-to-reach regions (Jones, Rowley , 2021: 66).

Overcoming technological obstacles is mostly dependent on research and development. Innovation can be stimulated by investing in next-generation turbine technology, such as vertical-axis designs and larger-capacity turbines. Opportunities for advancements in deeper waters will arise from the testing and validation of floating wind systems. To develop these technologies and lower related costs, cooperation between government, business, and academia is crucial (Jones, Rowley , 2021: 67).

Finally, it is critical to increase the accessibility and utilization of meteorological and environmental data. Operational planning and site assessment can be improved by implementing sophisticated monitoring systems for oceanographic and meteorological data. Better understanding of wind farm interactions and the location of turbines for optimal efficiency can be gained via simulation models. Furthermore, carrying out thorough studies of marine ecosystems helps guarantee regulatory compliance and lessen environmental effects, promoting sustainable growth (Jones & Rowley , 2021: 67).

Strategies that lessen ecological effects while advancing sustainable development are needed to address the environmental issues of offshore wind generation. Before beginning any project, it is crucial to carry out thorough environmental impact assessments (EIAs) in order to detect any potential threats to marine life. By creating buffer zones surrounding delicate habitats, ecosystems can be shielded from the disruptions brought on by activities and construction. Action plans for biodiversity must also be created and carried out in order to help habitat restoration and lessen the effects on endangered species (Jones, Rowley , 2011: 68).

Mitigating noise and vibration impacts is another key factor. Underwater noise during construction can be greatly decreased by using low-noise installation methods like vibratory piling or gravity-based foundations. Marine animals can be safely kept out of building areas by using acoustic deterrent devices. Furthermore, disruptions to marine life can be reduced by planning construction projects at times when marine animal activity is lower (Jones, Rowley , 2011: 68).

Preserving marine habitats also requires minimizing seafloor disturbance. While geophysical and geotechnical assessments can determine the best turbine positions with the least amount of biological disturbance, environmentally conscious foundation designs can assist lessen physical impacts on seabeds. To preserve the integrity of these vital ecosystems, creative anchoring and cabling techniques should be used to prevent harming coral reefs and benthic habitats (Jones, Rowley , 2011: 68).

Turbines should be positioned and designed to reduce hazards, avoiding feeding areas and migratory routes, in order to control conflicts with birds and marine animals. Wildlife activity can be tracked by real-time monitoring devices, which enable operators to make necessary adjustments to operations. Bird and bat dangers can be further decreased by creating collision avoidance technologies, such as radar-based deterrents or painting blades with obvious patterns (Jones, Rowley , 2011: 68).

Long-term environmental sustainability is mostly dependent on monitoring and adaptive management. Programs for ongoing observation should be put in place to evaluate the environmental effects of wind farms over the course of their existence. Monitoring data and shifting environmental conditions should inform management strategy adaptations. Enhancing industry best practices can also be achieved by disseminating findings to stakeholders and the larger renewable energy community (Jones, Rowley , 2011: 68).

Another top goal is to lessen noise and sight pollution. Innovations in turbine design, like choosing hues that complement the horizon, can lessen the visual impact. Coastal towns benefit from less noise and visibility when wind farms are positioned far enough away from shorelines. During repair activities, operational processes should also be adjusted to minimize noise pollution above water (Jones, Rowley , 2011: 69).

Effectively tackling environmental concerns requires cooperation and stakeholder engagement. The ecological effects of offshore wind can be better understood by collaborating with local stakeholders, conservation groups, and academic institutions. While open communication regarding environmental mitigation strategies fosters support and trust, involving local communities and indigenous groups in planning procedures guarantees that their concerns are taken into account (Jones, Rowley , 2011: 69).

Last but not least, sustainable decommissioning techniques need to be given top priority. It is crucial to make plans for the safe disposal of turbines and associated infrastructure at the end of their useful lives. Waste can be decreased by recycling or reusing materials whenever feasible, and a positive legacy can be left by returning marine environments to their pre-construction condition or better (Jones, Rowley , 2011: 69).

A multifaceted strategy centered on cost reduction, investment growth, and long-term sustainability is needed to address the economic issues facing offshore wind generation. Promoting cost-cutting through innovation is one of the main tactics. To increase turbine efficiency, create floating platforms, increase rotor diameters, and use modern materials to reduce capital and operating costs, research and development expenditures are essential. Digitalization is also important, with tools like AI-driven analytics, digital twins, and predictive maintenance improving efficiency and reducing downtime. Manufacturing and deployment costs can be further reduced by standardizing parts and processes (Jones, Rowley , 2011: 69).

To sustain the offshore wind industry, incentives and policy assistance are crucial. Initial financial costs can be lessened by offering tax credits and subsidies, such as production tax credits (PTC) or investment tax credits (ITC), early in the project development process. Mechanisms for pricing carbon should be put in place to increase the competitiveness of renewable energy sources relative to fossil fuels. Additionally, the time and expenses involved in project development can be greatly decreased by expediting regulatory procedures and making permitting simpler (Williams, 2023: 15).

An other successful tactic is to encourage public-private collaborations. International organizations, governments, and private developers can work together on joint investments, sharing expenses and risks. One of the best ways to fund projects and draw in environmentally conscious investors is to issue green bonds tailored to offshore wind projects (Williams, 2023: 15).

Improving grid infrastructure is essential to offshore wind energy's success. Energy losses can be reduced and wind power integration into national networks facilitated by investments in interconnection points, offshore substations, and underwater cables. To solve intermittency and guarantee a steady power supply, large-scale energy storage solutions must be developed and implemented (Williams, 2023: 16).

Attracting investment in offshore wind projects requires reducing the financial risks involved. To address the particular risks associated with development and operation, specialized insurance plans had to be created. Projects can become more financially feasible by using revenue stabilization techniques like contracts for difference (CfD) or long-term power purchase agreements (PPAs), which can offer steady cash streams (Williams, 2023: 16).

The expansion of offshore wind energy requires the development of a competent labor force. By establishing training programs, managers, engineers, and technicians can acquire the specialized skills needed for the field. Workforce capacities can be further improved through international collaboration to exchange lessons learned and best practices (Williams, 2023: 17).

Another important tactic for cutting expenses and boosting effectiveness is scaling up deployment. Larger projects can benefit from centralized logistics and bulk buying, which allow for economies of scale. Creating wind farm clusters lowers costs even more by enabling the shared use of infrastructure like ports, ships, and grid connections (Williams, 2023: 17).

A viable way to access wind resources in deeper waters, where wind speeds are frequently stronger and more reliable, is through floating offshore wind technology. Putting money into this creative strategy can open up a lot of offshore wind energy potential (Jones, Rowley , 2011: 71).

For offshore wind projects to succeed, social acceptance and community involvement are essential. Open and honest communication with local communities can help to resolve issues and build support. Public support can be increased by making sure that local economies gain from supply chain participation, port development, and job creation (Jones, Rowley , 2011: 72).

Lastly, addressing the financial obstacles in offshore wind generation requires international cooperation. International joint ventures can combine resources and experience, and advancing global standards can lower costs and ease technology transfer. Offshore wind energy can become a more sustainable and cost-competitive pillar of global renewable energy initiatives by fully tackling these issues (Jones, Rowley , 2011: 72).

Ensuring public approval and stakeholder engagement is one of the major societal concerns. Early and open communication with fishermen, local communities, and other stakeholders is crucial to achieving this during the project design phase. Trust and support can be developed by outlining the advantages of offshore wind energy in detail and resolving any reservations. Campaigns for education and awareness, including public forums, workshops, and educational initiatives, can also contribute to a greater understanding of the financial and environmental benefits of offshore wind energy. Establishing just compensation procedures is essential for individuals who will be directly impacted, such as fishermen or coastal inhabitants, in order to minimize possible interruptions and guarantee fair treatment (Jones, Rowley , 2011: 72).

The establishment of jobs and skill development present another social challenge. The creation of local jobs should be the top priority for offshore wind projects in order to boost the local economy. In order to ensure that local labor can effectively contribute to offshore wind farm projects, vocational training programs should be designed to give workers the skills they need to build, maintain, and operate these installations (Jones, Rowley , 2011: 72).

Environmental and aesthetic problems are also important. In order to reduce the visual impact of wind turbines and steer clear of important habitats or marine migration routes, careful site selection is essential. Adopting eco-friendly turbine designs can also lessen the possibility of harm to ecosystems and marine life, striking a balance between environmental preservation and the demand for renewable energy (Williams, 2023: 22).

The legislative and regulatory structures that oversee offshore wind generation frequently give rise to political difficulties. Developers can experience fewer delays and uncertainty if permitting procedures are streamlined to become transparent and predictable. To promote investment in offshore wind projects, supportive policies like feed-in tariffs, tax breaks, or subsidies are crucial. International cooperation is also essential, especially when tackling common issues like grid interconnections and maritime zoning, which frequently include several nations (Jones, Rowley , 2011: 73).

Another crucial area that has to be improved is interagency coordination. A more unified strategy may be ensured and bureaucratic obstacles can be decreased by establishing a centralized authority to supervise offshore wind development. To properly coordinate efforts and resources, cooperation between the public and private sectors as well as between the federal, state, and local governments is equally crucial (Jones, Rowley , 2011: 73).

Integration of the energy market presents further difficulties. To effectively manage the fluctuating production of offshore wind energy, grid infrastructure must be strengthened and expanded. In order to encourage the incorporation of renewable energy sources and offer suitable recompense for the distinct features of offshore wind generation, market changes had to be implemented (Williams, 2023: 23).

For offshore wind energy to be developed and scaled successfully, supply chain and manpower issues must be resolved. First and foremost, it is imperative to improve local manufacturing and infrastructure. To guarantee that port infrastructure can manage the extensive logistics needed for turbines, blades, and foundation components, investments should be made in this area. While fostering modularity by pushing standardized designs for turbines and components might increase compatibility and minimize production complexity, supporting local manufacture through incentives can shorten supply chains and lessen reliance on imports (Jones, Rowley , 2011: 73).

Another important area of attention is supplier diversification. By encouraging competition and enrolling several providers for essential parts like cables, nacelles, and blades, reliance on a small number of suppliers can be lessened. Additionally, through specialized funding and training initiatives, small and medium-sized businesses (SMEs) ought to be encouraged to join the market. Digitalization and sophisticated logistics planning tools should be used to alleviate logistical bottlenecks and expedite the movement of parts from manufacturing facilities to installation locations. Delays and inefficiencies can also be minimized by using offshore hubs or storage facilities. Furthermore, it is crucial to mitigate material shortages, which can be accomplished by giving circular economy techniques like recycling metals and rare-earth elements from retired turbines top priority. The supply chain can be strengthened even more by establishing strategic stockpiles of vital raw materials, such as copper and rare-earth elements (Jones, Rowley , 2011: 74).

In order to overcome obstacles in the offshore wind energy industry, workforce development is also essential. Building a skilled workforce requires upskilling and training. Governments, academic institutions, and the corporate sector should collaborate to create specialized courses in offshore wind technology, operation, and maintenance. For technicians, engineers, and other workforce positions, apprenticeship programs can offer practical experience, and certificates ought to be in line with international safety and technical requirements. STEM education should be promoted to create a talent pool for engineering, data analysis, and technology positions in order to fill labor shortages. Professionals in the oil and gas industry should also be given incentives to switch to offshore wind through reskilling initiatives (Jones, Rowley , 2011: 74).

Equally vital is promoting diversity in the workforce. Through mentorship programs and targeted grants, underrepresented groups—such as women and minorities—should be encouraged to participate in order to actively promote inclusivity. To create labor pools, local communities close to offshore wind project areas can also be included. Offering reasonable pay and benefits coupled with clear career growth pathways can help retain personnel, which is another top objective. Retention rates can be further increased by improving work-life balance, especially for technicians employed in demanding offshore locations (Jones, Rowley , 2011: 74).

To guarantee the smooth integration of personnel and supply chain plans, cross-cutting recommendations are crucial. Collaboration between the public and commercial sectors is essential, with governments supporting workforce development and supply chain strengthening through finance and legislation. To match training programs with industry demands, offshore wind developers, manufacturers, and educational institutions should work together. Innovation and digitization have the potential to be revolutionary as well. Supply chain management, workforce training simulations, and predictive maintenance can all be enhanced by utilizing digital tools like AI and IoT. Additionally, funding for research and development can investigate cutting-edge building techniques and materials (Jones, Rowley , 2011: 74).

Finally, for the offshore wind energy industry to flourish sustainably, policy and regulatory support are essential. To lower the financial risks for developers and manufacturers, governments should implement long-term, stable policies like tax credits and subsidies. Enforcing local content criteria through policy can encourage domestic worker involvement and supplier chains. The offshore wind energy industry may overcome logistical and human capital issues and achieve sustainable and effective growth by tackling these issues comprehensively (Jones, Rowley , 2011: 75).

4.3. Evaluation of Offshore Wind Energy Implemenations in Germany and Netherlands

One of the most important and dynamic elements of Europe's renewable energy transition is offshore wind generation. Germany and the Netherlands stand out among the nations spearheading this change because of their aggressive offshore wind goals, comprehensive policy frameworks, and growing infrastructure and innovation expenditures. Both nations have advanced significantly in the development of offshore wind energy projects as of 2025. The extent to which Germany and the Netherlands have achieved their offshore wind energy objectives and the extent to which they are on track to reach their future goals are examined in this section (European Commission, 2024).

With its Energiewende (Energy Transition) plan, which prioritizes decarbonization, sustainability, and the phase-out of nuclear power, Germany, the largest economy in Europe, has long placed a high priority on renewable energy. In this shift, offshore wind energy is essential. Germany has more than 8.3 gigawatts (GW) of offshore wind capacity in operation as of early 2025, mostly in the North and Baltic Seas. This accomplishment shows a consistent move toward medium- and long-term goals and is consistent with previous 2020 targets (BMWK, 2024).

According to its modified Wind Energy at Sea Act (Windenergie-auf-See-Gesetz), Germany has set one of the most ambitious offshore wind ambitions in Europe: 30 GW by 2030, 40 GW by 2035, and a long-term aim of 70 GW by 2045. The government has started programs to find and pre-develop new wind zones, boosted financial incentives, and expedited auctions in recent years. There is a robust pipeline that is in accordance with national goals, as seen by the numerous high-capacity projects that are currently under way and expected to be completed by 2030, like the Nordseecluster and EnBW's He Dreiht (Agora Energiewende, 2024).

Notwithstanding these advancements, Germany's offshore wind industry has continued to encounter obstacles that could postpone significant future developments. The absence of synchronized grid infrastructure is the most significant of these. Offshore wind farms have been built, but onshore system growth has lagged behind, especially when it comes to delivering electricity to the industrial centers in the south. The efficiency of offshore wind output has decreased as a result of curtailments and energy losses brought on by this mismatch between the transmission and generation facilities (Energy Monitor, 2023).

The approval of new wind farms has also been delayed by complicated regulatory and permitting processes. Development delays have been extended by environmental impact assessments, maritime traffic issues, and the division between federal and state sovereignty. Reforms to expedite permitting procedures have been implemented by the German government, although administrative execution is still slow. Further impediments to the expansion of offshore wind areas include growing concerns about marine biodiversity and spatial conflicts with maritime, military, and fishing zones (WWF Germany, 2024).

Germany, however, is still innovating and adapting. The combination of offshore wind and green hydrogen production is a noteworthy trend. A number of pilot projects, including those at Wilhelmshaven and Helgoland, seek to electrolyze hydrogen using offshore wind energy. This facilitates sector coupling and promotes industrial decarbonization, giving offshore wind a new level of strategic significance. The European Union's overarching objective of creating a hydrogen economy by 2030 is likewise in line with these trends (Hydrogen Council Germany, 2024).

As of 2025, if continuous reforms and investments continue, Germany is mostly on track to reach its 2030 objective of 30 GW. The ambition is still unparalleled in Europe, and although there will be challenges along the way, Germany is well-positioned to realize its vision because to the foundations established over the previous 20 years. To sustain momentum, however, the upcoming years will require not only technology advancements but also policy coherence, stakeholder alignment, and expedited permitting procedures (IEA, 2024).

With a practical and well-coordinated approach, the Netherlands has quickly become a major player in the offshore wind industry. With over 4.7 GW of installed offshore wind capacity as of 2025, the nation has surpassed intermediate benchmarks and is well headed toward meeting or possibly exceeding its 2030 objective of 21 GW. The foundation of the Dutch approach is centralized planning, minimal regulatory obstacles, and strong investor trust, all of which have accelerated project development (Netherlands Enterprise Agency, 2024).

The Dutch model differs from Germany's decentralized strategy in that offshore wind zones are pre-developed by the national government, including permits, grid connections, and environmental studies, before being put up for auction to developers. As a result, there is less uncertainty, development times are shortened, and foreign investors find the market appealing. The Dutch offshore wind industry is mature, as evidenced by the record-low prices at which tenders have been won in recent years, including some zero-subsidy bids. The success of the strategy is demonstrated by projects like Hollandse Kust Noord and Zuid, which are now being built or partially completed (Wind Europe, 2023).

The Netherlands is incorporating offshore wind into its larger energy and industrial objectives in addition to increasing capacity. Offshore wind power is being combined with CO_2 collecting infrastructure, storage options, and hydrogen production through programs like the North Sea Energy Program. These multipurpose platforms are increasing spatial efficiency in the North Sea, one of Europe's most heavily used marine regions, in addition to diversifying the use of offshore energy (IRENA, 2024).

The North Sea Agreement, which strikes a balance between ecological protection and energy development, is another example of the Dutch government's strong commitment to sustainable offshore development. This entails pledges to improve biodiversity, meticulous spatial design, and stakeholder interaction with environmental, shipping, and fishing organizations. Compared to certain neighboring countries, these initiatives have led to a greater level of social acceptability and less judicial challenges (WWF Netherlands, 2023).

With plans to reach 50 GW of offshore capacity by 2040, the Netherlands is already getting ready for advancements that will occur after 2030. The government is investigating the possibilities of floating wind platforms and offshore energy islands, which would provide access to farther-off places and deeper waters. The Netherlands is establishing the foundation for a long-term, sustainable offshore wind economy by proactively addressing future requirements, including as storage, interconnection, and system integration (Offshore Wind Innovation Centre, 2023).

The Dutch offshore wind concept is a prime example of executional excellence as of 2025. The Netherlands is very likely to meet, if not surpass, its 2030 targets given the current rate of implementation and forward-planning processes, even though environmental and spatial restrictions will become more urgent as capacity grows (GWEC, 2024).

CONCLUSION

A key component of Europe's larger shift to sustainable, low-carbon energy systems is the development and application of offshore wind energy throughout the EU, especially in the North Sea region. The many facets of wind energy and offshore wind energy have been thoroughly examined in this thesis, from the fundamental ideas and their inherent benefits and drawbacks to the energy policies and renewable energy strategies of the European Union to the particular projects and development paths of the North Sea states, with a focus on Germany and the Netherlands. These two nations' experiences show both common potential and nation-specific difficulties that are relevant to the offshore wind industry throughout the EU, despite the fact that they were mostly used as illustrative examples.

First, the thesis restates wind energy's increasing importance as a renewable energy source in the European and worldwide energy scene. Because of its special benefits, including its limitless supply, cheap post-installation operating costs, and substantial potential to cut greenhouse gas emissions, wind energy is a key component in the fight against climate change and the improvement of energy security. Large tracts of open space that can support massive wind farms, stronger and more constant wind speeds over the sea than on land, and a decrease in common onshore conflicts like noise and visual disturbances make offshore wind energy a particularly promising subset of wind power. These features help explain why offshore wind energy is becoming more and more appealing for growing renewable capacity. The high capital costs of installation and maintenance, the intricate logistical requirements for construction and grid connection, the ecological concerns associated with marine environments, and the technical difficulties of incorporating variable power sources into current energy systems are some of the significant obstacles that restrain this growth.

Offshore wind energy has developed quickly thanks in large part to the European Union's proactive energy policy. The EU has set aggressive goals for the deployment of renewable energy and carbon neutrality through extensive policy frameworks including the European Green Deal and the Renewable Energy Directive. In addition to offering legislative direction, these policies promote financial incentives and other support systems that are crucial to the expansion of the offshore wind industry. With offshore wind technology developing as a crucial strategic element of the continent's energy future, Europe has established itself as a global leader in the deployment of renewable energy.

From wind energy's early, modest use in Europe to its current state, which is characterized by advanced technology and growing economies of scale, this thesis has charted its historical development. Over the past 20 years, wind energy has grown rapidly worldwide, with offshore wind becoming more and more significant. The EU has taken advantage of this momentum, converting legislative goals into significant capacity additions, motivated by both economic interests and environmental objectives.

With a focus on the North Sea, this thesis emphasized the region's vital significance as a European offshore wind energy hub. Large-scale offshore wind projects are made possible by the Southern North Sea, which is shared by the Netherlands, Germany, Belgium, and the UK. It provides ideal circumstances, including shallow oceans, consistent wind resources, and close proximity to significant energy consumers. This area, where technology advancement and regional collaboration meet, has turned into a model for offshore wind deployment.

Within the larger EU framework, the experiences of Germany and the Netherlands offer specific examples of offshore wind energy developments at the national level. The Netherlands has become a major participant in offshore wind by taking advantage of its advantageous coastline location and robust regulatory backing. Dutch offshore wind projects benefit from aggressive national targets in line with EU directives and generally shallow coastal waters that make installation easier and lower costs. In the upcoming decades, the Netherlands plans to build large offshore wind farms that will significantly boost its production of renewable electricity and lower carbon emissions.

In contrast, Germany's offshore wind industry is distinguished by its significant cumulative capacity and early investments. Using its strong industrial base and technological know-how, Germany was one of the first EU nations to build offshore wind farms on a large scale. Nevertheless, the German offshore wind industry also has particular difficulties, such as complicated grid integration problems, which are partly brought on by the wind farms' geographic dispersion and the country's pre-existing energy infrastructure, as well as legal and regulatory barriers that occasionally impede project progress. Notwithstanding these obstacles, Germany is nonetheless dedicated to increasing its offshore wind capacity in accordance with its national energy transition objectives, anticipating that offshore wind would be crucial to achieving its challenging climate goals.

These national examples highlight the reality that although the EU establishes broad objectives and regulations, national characteristics like location, legal frameworks, market dynamics, and technological prowess determine whether offshore wind energy is realized. Appreciating the variety of development paths within the EU's offshore wind sector requires this detailed understanding.

To guarantee ongoing growth, however, a number of obstacles must be overcome in the EU's offshore wind energy development. Environmental issues are of utmost importance; offshore wind farms have the ability to impact fishing grounds, bird migration patterns, and biodiversity by interacting with delicate marine ecosystems. To reduce negative consequences, these ecological factors require in-depth environmental impact assessments and continuous monitoring. Furthermore, continuous innovation and investment are needed to address technological issues including establishing efficient offshore grid infrastructure, guaranteeing the robustness and dependability of turbines in challenging maritime conditions, and striking a balance between intermittent renewable power and grid stability.

Economically, without sufficient legislative support and financial incentives, the high upfront capital costs and protracted project development timetables may discourage investment. Complicated regulations, such as drawn-out permitting procedures and disparate member-state regulations, can impede development even further. Therefore, preserving investor trust and speeding adoption require simplified approvals, harmonized rules, and supportive market frameworks.

This thesis made a number of suggestions to support the efficient and sustainable expansion of offshore wind energy in the EU in light of these difficulties. A more integrated and robust energy market might be produced by improved cross-border collaboration among North Sea governments, which could maximize resource allocation, grid connectivity, and project development. Research and development expenditures could increase offshore wind's reach and dependability, especially in deeper oceans where conventional fixed-bottom turbines are impractical. This is especially true for developing technologies like floating offshore wind turbines and energy storage devices.

To foster societal acceptance and proactively resolve problems, stakeholder engagement—including those of local communities, environmental organizations, and maritime industries—should be given top priority. Adaptive management techniques and transparent environmental assessments can help achieve this objective. Policies must keep changing to provide long-term, stable, and transparent frameworks that encourage innovation and involvement from the private sector.

In conclusion, offshore wind energy in the North Sea nations of the European Union represents a complicated array of obstacles as well as a promising opportunity. The Netherlands and Germany serve as examples of the many ways that EU member states are promoting offshore wind projects. These examples highlight the strategic value of offshore wind in Europe's energy transition by striking a balance between national conditions and the goals of the EU as a whole. Using collaborative, creative, and flexible approaches to tackle technical, environmental, financial, and regulatory obstacles will be essential to the offshore wind energy industry's successful growth. Offshore wind energy has the potential to be a key component of Europe's sustainable energy future with continued dedication by governments, businesses, and stakeholders. It will make a substantial contribution to energy security, climate goals, and economic expansion in the ensuing decades.

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