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Master Thesis

Offshore Wind Power: Climate Change Mitigation and Geopolitics

by

Lydia Chatzidaki

Supervisor: John Paravantis

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Abstract

One, if not the greatest, challenges humanity and our planet faces nowadays is climate change. The use and extraction of fossil fuels, or in other words conventional energy sources, have taken a toll on earth. Renewable energy sources seem to be an invaluable tool in the ongoing battle to mitigate climate change and create a sustainable future for all. Focusing on wind and especially offshore wind power, a relatively new and rapidly growing renewable source, this study aims in exploring offshore wind power trends in Europe, China, Greece and other active regions (e.g., the United States of America, Vietnam, South Korea, Japan and Taiwan). A combination of comparative analysis and case study approach forms the methodological framework used. Results show that each region shows a rapid offshore interest and growth. The extent of the aforementioned growth though, differs between regions and depends on various factors such as economic and technological growth but also on the geopolitical role renewable energy begins to play in the global agenda. Even though all regions recognize the significance of offshore wind and energy transition in general there is still a long way to go.

Keywords: Greek offshore wind strategy, Offshore wind power, Offshore wind geopolitics, Renewable energy, Wind power

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Chapter 1: Introduction

1.1 Introduction

As per the findings of the Intergovernmental Panel on Climate Change (IPCC), the phenomenon of global warming is substantiated, with human actions identified as the primary catalyst, resulting in an estimated temperature increase of approximately 1.0 °C above pre-industrial levels. This trajectory is anticipated to escalate to 1.5 °C within the timeframe spanning from 2030 to 2052.[1] In reaction to the environmental dangers stemming from global warming, there is a critical imperative to elevate the utilization of renewable energy sources. This strategic action is indispensable not only to enhance energy security but also to cultivate a more sustainable and conducive environment.[2]

Wind stands out as an appealing energy asset owing to its renewable nature, minimal environmental impact, social acceptability, economic viability, and environmental sustainability.[3] Various options exist for harnessing wind energy, including onshore and offshore approaches. While onshore wind energy has been used for over two millennia, the utilization of offshore wind power is a relatively recent development. In recent times, there has been a notable shift in the wind power sector towards offshore installations, tapping into the expansive and favorable wind conditions present in open sea areas for large-scale electricity generation.[4]

Amid discussions on energy and geopolitics, conventional attention gravitates towards the influence of oil and gas on interstate dynamics. However, there is an increasing acknowledgment of the importance of renewable energy generation and the trade of associated materials worldwide.[5]

Motivated by the subject of offshore energy and the related geopolitics, this study aims to approach offshore wind power holistically, thus the research questions are formed as following:

1. What role does offshore wind power assume in facilitating Europe's transformation into an autonomous and influential energy player?

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[1] Intergovernmental Panel on Climate Change (IPCC) (ed.), 2022
[2] Ramadan, 2017
[3] Burton *et al.*, 2011
[4] Markard and Petersen, 2009
[5] Hatipoglu, Muhanna and Efird, 2020

2. What are the implications of offshore wind farm development on the dynamics of international geopolitics?
3. Where is Greece positioned within the framework of the European offshore wind power agenda?

1.2 Structure of Thesis

The subsequent sections of this study are organized as follows: Chapter 1 serves as an introduction, offering a comprehensive overview of offshore wind power. Chapter 2 contains the literature review navigating through climate change, renewable energy sources, and wind power. Chapter 3 provides the research methodology adopted for this study. Following this, Chapter 4 represents the outcomes of our research pertaining to offshore wind power and its associated geopolitics. This chapter also entails a discussion on the aforementioned subjects. Finally, Chapter 5 outlines the study's summary and proposes subjects for future research in this domain.

Chapter 2: Literature Review

2.1 Introduction

This chapter focuses on establishing a solid theoretical foundation concerning the dynamics of climate change, with a particular emphasis on renewable energy technologies, notably wind power. This foundational framework is crucial for deepening the reader's comprehension of the analyses presented in subsequent sections.

2.1.1 Climate Change

Currently, the phenomenon of global warming, inevitably leading to climate change, emerges as one of the paramount existential threats facing humanity. At the core of this transformative process lies the greenhouse effect, a mechanism by which our planet simulates the characteristics of a greenhouse structure, retaining thermal energy in the atmosphere and thereby elevating Earth's temperature—analogous to the workings of an actual greenhouse. The major contributors of this climatic metamorphosis are greenhouse gases, several of which are in fact naturally occurring and serve the vital function of maintaining a habitable planet. However, the proliferation of human activities since the beginning of industrial age, particularly the burning of fossil fuels such as coal and oil, has induced a significant escalation in the concentrations of these greenhouse gases within the atmosphere, with carbon dioxide (CO_2) standing as the preeminent contributor to global warming.

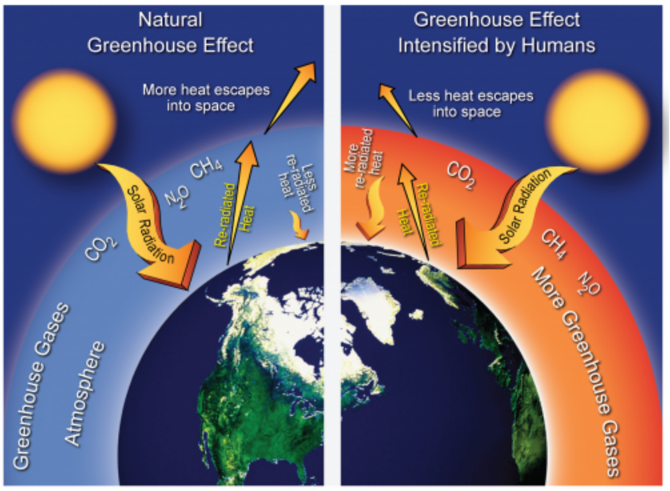

Figure 1: Human Influence on the Greenhouse Effect [6]

Traditional energy sources, notably coal, oil and natural gas, serve as significant factors to the ongoing challenge of climate change and the continuous dependance on them exacts a toll on public health and the environment. The repercussions of climate change, are already manifesting in the form of heightened risks and prolonged periods of drought and wildfires, diminishing snowpack, rising sea levels and the imperilment of vulnerable wildlife species.[7]

On a global scale, there have been concerted efforts to mitigate and potentially arrest climate change, exemplified by international accords like the Kyoto Protocol[8] and the Paris Agreement[9]. The critical imperative at present is to identify strategies to effectively reduce CO_2 and greenhouse gas emissions in general, progressing toward the aspirational goal of achieving net-zero emissions. A salient means to actualize this objective, involves the progressive phasing out of fossil fuel combustion for energy production in favor of renewable energy sources.[10]

2.1.2 Renewable Energy Sources

The ongoing depletion of fossil fuel reserves, coupled with the environmental challenges posed by continuously rising energy needs, is driving a transformative shift towards a more sustainable, and environmentally responsible path of development, where renewable energy

[6] U.S. National Park Service, 2012
[7] Kumar, Singh and Kumar, 2021
[8] United Nations Framework Convention on Climate Change (UNFCCC), 1997
[9] United Nations (UN), 2015
[10] European Commission, no date

sources are widely embraced. The realm of renewable energy is experiencing rapid expansion, characterized by a multitude of advancements and practical applications.

Renewable energy harnesses sources that, by definition, regenerate within a human lifespan, thus preserving the planet's finite reserves. These resources—spanning sunlight, wind, precipitation, tidal movements, wave energy, biomass, and geothermal heat—are both abundant and sustainable. Moreover, they offer the advantage of minimal environmental degradation compared to conventional energy sources.[11]

On the contrary, finite quantities of fossil fuels like gasoline, coal, and natural gas are steadily decreasing as they are extracted. The depletion of these conventional resources, exacerbated by escalating demand, compels policymakers and planners to explore alternative energy sources. While commercial energy sources such as coal, oil, and natural gas remain prevalent, renewable energy is progressively assuming greater significance. It is crucial in the pursuit of sustainable development, offering a long-term, cleaner energy solution that mitigates local and global atmospheric emissions while fostering employment opportunities for local communities.[12] Renewable energy has consistently outpaced all other energy sources since 2011, with 2019 setting a new milestone as clean energy capacity surged by over 200 gigawatts, marking the most substantial growth to date.[13]

The relentless global expansion of road transport, manufacturing activities, and fossil fuel-dependent power generation, alongside the unregulated incineration of waste in urban areas, contributes to heightened air pollution levels. Furthermore, the use of charcoal and fuelwood for heating and cooking in many developing regions significantly compromises indoor air quality. The emissions of particles and other pollutants from fossil fuel combustion pose a severe health hazard, leading to millions of premature deaths and incurring substantial economic costs.

In contrast, renewable energy sources release minimal to no air pollutants, enhancing public health and environmental well-being. This transition towards renewable energy not only addresses the urgent need for clean, sustainable power but also promises a brighter, more environmentally responsible future.[14] Throughout history, all industrial revolutions have been fundamentally characterized by their association with energy revolutions. The inaugural

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[11] Australian Renewable Energy Agency, no date
[12] Topaloglou *et al.*, 2024
[13] International Energy Agency (IEA), 2020
[14] REN21, 2020

industrial revolution, spanning from 1760 to 1840, marked the advent of mechanization and set in motion a trajectory that has now culminated in the fourth industrial revolution.[15] This latest phase is distinctive in its endeavors to seamlessly integrate production processes with alternative and renewable energy sources[16,17], i.e. sources that are perpetually replenished or replenishable within exceptionally brief timeframes and from which our planet has in abundance for us to exploit. These abundant energy sources, which our planet readily provides for us to harness, encompass solar, wind, hydro, biomass, geothermal, and marine or ocean energy.[18] In recent times, new and unconventional sources have also arisen, including waste-to-energy (WtE), reflecting the evolving landscape of sustainable energy options.

Renewable energy stands as a potent catalyst for fostering climate resilience, improving public health, and bolstering economic vitality. A multitude of renewable energy sources, such as wind, solar, and geothermal power, are characterized by their carbon-neutral nature and their capacity to generate electricity. Though geothermal energy systems do emit some air pollutants, their overall contribution to air emissions remains considerably lower in comparison to coal- and natural gas-based power generation. Furthermore, the inherent advantages of wind and solar energy are evident in their minimal water requirements, resulting in a preservation of water resources. This preservation, in turn, avoids competition with agricultural, residential, and wildlife needs – thus alleviating the strain on water supplies – as well as the pollution of water resources. Hence, it is evident that this shift toward renewable energy aligns with a broader vision of ecological and economic sustainability. This critical shift in energy utilization exemplifies the dynamic nature of industrial progress in our pursuit of greater sustainability and resilience.[19]

2.1.3 Wind Power

The prominence of wind energy relative to other renewable technologies can be attributed to a convergence of two pivotal factors: resource availability and the advanced cost efficiency of the technology. First and foremost, wind energy, along with solar, wave, and tidal energy, stands out due to the abundance of available resources, surpassing the availability of

[15] Groumpos, 2021
[16] Onu, Pradhan and Mbohwa, 2023
[17] Jena, Mishra and Moharana, 2020
[18] Aust, 2014
[19] Hassan *et al.*, 2024

geothermal, small-scale hydropower, and biomass. Furthermore, the advanced stage of wind energy technology is a distinguishing feature, rooted in centuries of use in various economic activities such as sailing, irrigation, and milling. This extensive history sets it apart from other technologies like solar, wave, and tidal energy, which have not undergone such a prolonged evolutionary process.[20]

The utilization of renewable energy resources, with a particular focus on wind power, has garnered substantial attention from governmental bodies and private institutions. This heightened interest arises from the recognition that renewable energy, especially wind power, stands as one of the most compelling and competitive alternatives in the ongoing global energy transition adopted by numerous nations. Wind power assumes a pivotal role in curbing greenhouse gas emissions, therefore contributing to the mitigation of global warming. Additionally, it offers the advantage of diversifying a country's energy portfolio, a particularly significant consideration in regions where hydropower holds substantial prominence.

However, to fully capitalize on wind power, understanding and managing its variability are paramount. Efforts to expand wind power generation necessitate a comprehensive grasp of its fluctuations and methods to minimize uncertainties related to its production. Employing technical methods such as simulation and forecasting becomes instrumental in supplying decision-makers with enhanced information to inform strategic choices. In this context, wind power emerges as a linchpin in the endeavor to advance sustainable energy solutions.[21]

Wind power exhibits characteristics of stability in its installations, a decline in costs within a fiercely competitive industry, and a growing emphasis on offshore wind energy. Notably, the Asian continent commands the most extensive regional market share, contributing almost 52% of the added capacity by the year 2018. The decrease in costs serves to invigorate markets and boost sales, while the industry grapples with various challenges through continual technological advancements, encompassing the development of larger turbines, enhanced plant efficiency, and heightened output. These innovations collectively work to drive down electricity costs associated with wind power generation. Remarkably, at least 12 countries achieved a remarkable milestone in 2018 by generating approximately 10% of their yearly electricity consumption from wind power, underscoring the global shift from feed-in tariffs (FiT) towards competitive methods like auctions and tenders. This transition has induced fierce

[20] Esteban *et al.*, 2011
[21] Vargas *et al.*, 2019

price competition, exerting pressure across the entire industry and posing challenges for both wind turbine producers and developers. Furthermore, the success of wind power has triggered fresh experimentation, albeit sometimes marred by inadequately designed and implemented tender processes.[22]

The global electricity landscape is also witnessing high levels of penetration from solar photovoltaic (PV) and wind power, firmly establishing these technologies as mainstream options within the power sector. Leading the charge, Denmark, Uruguay, Ireland, Lithuania and Germany achieved notable milestones by generating over 25% of their electricity from solar and wind sources. Notably, Spain, Greece as well as the United Kingdom also made substantial progress, contributing between 12% to 15% of their electricity from solar and wind power. This paradigm shift underscores the increasing significance of these renewable energy sources in the world energy matrix.[23,24]

2.1.4 Offshore Wind Power

The genesis of offshore wind turbines dates back to the early 1930s when the concept of placing wind turbines on pylons was initially proposed. While these early ideas did not come to fruition, they laid the foundation for a promising beginning. Fast forward to 1972, approximately four decades after the inception of these early ideas, Dr. William E. Heronemus, a professor at M.I.T. University, introduced a groundbreaking concept: the deployment of large floating platforms for wind turbines to generate electrical energy.[25]

It was not until 1990, nearly two decades after Dr. Heronemus' visionary idea, that the first offshore wind turbine was realized by a company known as 'World Wind.' This pioneering offshore wind turbine found its home in Nogersund, situated 250 meters offshore in water depths of 7 meters in the northern part of Sweden. With a rated power of 220 kW, this offshore wind turbine marked a significant milestone in the journey towards harnessing wind energy at sea.[26,27] In 2007, a significant milestone was achieved as wind energy contributed to 1% of the

[22] OECD, 2018
[23] Capizzi *et al.*, 2019
[24] Jaeger, 2023

[25] Heronemus, 1972
[26] Bilgili, Yasar and Simsek, 2011
[27] Nikolaou, 2004

world's electricity production,[28] primarily from onshore wind farms. Notably, offshore wind installations were quite limited, with just 2,000 MW installed by the end of 2009, a symbolic figure.

Several factors contribute to the current development of offshore wind energy. A fundamental factor is the scarcity of available land for onshore wind farms, often due to competing land use. Additionally, offshore wind farms are often seen as having a lower environmental impact compared to onshore facilities. Government support also plays a pivotal role in promoting offshore wind growth. The confluence of abundant resources and the maturity of offshore wind technology places it closer to onshore wind in terms of advancement compared to other renewable technologies.

Nonetheless, offshore wind energy presents unique challenges in terms of the environment, as the complexities of designing, constructing, and operating facilities in a marine setting add numerous variables to consider.[29] In the following paragraphs, we outline the principal strengths and weaknesses of offshore wind technology compared to onshore.

One of the primary advantages is the superior quality of wind resources at sea, characterized by higher and more uniform wind speeds. This results in less turbulence and fatigue, thereby extending the lifespan of offshore wind turbine generators. The attributes of the turbulent air layer near the surface also allow for lower turbine placement, which is not achievable with onshore turbines. A second advantage is the availability of more extensive open areas in the sea, which can accommodate larger wind farms. The remote locations of offshore wind farms reduce environmental concerns, particularly related to noise emissions and visual impact. The ability to install larger wind turbine units in these expansive areas leads to greater energy production per unit.

On the downside, the first drawback pertains to the high costs associated with permitting, engineering, construction, and operation, primarily due to the challenging nature of offshore operations. Offshore installations also require extended electrical networks, as the resources are often located far from consumer centers. The cost per megawatt of offshore wind farms has increased in recent years.[30] This increase can be attributed to ongoing learning and development processes. A second disadvantage involves the need for advanced technology

[28] Breeze, 2008
[29] Jeng, 2008
[30] International Renewable Energy Agency (IRENA), 2023

specific to offshore wind farms. This applies to wind turbine generators, which must withstand the marine environment, including corrosion conditions. Foundations, marine operations, and accessibility restrictions pose additional challenges during construction and operation phases. A third drawback arises from the minimal roughness of the ocean surface, leading to higher turbulence offshore compared to onshore areas. This results in significant wake effects from wind turbine generators, impacting the turbines' lifespan. To mitigate this, wind turbines must be spaced apart adequately. The evaluation of wind resources is also more complex and costly in offshore settings compared to onshore areas.

In light of the evident cost disparity between onshore and offshore wind power, efforts are required to propel the development of offshore wind technology. Advances in various aspects, including wind turbine technology, foundations, and construction and operation procedures, are essential to address the unique challenges of offshore wind energy.[31]

As far as the technological aspects are concerned, in contrast to onshore wind turbines that necessitate taller towers, offshore wind turbine towers can be shorter due to the altered surface conditions, requiring less height to access equivalent wind speeds. These towers typically consist of tapered tubular steel sections, with diameters ranging between 3 meters and 5 meters for a 4 MW wind turbine, and increasing to between 5 meters and 7 meters for a 6 MW wind turbine. The choice of foundation type for offshore wind turbines is contingent upon the water depth at the site. Generally, five distinct foundation types are utilized: monopile, gravity, tripod, jacket, and floating. Monopile foundations are the most prevalent, constituting 96% of intsalled offshore wind turbine foundations, with jacket foundations following as the second most common choice. [32,33]

[31] Esteban *et al.*, 2011
[32] Higgins and Foley, 2014
[33] Shi *et al.*, 2015

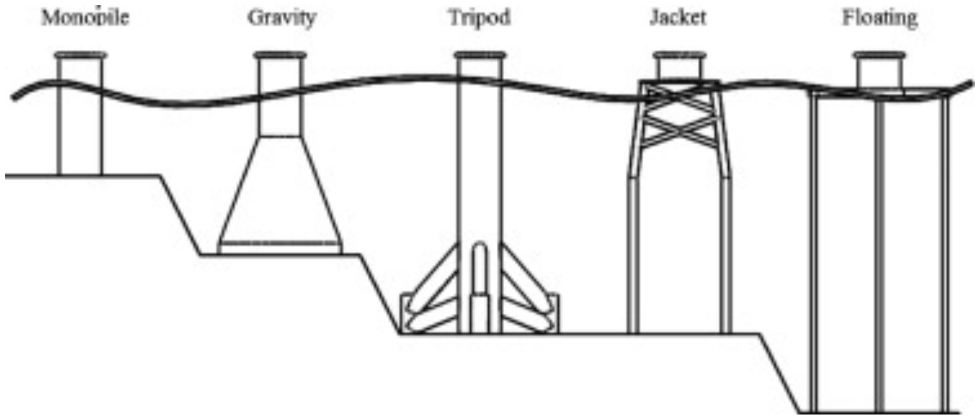

Figure 2: Foundation types of offshore wind turbines [32]

Offshore wind turbine structures present economically feasible solutions in shallow waters with depths not exceeding 50 meters.[34] However, for deeper waters ranging from 100 meters to 900 meters, floating wind turbines are necessary, as they can be installed within this depth spectrum. Unlike fixed foundations, the foundations of floating turbines are buoyant structures instead of being anchored to the seabed.[35,36]

Three distinct types of support structures are utilized for floating offshore wind turbines. The first is the tension leg support system, characterized by the connection of three or four mooring cables from the floating substructure to the seabed. These mooring cables are maintained under tension, providing static support to the wind turbine. However, the size of the substructure imposes limitations on this technology; if the substructure exceeds a certain size, the tension in the cables must be significantly increased, thereby escalating installation costs.

The second type of support structure for floating wind turbines is the spar buoy system. This involves a substructure that resembles a tower, sometimes referred to as a transition piece, which is filled with ballast and connected to the seabed via mooring cables.

The third support structure variant is the semi-submersible configuration, which encompasses various designs. The fundamental principle involves affixing floating structures to the main substructure or transition piece. Static stability is possible through manipulation of the buoyancy within these semi-submersible structures. Mooring cables connect the floating substructure to the seabed.

[34] Lackner and Rotea, 2011
[35] Jonkman, 2007
[36] Zountouridou *et al.*, 2015

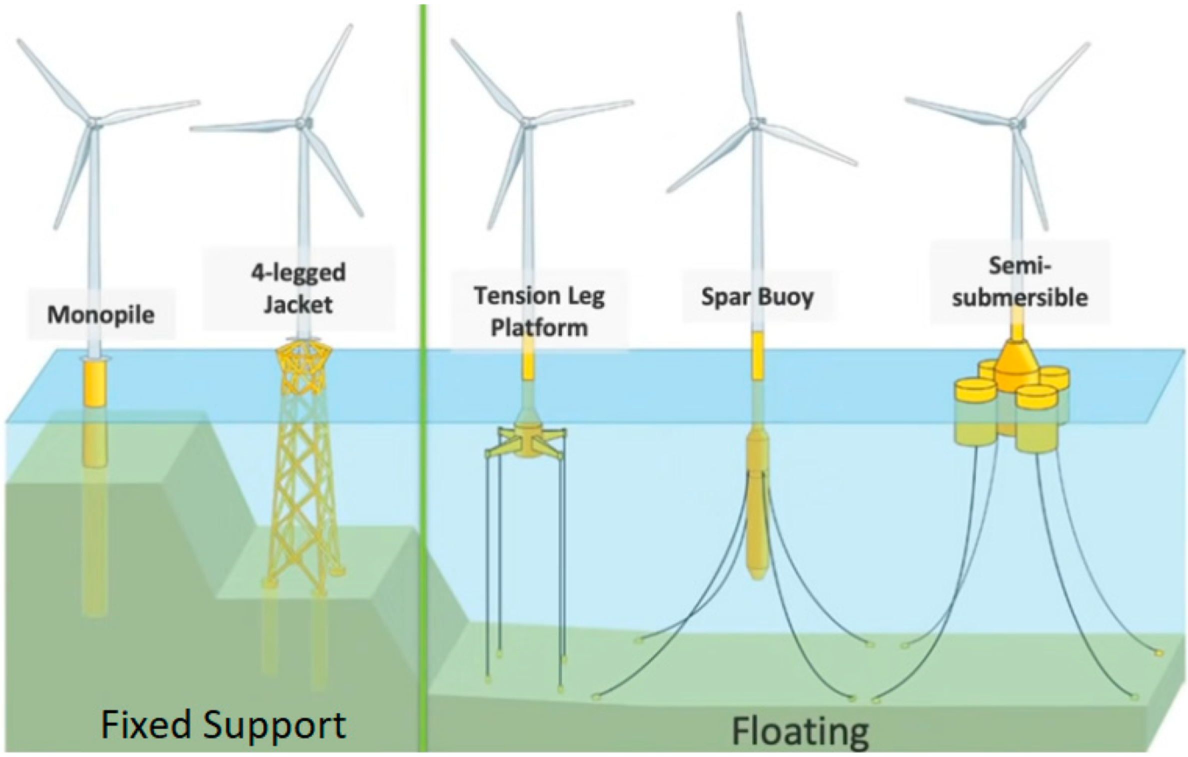

Figure 3: Offshore wind turbines' supporting structures [37]

It is essential to clarify that when a floating structure is described as "static," it does not imply complete immobility. Floating offshore wind turbine structures are permitted to move within a defined circular area, known as the “watch circle”, typically with a diameter of 180 meters. This design feature aims to prevent wind turbine blades from experiencing excessive wind loads that could possibly cause structural damage. Nevertheless, this introduces a further complexity for the mooring cables, as they must be sufficiently flexible to accommodate the movement of the floating platform.[38,39]

[37] Musial, 2020
[38] Bae, Kim and Kim, 2017
[39] Asim *et al.*, 2022

Chapter 3: Methodology

3.1 Research Questions

In this research thesis we aim to understand and analyze the ways in which offshore wind power affects while at the same time participates in the formation of the new international geopolitical scene, as well as the ways in which it determines the position of Europe, and by extension Greece, on the world geopolitical map. Thus, the research questions are formed as following:

1. What role does offshore wind power assume in facilitating Europe's transformation into an autonomous and influential energy player?
2. What are the implications of offshore wind farm development on the dynamics of international geopolitics?
3. Where is Greece positioned within the framework of the European offshore wind power agenda?

3.2 Suggested Methods

In this study, a methodological framework combining comparative analysis and case study approach is employed, predominantly drawing upon secondary sources to fulfill the research objectives.

Firstly, a comparative analysis is conducted to investigate the offshore wind power sectors in China and Europe, which are identified as leading actors in this domain globally. This study also extends to examining the development of offshore wind power across other significant regions, including the USA, Vietnam, South Korea, Japan and Taiwan. The objective is to analyze and discuss the implications of offshore wind power on international geopolitics. The use of this qualitative methodology facilitates a comprehensive exploration of offshore wind power in the world map, allowing for an in-depth analysis. Moreover, with this approach we have the opportunity to simultaneously examine multiple examples, furtherly enhancing our investigation.

Europe is characterized by several nations with rapidly advancing offshore wind power facilities. Greece, as a European nation that possesses considerable potential for offshore development due to its extensive maritime boundaries, has been selected as a case study.

The research initiates with a brief introduction and then, a comprehensive literature review follows aimed at facilitating the aforementioned comparative analysis. Additionally, we explore the geopolitical aspect of renewable energy and mention distinct examples of how offshore wind power in particular can influence international geopolitics. Afterwards, a comprehensive case study of Greece is presented, focusing on its prospective development and potential roles within the geopolitical landscape from the perspective of offshore wind power.

Chapter 4: Results

4.1 Introduction

Offshore wind power and its distinctive characteristics, has already been comprehensively elaborated on in the previous chapter. This chapter's objective is to answer the core questions of the thesis, diving deep into the offshore wind power trends, facts and developments in China, Europe and other significant regions, including the USA, Vietnam, South Korea, Japan and Taiwan. Since we aim to look at the geopolitical perspective of offshore wind power, the newly explored combination of renewable energy and geopolitics will be examined, followed by specific examples that prove offshore wind power's significant influence in international geopolitics. Also, a case study is deemed as necessary, in order to understand Greece's position within the framework of the European offshore wind power agenda. In the end of this chapter there will be a brief but detailed discussion.

4.2 Offshore Wind Power in China

The Chinese government has made a resolute commitment to achieve peak carbon dioxide emissions by 2030 and reach carbon neutrality by 2060 as part of its comprehensive approach to combat climate change. In pursuit of these ambitious goals, renewable energy assumes a pivotal role in China's energy strategy, serving as a linchpin for reducing greenhouse gas emissions while strengthening energy security. Over the past decade, offshore wind energy production in China has experienced a notable acceleration, primarily propelled by relevant policy incentives.[40,41,42,43,44] China is endowed with abundant offshore wind resources, stretching along its extensive 18,000 km coastline and encompassing 6,000 islands.[45,46] The allure of offshore wind power in China is heightened by the proximity of these resources to densely populated and developed regions. The first offshore wind farm in China, the Shanghai Donghai Bridge Offshore Wind Farm, was commissioned in 2008 near Shanghai in the East

[40] Liu *et al.*, 2015
[41] Zheng *et al.*, 2016
[42] Yang *et al.*, 2017
[43] Wei *et al.*, 2017
[44] Wu *et al.*, 2019
[45] Hong and Möller, 2011
[46] Da *et al.*, 2011

China Sea.[47] Comprising 34 wind turbines with a total capacity of 102 MW, it commenced operations in 2010, providing green energy for the 2010 Shanghai World Expo and marking the inception of offshore wind power development in heavily populated coastal areas.

According to the Global Offshore Wind Power Report 2022 released by the Global Wind Energy Council on June 29th, 2022, China accounted for a staggering 80% of the overall new offshore wind installations in 2021, amounting to approximately 21.1 GW. By the end of 2021, the total global offshore wind installation reached about 55.9 GW, with China contributing 47%, establishing itself as the global leader in installed capacity.[48]

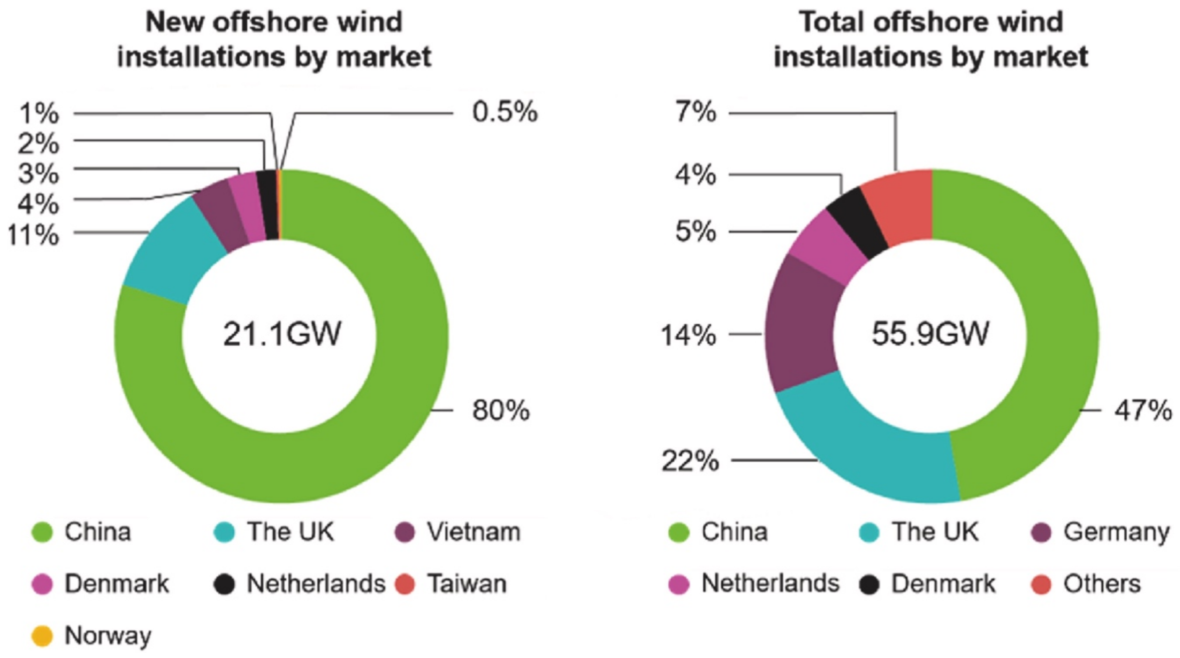

Figure 4: China's offshore market dominance in 2021 [48]

Moving into 2022 though, according to the Global Offshore Wind Power Report 2023 released by the Global Wind Energy Council on August 28th 2023 China still ranked first with a percentage of 57,6% in the overall new offshore wind installations amounting to approximately 8.8 GW, a significantly lower amount than 2021. By the end of 2022, the total global offshore wind installation rose to about 64.3 GW, with China contributing 48.9%, establishing itself once again as the world leader in installed capacity.[49]

[47] Chang and Jeng, 2014
[48] GWEC, 2022
[49] GWEC, 2023

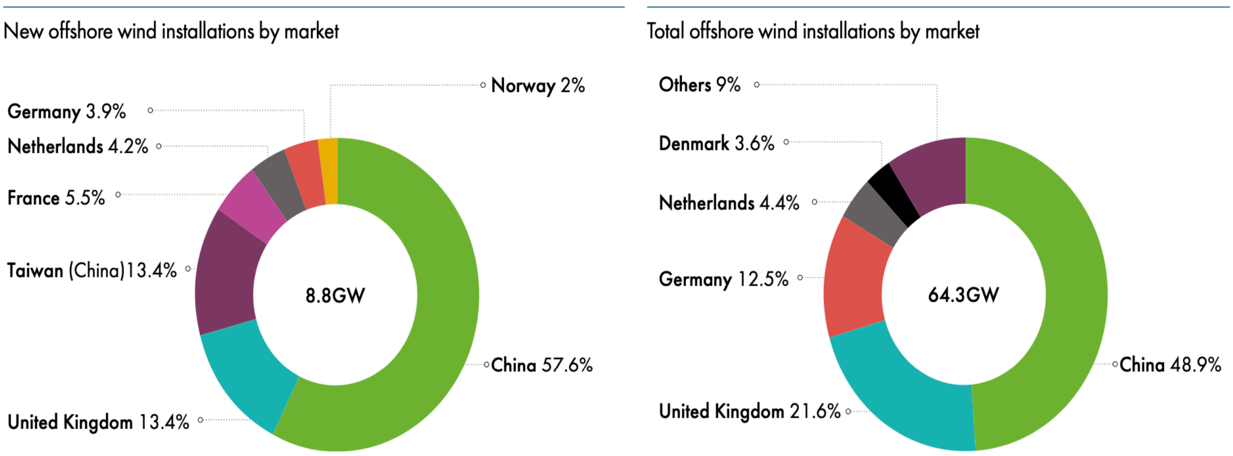

Figure 5: China's offshore market dominance in 2022 [49]

The Chinese offshore wind industry, as it continues to grow, is witnessing: the adoption of large-scale units, the creation of extensive wind farms, and the exploration of wind energy utilization in deep and open seas. While current developments predominantly occur in relatively shallow waters and nearshore locations, the industry is gearing up to venture into the deep and open sea, where floating wind platforms will lead. The appearance of floating platform offshore wind power presents an opportunity for oil and gas conglomerates to expand their operational scope and transition into the renewable energy domain, thereby broadening their corporate portfolios beyond traditional fossil fuel endeavors. This paradigm shift signifies a pivotal transformation from conventional oil and gas entities to multifaceted energy corporations.[50] Oil and gas corporations frequently engage in collaborative ventures with specialized service providers to facilitate the establishment of offshore wind power installations, particularly those employing floating platform designs. Noteworthy is the example of Total, the French energy giant, which, in March 2020, disclosed its acquisition of an 80% stake in the 96 MW Erebus floating offshore wind power project, slated for development off the coast of Wales, United Kingdom.[51] Other prominent players such as the multinational oil corporation BP (British Petroleum), which has initiated a joint venture with the Norwegian counterpart Equinor to establish floating platform offshore wind power installations along the Brazilian coastline, have exhibited comparable dedication to diversification.[52]

[50] Mathews *et al.*, 2023
[51] Hill, 2020
[52] Raval and Meyer, 2020

The first floating offshore wind power project, with a planned capacity of 1 GW, was authorized in September 2022 for implementation in Wanning, Hainan province. This project, slated to be executed in two phases (0.2 GW by 2025 and 0.8 GW by 2027), underscores China's commitment to harnessing wind power resources in the deep sea. As the Chinese offshore wind industry charts its course toward deep-sea deployment, efforts are concentrated on upscaling offshore wind turbines to enhance design efficiency.[53] Large-scale wind turbines present a substantial challenge to foundation technology, offering potential for the development of a solid manufacturing and construction industry in China. The pursuit to enhance foundation design efficiency, leading to cost reductions, is anticipated to catalyze a swifter growth of the offshore wind industry in the China.[54]

4.2.1 Offshore Wind Power in Europe

In Europe, the trajectory of offshore wind power gained momentum with the installation of the world's inaugural offshore wind power plant in Denmark in 1991. This developement trend is poised to persist and escalate, contributing substantially to the region's energy portfolio. The impetus for this expansion is fortified by robust support for renewable energies through regulatory policies, financial motives, and public funding, thereby enhancing their competitiveness.[55]

Europe has emerged as a leading market for offshore wind technology, representing over 45% of global installations, primarily concentrated in nations bordering the North Sea such as the UK, Germany, the Netherlands, and Denmark, where bottom-fixed installations predominate.[56] Additionally, Northern Atlantic Europe has garnered significant attention for the prospective growth of floating offshore wind farms,[57] with a surge in new installations anticipated in the foreseeable future.[58,59]

Notably, eleven European countries have played pivotal roles in shaping the installed capacity of offshore wind farms until 2019, with the UK and Germany emerging as leaders in this domain. Up to 2019, approximately 89% of the total installed capacity in European offshore

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53 Zhou, 2021
54 Zhang and Wang 2022
55 Behrendt, 2015
56 Durakovic, del Granado and Tomasgard, 2023
57 Martinez and Iglesias, 2022
58 Buljan, 2022
59 Martinez, Murphy and Iglesias, 2023

wind farms comprised facilities with a rated power exceeding 150 MW. The concentration of offshore wind capacity is pronounced in five countries, accounting for about 98% of the total. In this context, the UK and Germany jointly contribute 80% of the installed capacity for plants above 150 MW, leaving the remaining 20% to be distributed among Belgium, Denmark, and the Netherlands, with respective shares of 8%, 8%, and 4%.[60]

The UK, commanding 44% of the operational offshore wind turbines, stands out as the country boasting the most extensive installed capacity in this sector.[61] It's crucial to underscore that several other European countries, including Finland, Ireland, Norway, Sweden, Spain, and France, actively partake in offshore wind energy generation. However, until 2020, none of them had yet ventured into farms exceeding 150 MW.[60]

According to the Global Offshore Wind Report 2023[49], Europe emerged in 2022 as the primary contributor to offshore wind capacity expansion, with 2.5 GW integrated into grids across six nations, mirroring trends observed in preceding years. The United Kingdom solidified its leading status within the European offshore wind sector, notably by finalizing the deployment of the remaining wind turbines (924 MW) at the monumental 1.4 GW Hornsea Project 2, now recognized as the world's largest operational offshore wind farm. Additionally, the UK grid welcomed 27 wind turbine units (255 MW) from the 1.1 GW Seagreen project.

France marked a significant milestone with the full commissioning of its inaugural commercial offshore wind endeavor, the 480 MW Saint-Nazaire wind farm, positioning itself as the second largest European market for offshore wind in 2022, followed closely by the Netherlands (369 MW) and Germany (342 MW). Over the following two years, France is anticipated to be a focal point in the global floating wind sector, with 85 MW earmarked for development across three projects, namely Les Eoliennes Flottantes du Golfe du Lion (EFGL), EolMed, and the Provence Grand Large (PGL), following successful government tenders.[49]

Italy celebrated the activation of its debut commercial offshore wind project, the 30 MW Beleolico offshore wind farm, notable for its utilization of ten wind turbines from Mingyang, marking both the introduction of Chinese wind turbine technology to European waters as well as the inaugural offshore wind project in the Mediterranean Sea.[49]

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[60] Soares-Ramos *et al.*, 2020
[61] Higgins and Foley, 2013

Meanwhile, Norway encountered delays in the completion of the 94.6 MW Hywind Tampen floating wind project, featuring 11 wind turbines from Siemens Gamesa and a concrete SPAR-type floating foundation, resulting in the operation of only seven wind turbines (60.2 MW) due to supply chain constraints. Notably, the commissioning of a 6.2 MW floating wind turbine provided by Chinese CSSC Haizhuang contributed to a total of 66.4 MW of floating wind capacity commissioned in 2022.[49]

The persistent need for additional offshore locations and gigawatt-scale capacities has spurred the advancement of energy islands, artificial islands situated offshore or in remote locations, functioning as centers for the generation and dissemination of electricity, frequently prioritizing renewable energy sources.[62] The North Sea stands out as a primary area of global attention for their establishment, due to the ongoing multinational collaboration in offshore wind initiatives, ambitious targets for offshore wind expansion, and the presence of shallow waters facilitating development between the United Kingdom and Scandinavia. The Esbjerg Declaration[63] entails a pledge to cooperate on the development of energy islands. A bilateral agreement between Denmark and Belgium has been established, aimed at facilitating the construction and interconnection of a 3 GW energy island by 2033, with subsequent plans to expand the connected capacity to 10 GW by 2040. Moreover, the Esbjerg Declaration underscores a commitment to establish a second energy island in the North Sea and to conduct additional assessments for potential energy island locations, emphasizing the imperative for expediting the approval process.[49]

From a regional standpoint, the North Sea stands out as a pivotal source of offshore wind energy for the European market, owing to its extensive potential and existing offshore wind infrastructure. Following closely, the Baltic Sea emerges as the second most promising region in Europe concerning both potential and planned offshore wind capacity. Noteworthy factors contributing to the Baltic Sea's suitability for offshore wind expansion include its favorable proximity to the coastline, which reduces grid connection costs, and its underestimated wind power potential within this semi-enclosed basin.[64,65,66] Furthermore, regional collaboration and national policies geared towards fostering Baltic wind energy development bolster its prospects. With the exception of Russia, all littoral states are members of the European Union

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[62] Rettig, Fischhendler and Schlecht, 2023
[63] Esbjerg Group, 2023
[64] Hallgren *et al.*, 2020
[65] Hallgren *et al.*, 2020
[66] Rusu, 2020

(EU), with each expressing intentions to escalate offshore wind utilization by 2030. Among EU Baltic countries, Germany, Denmark, Finland, and Sweden have collectively installed 2.2 MW of offshore wind capacity in the Baltic Sea as of the close of 2020.[67] Conversely, Estonia, Latvia, Lithuania, and Poland—comprising the Central-Eastern European states (CEE)—are increasingly committed to offshore energy advancement, evidenced by their implementation of policies and initiatives targeting the stimulation of investments in offshore wind projects.[68]

4.2.2 Offshore Wind Power in other active regions

4.2.2.1 United States of America

In the Americas, the United States stands as the sole market where offshore wind initiatives are currently operational. Until 2020, the American continent had only one offshore wind energy installation, situated in the US, with a capacity of 0.03 GW.[69] In 2020, a second offshore wind farm commenced operations along the Virginia coastline.[70] However, there were no new offshore turbines or projects commissioned in 2022, mirroring the previous year's trend. Anticipated shifts are on the horizon, notably with the inaugural power generation anticipated at the 806 MW Vineyard Wind 1 project scheduled for October of 2023, alongside the expected commissioning of the 132 MW South Fork offshore wind project by the conclusion of 2023. This signifies a nascent stage for offshore wind development in the Americas, setting the stage for potential growth and diversification in the future.[49]

4.2.2.2 Vietnam

In 2021, Vietnam witnessed the operational commencement of one offshore wind energy plant, boasting a capacity of 99 MW, alongside the initiation of 20 additional projects with a combined capacity of 779 MW. Notably, fifty projects transitioned into the construction phase, among them La Gan and Thang Long, each having a substantial capacity of 3.5 GW. This surge in offshore wind energy investments is primarily attributed to the impending expiration of Feed-in Tariffs schemes established in 2011. However, Vietnam's offshore wind energy development faces formidable obstacles, including protracted approval procedures, limited

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[67] WindEurope, 2021
[68] Pronińska and Księżopolski, 2021
[69] Díaz and Guedes Soares, 2020
[70] Russell, Bingaman and Garcia, 2021

collaboration between governmental and private entities, and the substantial cost associated with deep-water offshore wind energy endeavors.[71] The offshore wind sector aims to achieve a capacity of 6 GW by the year 2030, with a notable escalation to 91 GW by 2050. This target distribution entails the development of 3 GW in northern regions and an equivalent 3 GW in southern territories. Notably, the divergence in wind resources between these regions may necessitate the formulation of distinct regional policies to effectively harness their respective potentials.[49]

4.2.2.3 South Korea

As of now, South Korea's installed capacity stands at 124.5 MW. Although the aggregate offshore wind capacity associated with granted electric business licenses has reached a commendable 20.8 GW as of December 2022, numerous projects encounter impediments and protracted permitting procedures attributed to inadequate policy backing and regulatory ambiguity.[49] Remarkably, the nation boasts a remarkable potential capacity of 277 GW[72] for floating offshore wind power, with 6.7 GW of floating offshore wind projects currently in the authorization phase, positioning Korea's floating offshore wind pipeline among the most substantial globally.[73]

4.2.2.4 Japan

Japan has undertaken a deliberate and gradual departure from its previous energy strategy centered around nuclear power and fossil fuels. The impetus for this shift arose from the Fukushima nuclear disaster of March 11, 2011. Subsequently, Japan embarked on a committed clean energy transition, exemplified by its late 2019 announcement of a new target: achieving 10 GW of offshore wind power capacity by 2030.[74] In July 2020, the Japan’s Ministry of Economy, Trade and Industry unveiled plans to approve three to four offshore wind power projects annually for the next decade, totaling 30 projects, while enhancing grid flexibility to accommodate renewable energy expansion. The government’s goal is to elevate the percentage of renewable energy from 17% in 2018 to 22-24% by 2030.[75] Subsequently, Japan released the

[71] Do *et al.*, 2022
[72] Green Energy Strategy Institute, 2022
[73] Venkat, no date
[74] REVE, 2020
[75] Nikkei Asia, 2020

Offshore Wind Industry Vision document in late 2020, outlining intentions to allocate 1 GW of offshore wind power capacity annually from 2020 to 2030, with a projected total capacity of 30-45 GW by 2040. The strategy emphasizes the robust development of a domestic supply chain, targeting a 60% local supply share by 2040, alongside cost reduction goals to achieve 8-9 Yen per kWh.[76,50] The commercial operation launch of Japan's first large-scale offshore wind farm, the 140 MW Akita Noshiro Offshore Wind project, at the outset of 2023 signifies a significant achievement for the Japanese wind industry and heralds the commencement of a quick expansion of Japan's offshore wind capacity.[49]

4.2.2.5 Taiwan

The state of Taiwan has framed its offshore wind power industry strategy around fostering competitive conditions through liberalization, coupled with the establishment of pragmatic targets for both offshore wind power farm construction and the development of domestic production chains. This approach aims to foster the growth of manufacturing operations within Taiwan in tandem with the expansion of offshore wind farms.[77] Progress within the industry has generally aligned with these strategic objectives. Initially, the government set a target of achieving 27 GW of installed renewable capacity by 2025, with 5.5 GW allocated to offshore wind power projects. In April 2018, the Ministry of Economic Affairs announced contracts awarded to seven developers for the delivery of 738 MW of grid-connected offshore wind power by 2020, with an additional 3 GW slated for completion by 2025. At the Global Offshore Wind Summit Taiwan Virtual 2020 held in October 2020, Taiwan's Bureau of Energy projected that the country's offshore wind power industry would generate 59 terawatt-hours annually by 2035. This development trajectory is expected to yield 57,000 jobs and attract over US$ 89.8 billion (NT$2.6 trillion) in investments from both foreign and domestic sources, leading to an annual decrease of carbon emissions by 32.7 million tones.[78,50]

4.3 Geopolitics and renewables: a newly explored combination

The originators of geopolitics initially envisioned it as a deterministic link between geography and global events, concentrating on the enduring competition, territorial ambition, and military

[76] Pinsent Masons, 2020
[77] Chien, 2020
[78] Oung, 2020

tactics of imperial powers.[79] Over time, the concept of geopolitics evolved to signify the impact of geography on state power and international affairs, shifting away from determinism to highlight the strategic significance of natural resources, their geographical placement, transportation networks, and critical chokepoints.

During World War I, the advent of mechanized warfare prompted Winston Churchill's pivotal decision to transition the British navy from coal to oil. Consequently, access to oil became a central facet of geopolitical analysis.[80] As car ownership continued to expand, Western nations became reliant on oil imports from the Middle East, leaving them vulnerable to the oil crises of 1973 and 1979. These events shifted the focus of oil security from a military concern into one of economic stability.[81,82] Geopolitical analysis often zeroed in on great power rivalries in oil-rich regions like the Persian Gulf, Caspian, or Arctic, as well as critical chokepoints such as the Strait of Hormuz or the Suez Canal.[83,84] At times, this analysis adopted a neo-Malthusian, peak-oil perspective.[85] Subsequently, the gas crises between Russia and Ukraine in 2006 and 2009 intensified concerns about natural gas, emphasizing monopsony, gas transportation infrastructure, pricing power, and supply disruption as tools in foreign energy policies.[86,87]

The field of geopolitics, when it comes to "conventional" energy (i.e., oil, natural gas, coal) encompasses a vast body of literature. Interestingly, the existing discussion within geopolitics and international relations has only begun to delve into the possible geopolitical implications of transitioning to renewable energy sources, leaving considerable room for further exploration and analysis.[88] The current rapid incline of renewable energy is propelling a new phase in geopolitical thinking, centered on potential shifts in state positions within the international system due to the rise of renewables.[89,90,91,92] Despite representing a fresh avenue for

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79 Tuathail and Dalby, 1998
80 Yergin, 2011
81 Russett, 1981
82 Kelanic, 2016
83 Barnes and Jaffe, 2006
84 Øverland, 2010
85 Klare, 2012
86 Sharples, 2016
87 Orttung and Overland, 2011
88 Criekemans, 2018
89 Bazilian, Sovacool and Moss, 2017
90 Hache, 2018
91 Paltsev, 2016
92 Scholten and Bosman, 2016

geopolitical analysis, a few arguments keep recurring and may become entrenched as common knowledge. These frequently address the transference of oil and gas geopolitical dynamics to renewable energy sources, despite the significant disparities between these sources and their respective technologies and infrastructure. Whilst transitioning from fossil fuels to renewables, geopolitical analysis retains its focus on resource-rich areas, crucial infrastructure, transportation routes, control over energy supplies, and the potential for supply disruptions. The fundamental belief persists that dominance over resources and their distribution confers power to states in the global arena.

There is an existing risk, when projecting historical patterns from the fossil-fuel-dominated energy paradigm onto the emerging system that is based on renewable energy. The historical competition among major players for control over oil may transmute into a future competition for critical materials in the renewables sector. The resource curse associated with oil may find its echo in a similar curse tied to critical materials and the export of renewable energy. Moreover, the historical use of disruptions in oil and gas supplies as geopolitical tools may evolve into disruptions in electricity supplies.[93,94] While these phenomena might be replicated, the automatic assumption of such recurrence would be premature.

The fundamental challenge lies in the transformative impact of renewables on the foundations of international energy affairs. Due to the more even geographical distribution of renewable energy resources compared to fossil and nuclear fuels, the economic and security benefits of energy access will be more equitably shared among nations. This shift ought to mitigate risks linked to transportation chokepoints as well as diminish the incentive for major players to strive for control over specific strategic areas. Essentially, international energy affairs are poised to become less centered on geographical areas and resources, thereby diminishing their inherently geopolitical nature. Given the abundance but diffuseness of renewable energy resources, the emphasis will shift to the significance of technologies for capturing, storing, and transporting them. Consequently, the landscape of international energy competition is likely to evolve from the control of physical resources, their locations, and transportation routes to a focus on technology and intellectual property rights.[95]

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[93] Johansson, 2013
[94] Moore, 2017
[95] Overland, 2019

4.3.1 Examples of offshore wind power's influence in international geopolitics

A clear example of the way offshore wind power affects geopolitics is the South China Sea conflict. The region boasts significant offshore wind energy potential, characterized by a wind density surpassing 150 W/m^2. Particularly, the northern reaches of the South China Sea exhibit the most robust wind resources, with an energy density varying from 350 to 600 W/m^2 and energy storage capacity between 3 × 103 to 5 × 103 kWh/m^2. The harnessing of wind energy offers favorable environmental impacts. However, there exists an unequal distribution of wind energy potential along the Chinese coast, posing limitations to its comprehensive growth.[96] The alignment with United Nations Sustainable Development Goals (SDGs) 7 (Clean Energy) and 17 (Global Partnerships) centers on the increase of investments, capacity, and infrastructure for renewable energy in the South China Sea, which poses as instrumental for fostering regional stability.[97] A strategic emphasis on reinforcing collaborations between China and smaller South China Sea nations, encompassing investment, research, technological exchange, and best practices in offshore wind energy, holds promise for mitigating conflicts stemming from hydrocarbon pursuits. Offshore wind power offers a pathway to address existing asymmetries in the South China Sea through Cooperative Sustainable Development frameworks, contingent upon China's cooperation. China's recent diplomatic efforts, coupled with its economic imperatives, underscore a departure from pure geopolitical ambitions towards fostering economic interdependence and regional amity. Active participation in the South China Sea necessitates China's recalibration of its regional presence, prioritizing robust cooperation over asymmetrical power dynamics.[98]

Additionally, the case of the Baltic Sea poses another great example. Historically, the Baltic Sea region has long been characterized by a geopolitical struggle for dominance between Russia and Germany. However, during the Cold War era, it was not characterized by acute geopolitical tensions, largely due to the presence of the so-called Nordic balance. The conclusion of this rivalry, facilitating NATO's and the EU's expansion into Baltic states, marked a significant shift in the regional power dynamics, with the region coming under Western influence institutionally. This transition has been interpreted by Russia as a threat to its national security, particularly with the growing Western presence, notably NATO's, in the region. Despite efforts by the EU to foster a broader security community encompassing some

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[96] Zhang, Lin and Liu, 2014
[97] Sajith *et al.*, 2022
[98] Aswani, Sajith and Kumar, 2023

of Russia's former Baltic territories, the country has opted for a divergent course of action.[99] The emergence of new offshore wind farms will significantly impact the dynamics of power and influence within the Baltic region's energy landscape, with broader implications for regional security. Across all Baltic countries, historically reliant on hydrocarbon imports, the expansion of offshore wind capacity will cater to the escalating demand for clean energy. Within the context of an integrated energy market, offshore wind stands as a pivotal contributor to the decarbonization agenda of the Baltic states' power infrastructure. Geopolitically, offshore wind initiatives foster collaborative dimensions of energy security, necessitating international cooperation throughout project planning and execution phases. The development of international strategic alliances is inherent to the vision of Baltic offshore wind projects. As these projects progress into production and distribution stages, these partnerships will be crucial in meeting the collective energy demands of the integrated market. Over the long term, a notable security implication of the increasing reliance on offshore wind energy in the Baltic region will be the reduction of import dependencies on foreign suppliers (i.e., Russia). This transition poses challenges for traditional exporters, leading to market losses and a corresponding decline in influence.[100,68]

4.4 Case study: Greece

In recent years, the Eastern Mediterranean has become a focal point for geopolitical tensions stemming from energy security concerns and aspirations linked to energy resources. The discovery of offshore hydrocarbons approximately a decade ago has prompted numerous governments in the region to propose ambitious projects aimed at transporting natural gas to Europe using submarine pipelines. This has led neighboring countries to delineate their Economic Exclusive Zones (EEZs), with examples including Cyprus aligning with Egypt and Israel, Greece with Egypt and Italy, and Turkey with Libya, among others. While states in the region have declared their EEZs, granted exploration and drilling licenses, and signed lucrative hydrocarbon agreements, the overlap in their declared maritime zones has created a complex situation hindering the development of reserves. Delimiting maritime zones poses significant political challenges as it involves considerations of sovereign rights and economic interests. Since 2014, two cooperative pillars have emerged, with Greece-Cyprus-Egypt and Greece-Cyprus-Israel regularly convening trilateral summits and signing agreements. Despite these

[99] Ekengren, 2018
[100] Caldara and Iacoviello, 2018

efforts, the region continues to face intricate geopolitical dynamics as it navigates the complexities of energy resource management and sovereignty issues.[101] As a result of the aforementioned hydrocarbon discoveries, not only have economic opportunities arisen, but also new security challenges have emerged, as each coastal state has sought to leverage its natural gas potential for political influence against neighboring states. Under US guidance, which perceives energy sector cooperation as a means to enhance alliances, the governments of Egypt, Cyprus, Greece, Israel, Italy, Jordan, and the Palestinian Authority established the Eastern Mediterranean Gas Forum in January 2019. This multinational body is charged with fostering the development of a regional gas market and establishing mechanisms for resource development.[102] Hence, the significance of the offshore resources uncovered near Egypt, Israel, and Cyprus transcends mere size, as they are intricately tied to specific geopolitical imperatives and ambitions.

Despite tensions among the region's nations regarding maritime zones and continental shelf claims, which have almost incited significant conflicts in recent years, the Mediterranean countries have been severely impacted by the climate crisis. This was particularly evident in 2021, when Greece and Turkey grappled with unprecedented wildfires. The Mediterranean's population, exceeding half a billion individuals, appears to confront deeply interconnected climate-related risks.[103] Transitioning to a green economy rather than relying on the exploitation of hydrocarbons seems to offer a viable solution to the evolving climate crisis. Despite historical and security-related tensions, the Mediterranean region exhibits economic heterogeneity, with countries varying significantly regarding economic and social development levels. Consequently, devising a unified energy and climate strategy is challenging, even when political and security issues are set aside. Nonetheless, climate change poses a critical threat to the Mediterranean region, affecting all states regardless of their current socio-economic or political circumstances.[104] Evidently, those who decide must transcend limited security perspectives and promptly engage in collaborative efforts to develop renewable energy projects aimed at fostering sustainability in the East Mediterranean region.[105,106]

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[101] Sotiriou, 2020
[102] Karagianni and Stergiou, 2019
[103] WWF Mediterraean Marine Initiative, 2021
[104] Dessì, Fattibene and Fusco, 2021
[105] Iseri, 2020
[106] Stergiou, 2023

January 2024 marked the initial strides towards offshore wind development in the region of Southeast Europe as Greece, Bulgaria, and Romania have jointly declared their intent to pursue offshore wind installation projects. The declaration was formalized in Athens during the annual meeting of the Central and South Eastern Europe Energy Connectivity (CESEC). The signatories emphasized the substantial potential of offshore wind in facilitating the decarbonization of their economies and in supplying neighboring countries with renewable energy resources. Additionally, these nations are enhancing collaboration in the realms of gas and green hydrogen. Moreover, the Bulgarian and Greek governments, formalized a Memorandum of Understanding to foster bilateral collaboration in the energy sector. The primary objectives encompass augmenting the exchange of electricity and natural gas, establishing hydrogen networks, enhancing the efficiency of renewable energy and hydrogen production in Southeastern Europe, advancing the digitization of power grids, and advocating for the implementation of the European Union's pertinent Projects of Common Interest (PCIs).[107] Lastly Corio Generation, a worldwide leader in offshore wind development, and the Greek technology company Globalsat have entered into a Memorandum of Understanding aimed at investigating prospects for offshore wind development in Greece. As per the terms of the agreement, the two entities will collaborate to evaluate suitable locations for the establishment of offshore wind farms and to identify tender opportunities, with the intention of participating in bids for the allocation of development rights.[108] Both aforementioned initiatives, show how through collaborative efforts to develop renewable energy projects, Eastern Mediterranean can battle climate change effectively and make another step towards being sustainable.

Greece possesses significant wind energy potential, particularly in offshore wind, which enhances and provides energy security for the country. Also, it holds promise for enhancing energy autonomy, particularly for its islands, harnessing its wind energy potential by implementing onshore wind farms across various island regions, such as Crete, Euboea (also known as Evia), and islands of the Aegean and Ionian Sea.[109] A significant development occurred in late July 2022 when the Greek Parliament ratified Greece's inaugural Offshore Wind Law, marking a pivotal step towards the initiation of offshore wind projects. The legislation designates the state-owned exploration entity, Hellenic Hydrocarbon Resources &

[107] Aposporis, 2024
[108] Buljan, 2023
[109] RAE, no date

Energy Resources Management, to oversee site surveys, allocation, and concession processes. Additionally, the national Independent Power Transmission Operator (IPTO or ADMIE) will be tasked with developing both onshore and offshore grid infrastructure. Greece aims to construct a minimum of 2 GW of offshore wind capacity by 2030 (according to the revised National Energy and Climate Plan)[110], with a substantial portion anticipated to be floating offshore wind due to the predominant water depths exceeding 50 meters along the Greek coastline. The enactment of the Greek Offshore Wind Law signals a significant boost for Europe's floating offshore wind industry.[111]

4.4.1 Strategic Plan

The Hellenic Hydrocarbons and Energy Resources Management Company unveiled the preliminary version of the National Offshore Wind Farms Development Program in October 2023. This program delineates the eligible Organized Development Areas and provides estimations regarding the capacity of offshore wind farm projects viable for development within both mid-term (up to 2030-2032) and long-term (post-2030-2032) time frames. The draft National Program outlines 25 designated areas, collectively spanning an area of 2,712 square kilometers, with a projected minimum capacity of 12.4 gigawatts.

The plan delineates ten (10) designated locations slated for development by 2030-2032, with an approximate cumulative capacity of 4.9 GW, primarily aimed at floating projects. Notably, these areas exclude the marine expanse between Evros and Samothraki, earmarked for pilot offshore wind farm initiatives. Specifically, the eligible areas for mid-term development are situated as follows:

- Eastern Crete, envisioned to host projects with a collective capacity of 800 megawatts (MW)
- Southern Rhodes, with an anticipated installed capacity ranging between 300 MW and 550 MW
- The central Aegean, projected to accommodate installations with a maximum capacity ranging between 200 MW and 450 MW
- The Evia-Chios axis, slated for an installed capacity of up to 300 MW
- The Ionian Sea, designated for a maximum installed capacity of 450 MW

[110] Hellenic Republic, Ministry of Environment and Energy, 2023
[111] Tang, 2022

A comprehensive set of 20 exclusion criteria has been established to protect environmentally sensitive zones and maritime activities across Greek territory. Such criteria encompass considerations such as national security, passenger navigation, airport proximity, coastal distance, areas of ecological and cultural significance, tourism, aquaculture, and other land uses.

Concerning the economic impact, the deployment of offshore wind farms holds the potential to significantly enhance Gross Domestic Product (GDP), with an average annual increase of up to €1.9 billion over the period spanning 2024 to 2050, while also yielding government revenues of up to €440 million annually. Moreover, the offshore development is expected to contribute substantially to job creation, supporting an estimated 44,400 employment opportunities annually during the same timeframe, as it was stated by the Head of the Foundation for Economic & Industrial Research that conducted the appropriate study.[112]

4.5 Discussion

Clearly, offshore wind power is still an emerging and valuable resource in the battle again climate change and a mean towards the establishment of energy security in a world that's self-sufficient and independent from conventional energy sources. China seems to lead the sector with Europe following closely while Asia Pacific Countries are rapidly starting to develop their offshore potential along with USA. As offshore development moves to deep sea, technologically advanced countries will be able to expand and fulfill their offshore renewable agendas, thus becoming leaders in the sector.

Geopolitically speaking, literature is still mapping the way we move into the new era of renewables and letting oil's influence come second is still a long way ahead. The war between Russia and Ukraine was a great example of that struggle. As Russia was the major gas supplier of Europe, the war and the sanctions that followed caused a disruption of gas supply in Europe that made her turn the focus into hydrocarbon's exploitation in an effort to maintain energy security. Therefore, literature still focuses on the meaning of conventional energy sources in global geopolitics and renewables, even though are explored more the last decade than before, remain underdeveloped.

Nonetheless, renewable energy and more specifically offshore wind power seems to build a new basis of geopolitical collaboration by strengthening political alliances through energy

[112] Hellenic Hydrocarbons and Energy Resources Management Company, 2023

transformation, thus leading to the formation of a new multipolar geopolitical map, much more diverse than the traditional one that prevailed all these years. In the new era of renewable energy, power seems to be diversified and decentralized from traditional oil hubs such as the middle east. Nowadays, new countries can transform into power players in the global energy map through the production, distribution and storage of renewable energy. Greece being one of them, is showing the way with radical transformation and adaptation of offshore wind power into its energy mix.

Chapter 5: Conclusion

5.1 Summary

During the last years, wind energy emerged as a pivotal and reliable source of electricity on a global scale. Beyond its role in electricity generation, wind energy contributes significantly to job creation, investment attraction, research, and overall economic activity within the energy sector. Europe, characterized as an energy-intensive continent deeply reliant on imported fuels, confronts a myriad of challenges including climate change, diminishing domestic energy reservoirs, escalating fuel expenses, and the looming specter of supply disruptions. Given these imperatives, Europe's goal is to leverage the substantial turnover in energy capacity to build a novel, forward-looking power infrastructure that is able to fulfill its energy needs in a sustainable manner. Offshore wind power poses as a powerful way to achieve that goal as it is positioned to spearhead the next phase of renewable energy development, potentially becoming one of the most promising and vast sectors within the renewable energy domain.[26]

In China, the swift economic growth observed has accentuated the struggle between escalating fossil fuel usage and the profound environmental hazards it poses. To address this pressing issue, the expanded utilization of offshore wind power emerges as a potential solution for long-term energy conservation and environmental sustainability. The advancement of offshore wind power is intricately linked to the evolution of offshore wind turbine and foundation technologies. As offshore wind turbines increase in scale and wind farms extend into deeper water depths, novel prospects and obstacles arise, necessitating further research and design enhancements for foundations, particularly in demanding marine environments.[54]

Moreover, it is worth mentioning that offshore wind power is anticipated to attract significant attention from oil and gas companies, marking a paradigm shift in competitive dynamics within the sector. Leveraging their extensive expertise in constructing offshore drilling platforms and associated supply chains, these companies have the chance to expand their operations from traditional oil and gas endeavors to encompass renewable power generation and, eventually, green hydrogen production. This transition heralds a new era of competition and collaboration within the emergent offshore wind power sector.[50]

When considering potential geopolitical ramifications, it is evident that fossil fuel exporters are poised to incur substantial losses, while identifying the winners presents a more nuanced challenge. Although numerous nations stand to gain from diminished import reliance and access to abundant renewable energy reservoirs, only a select few are poised to emerge as frontrunners in clean technology industries. The broader implications for global relations suggest a transition from non-symmetrical energy dependencies to more balanced, mutual dependencies, thereby reshaping existing energy associations into regional grid communities. Moreover, a diverse array of stakeholders is anticipated to engage in energy policy formulation, contributing to a democratization of both national politics and global relations, ultimately fostering stability across the board.[113]

Greece appears to be turning into a great example of the aforementioned. By leveraging wind power, on and offshore, Greece diversifies its energy mix, provides economic opportunities and regional influence in the Eastern Mediterranean as well as enhances energy security not only of the country itself but also for the whole Balkan region. Since Greece was always a country significantly dependent on oil and gas imports, having the ability to power itself through renewable energy reshuffles the geopolitical power cards, making the Mediterranean country a stronger and more independent power player in the global energy arena.

5.2 Recommendations for further research

As we move further into the era of renewables and energy transformation, nations struggle to detach from conventional energy sources and move its complete focus on renewable energy sources. While Europe and China lead the offshore wind sector so far, other countries such as the United States of America, Vietnam, South Korea, Japan, Taiwan and Greece also promisingly enter the offshore arena.

Existing literature seems to cover a broad spectrum of technological developments in the offshore sector such as floating wind farms and larger capacity turbines, but as technology moves forward, further research on technological advancements and cost reduction pathways for floating wind technologies seems a necessity. Another research topic is the integration of advanced digital technologies in offshore wind power. It is interesting to dive into the ways that Artificial Intelligence and Internet of Things could potentially optimize offshore wind power's maintenance and operations, as well as how operational cost reduction and efficiency improvements can be achieved through the impact of Digital Twins and Predictive Maintenance.

[113] Vakulchuk, Overland and Scholten, 2020

Additionally circular economy, being a prominent sector under the wide umbrella of sustainable economy, should be further investigated regarding offshore wind farms and their end-of-life strategies, including the recycle and repurpose of wind turbines' components as well as the potential benefits of the adaptation of circular economy principles in offshore wind projects for the economy as well as the environment.

Regarding the possible environmental impact of offshore wind power, extensive and long-term research is recommended. This research should evaluate the cumulative environmental effects of multiple offshore wind farms operating within a single region. It should investigate specific impacts on marine ecosystems and biodiversity, focusing on comprehensive environmental assessments.

In reference to the geopolitical aspects, further research is needed on the development and implementation of strategies to mitigate geopolitical risks associated with multinational offshore wind projects. Additionally, evaluating the effectiveness of various regulatory approaches in promoting innovation and investment within the offshore wind energy sector would be very useful. This is particularly important as offshore wind projects continue to advance rapidly worldwide.

An essential recommendation for further research is scenario modeling and forecasting, as it encompasses all previously discussed elements and categories. Creating and employing sophisticated models to forecast the future expansion of offshore wind energy across different economic, technological, and policy scenarios, could significantly aid policymakers and investors in making well-informed decisions.

Addressing the aforementioned research gaps will unarguably enhance our comprehensive understanding of the complex issues related to offshore wind power and its geopolitical implications, thereby facilitating informed policy-making and strategic planning.

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