5-2022

# A Study on Wind Farms in New Jersey : Life Cycle Assessment and Acceptance of Wind Farms by the Tourists

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## Abstract

New Jersey has taken steps to and aims to be carbon neutral by 2030. In order to achieve that a part of its Energy Master Plan focuses on building the wind energy sector. First part of this thesis presents a life cycle assessment on a hypothetical offshore wind farm 15 miles from the coast of New Jersey and compares the benefits of recycling the offshore wind farm at the end of its 20-year life cycle. The results indicated that 1) floating turbines cause less emissions than fixed turbines 2) recycling rotor will have a negative impact of 17% on the mineral resource scarcity 3) recycling nacelle will have a negative impact of 5% on the mineral resource scarcity. The second part of this thesis sheds light on the perceptions of tourists being able to see offshore wind turbines and their acceptance. The results indicated that 1) respondents with second hand experience of wind turbines preferred a room without wind turbines 2) respondents with first hand experience of wind turbines preferred a room with wind turbines 3) respondents are more likely to change their preference to indifference if they believe they or the environment is being harmed in the categories of creating jobs, producing clean energy, energy security, local tourism, property values 4) respondents who believe that wind turbines will have positive a affect on creating jobs, producing clean energy, energy security, marine environment are more likely to stay with their preference.


*Keywords*: Life Cycle Assessment, Wind Farms, New Jersey, Multinomial Regression

MONTCLAIR STATE UNIVERSITY

A Study On Wind Farms In New Jersey: Life Cycle Assessment And Acceptance Of Wind Farms

By The Tourists

by

Nawal Shoaib

A Masters Thesis Submitted to the Faculty of

Montclair State University

In Partial Fulfilment of the Requirements

For the Degree of

Master of Science

May 2022

College of Science and Mathematics

Department of Earth and Environmental Science

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**Acknowledgement**

None of this would have been possible without the Will of God.

I would like to thank Dr. Lal for giving the opportunity of working with him. The opportunity to work with him not only allowed me to finish my thesis for my masters but I was able to meet people who I will call friends for life. Dr. Smith, for mentoring me the various ways to perform LCAs, for listening to all my SimaPro rants and then helping me figure out what was wrong it. And of course, I would like to thank everyone at CESAC who helped me on my journey to become a master graduate. And finally, I would like to thank the members of my committee who read through my thesis and gave me valuable suggestions.

This would not have been possible without the constant support of my parents; Amma, Pappa, thank you. I would also like to take this opportunity to thank my support system, my brothers, Romman and Sameed, my sister-friend, Sibgha, and my husband, Hammad. Without you guys pushing me through the worst nights and the least bright days, I would not have the brains left to finish this thesis. And I would like to thank my cats, Chip and Dale, whose purrs got me through many a panic attack.

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Chapter 1

## Introduction

As the paradigm shifts of electrical power toward renewable energy increases across the globe, New Jersey follows suit. Since the Paris Agreement of 2015 world leaders and developed countries have been reducing their cardon emissions and moving toward generating power through more sustainable means than those derived from fossil fuels. In 2014 almost 39% of the electrical power generation of European Union (EU) was from petroleum and only 7% from renewable energy sources and biofuels. However, in 2019 use of petroleum for electrical power generation decreased to 34% and renewable energy and biofuels increased to 17% (Eurostat, 2022). One of the more popular sources of power is wind energy. While harnessing wind for energy has been a constant throughout the history of human advancement, it is now able to power full cities for years by making use of unobstructed wind supply in the ocean. Offshore wind industry has advanced tenfold in the last 20 years as the shift toward clean energy progresses. The advancement of course has led to higher, more powerful turbines which can be placed deeper and farther in the ocean allowing to reach high pressure winds unlike in a city filled with skyscrapers. In 2019 wind energy covered 15% of the total energy demand in EU (WindEurope, 2020). While the US saw a 99% increase in wind power generation from 2015 to 2021 (Jaganmohan, 2022).

In the continued efforts to combat climate change, in 2019 New Jersey passed its Energy Master Plan with the goals to reach carbon neutrality by 2050. Part of the steps to reach such was the construction of offshore wind farms, the first of which will be in operation by 2024. Although wind farms have been known to produce clean power, there are emissions related to their constructions, transportation, decommissioning, and disposal. In this thesis we delve deeper into the life cycle assessment of an offshore wind farm to quantify emissions related to it.

As wind farm gain more and more exposure there has been an increase in a very different aspect of wind energy as their numbers increase worldwide. The second part of this thesis will look at the development of the above-mentioned wind farm in New Jersey as a tourist attraction. For a very long-time wind farms have been treated as an eye sore (Henderson, 2002) by tourist surveys, while they have been thought to diminish viewsheds, cause landscape intrusion, make excess noise, disturb ecosystems and decrease recreational opportunity by the residents of the area near a wind farm as summarized by Cohen, Reichl, and Schmidthaler (2014). However, in the recent years there has been a shift in how tourists view wind farms from being an eye sore to a well sought out attraction as a direct result of the efforts by governments and environmentalists alike, by promoting wind farms with positive outcomes such as greenhouse gas reduction and energy supply security (Cohen, Reichl, and Schmidthaler, 2014).

As explored later in chapter 3, many developed European countries like Germany have invested heavily in energy tourism; tourism involving current or dormant electrical power production sites. A part of their tour guidebook is dedicated to sites ranging from old nuclear plants turned amusement parks to banging jumping from the top of a wind turbine (Nabiyeva, 2014). Similarly, in Croatia a village has turned the wind farm near it into a tourist experience bundling a wine tasting experience with the tour of the wind farm. Westerberg, Jacobsen, and Lifran (2015) note that in Northumberland, UK, tourists visual disamenity of the wind farm decreased if there were environmental policies present and wind farm related recreational activities associated. The author presents a similar idea for her survey in chapter 3 where she questions tourists in the tourist city of Ocean City, where the first wind farm will be built. The survey focuses on tourists being more or less inclined to getting a room with or without the view of offshore wind turbines depending on their opinions of job creation through wind farms, clean energy, impact on scenic beauty, energy security, local tourism, marine environment, property values, boat navigation, and commercial boating

## References


Cohen, J. J., Reichl, J., & Schmidthaler, M. (2014). Re-focussing research efforts on the public acceptance of energy infrastructure: A critical review. *Energy, 76*, 4-9. doi:https://doi.org/10.1016/j.energy.2013.12.056

Energy statistics - an overview - Statistics Explained. (2022). Retrieved February 2022, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview

Henderson, A. (2002). Wind power moves out to sea. *Physics World, 15*(7), 40-41. doi:10.1088/2058-7058/15/7/39

Jaganmohan, M. (2022). U.S. wind power generation 2021 | Statista. Retrieved February 2022, from https://www.statista.com/statistics/189412/us-electricity-generation-from-wind-energy-since-2005/

Nabiyeva, K. (2014). Germany sells guidebooks on renewable energy sites. Retrieved June 2020, from https://www.theguardian.com/environment/2014/jun/11/germany-sells-guidebooks-on-renewable-energy-sites

Westerberg, V., Jacobsen, J. B., & Lifran, R. (2015). Offshore wind farms in Southern Europe – Determining tourist preference and social acceptance. *Energy Research & Social Science, 10*, 165-179. doi:https://doi.org/10.1016/j.erss.2015.07.005

Wind energy in Europe in 2019. (2020). Retrieved 2 January 2022, from https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-Annual-Statistics-2019.pdf

# Chapter 2: Life cycle assessment of 1100MW wind farm in New Jersey

## Introduction

Advancement in all disciplines of life require advancement in electrical power production. Energy Information Association (EIA) has forecasted a 50% increase in energy demand worldwide (Kahan, 2019; Sourmehi, 2021). With fossil fuel reserves dwindling and the climate changing at an alarming rate due to carbon dioxide ($CO_2$) emissions, renewable, cleaner sources seem to be only way forward. Historically, the US has relied heavily on fossil fuels to fulfil its energy needs; today natural gas (40%) and coal (19%) are the largest sources of energy for electricity generation (EIA, 2021). Cleaner energy sources, such as nuclear and renewables, still only account for a relatively small proportion (19.8%) of the country's energy generation needs. However, with growing technological developments and global pressures to reduce environmental impact, renewable energy generation sources continue to gain momentum. Wind accounts for 8.4% of the country's electricity generation (EIA, 2021), and is the largest contributor of renewable energy generation today. Wind energy is harvested using turbines that turn by the force of wind, which in turn drives the generator, converting kinetic energy of wind to electrical energy. While many other renewable energy sectors have gained similar attention, wind energy has shown great success in areas with predictable high winds, such as coastal regions. Success of wind turbines in Europe over the past 30 years has been phenomenal; wind energy met the 16.4% of the electrical power demands across the European Union and the United Kingdom 2020 (WindEurope, 2021). The shift of clean energy toward renewables has decreased imports of combustible fuel, saving the economy 28 billion euros annually, while also decreasing carbon emissions by 21.7% (EEA, 2020). Offshore wind is responsible for approximately 17% of total wind power in Europe, providing nearly

40gigawatts (GW) annually (EEA, 2020), Moreover, power from wind and solar was cheaper than fossil fuel in Germany in 2021 (Moore, Brown, Alparslan, Cremona & Alster, 2021). New Jersey as a coastal state with high demand for energy has recognized similar opportunity to utilize cleaner energy generation resources to provide similar benefits for the state and beyond.

In 2019 it was announced that New Jersey aims to be carbon neutral by 2050 in the New Jersey Energy Master Plan (EMP). With this in motion it is only inevitable that sources such as solar, wind, biomass, geothermal, and hydropower will be utilized. However, the EMP focuses more on solar and wind energy. Even though solar energy has been a popular source of energy in the State for homeowners for some time now, wind farms producing more power than solar farms can be integrated with the already existing electrical grid as well without the hassle of installing solar panels on top of the house. Hence a wind energy plant will be immensely valuable for the State as it thrives to be carbon neutral. Currently, New Jersey has one wind farm in Atlantic City which is capable of producing 7.5 mega Watt (MW) of electrical power. Since 1MWh is enough to power about 813 homes for an hour given that average annual usage is about 10,812kWh, 7.5MW could power about 6000 homes for an hour. However, being a coastal State, New Jersey has the potential of generating about 280.2 TWh annually from offshore wind farms (Read, 2021). 280.2 TWh could potentially power 34,124,954 homes annually according to the data from EIA (2019). Furthermore, according to US census there are around 3.6 million homes in the state of New Jersey. Thus, wind power could technically power the entire state.

Since larger turbines can be installed offshore, Ørsted, a Danish solar and wind company proposed to develop a 1100 MW wind power plant off the coast of New Jersey. This proposal was accepted by the New Jersey Board of Public Utilities (NJBPU) in June 2019. The project is to be completed by 2024 and aims to provide $1.17 billion in economic benefits and 15000 job opportunities (Hutter, 2020). Furthermore, public copy of the proposal submitted in December 2018 clearly states that the plant can be developed further to achieve 3500 MW of energy, which they claim will be enough to power at least 2 million houses. Ørsted selected a site close to the previous wind farm, 15 miles off the coast of Atlantic City. Ocean Wind will install anywhere from 92 to 98 12MW Haliade X turbines manufactured by General Electric. These turbines stand at 260 meters (m) with 220m rotor diameter.

Nevertheless, potential alone is not enough proof that a wind farm will indeed help achieve carbon neutral goals. For milestones to be set there must be quantified proof. Such proof can be provided through Life Cycle Assessment (LCA). LCA is a cradle-to-grave approach to quantify the environmental impact in terms of emissions throughout the life stages of a system. Early development of LCA begun in the 1970s when emissions from industries and environmental impacts first become a concern and an issue for the general public. Guinée et al. (2011) claims the first LCA study was conducted for Coca Cola Company in 1969. While unpublished, the study conducted a cradle-to-grave analysis for the products of Coca Cola Company. Curran (2013) calls LCA a comprehensive method capable of allowing informed decisions that do not undermine the future environmental issues in the face of more imminent present issues. The development of the method, while slow, has been considerable. To make LCA results more meaningful input-output LCA was developed. It aggregates data and allows for results to be produced for each section of the product's life (Joshi, 1999). Such a method makes it simpler to pinpoint all the hotspots of emission in the product's life.

All materials, recourses, and energy that is used to extract raw materials, process them, manufacture the final product and its transport, followed by its installation, and finally decomposition, are accounted for in an LCA. Such an analysis gives an in-depth view of how emissions may affect the environment in terms of mid- and long-term consequences. LCA also provides the opportunity for scenario analysis, allowing one to consider alternative solutions for the purpose of comparative analysis; for instance, comparing the environmental impact of switching to wind energy to business-as-usual; fossil fuels. This thesis will use LCA to measure the environmental impact of offshore wind development in New Jersey by utilizing data which best represents current development plans and state infrastructure to generate a realistic vision of power generation.

**Problem Statement**

While wind energy plants have been a great success for Europe, there still stands the question of whether they will be as successful on the US's Eastern Coast. There are several studies that look into all aspects of a wind energy plant from technoeconomic analysis to life cycle analysis. However, most of these studies are either dated or lack the complexity of analysing different recyclable material scenarios or a deep sensitivity analysis. Such as the LCA Schleisner (2000) conducted considering two wind plants in Denmark. He compared greenhouse gas emissions from offshore wind farm to an onshore wind farm. Even though Schleisner included recycling into his LCA, he mostly only considered the recycle of metals. Furthermore, the offshore wind farm mentioned in the study has only 10 turbines and is 6 km away from shore. The turbines are 40.5m tall with a rating of 500kW. Ocean wind, on the other hand, is 30km from the shore, has 92 turbines, and has a hub height of 150m. Similarly, Kaldellis and Apostolou (2016) also compared offshore and onshore wind farms in several European countries. In their study they concluded that offshore wind farms are less efficient in terms of emissions despite converting more energy. However, with a distance much closer than 100km, average for the wind farms they considered, and with better recyclable materials, new analyses need to be conducted. Furthermore, with new offshore construction sites being developed and in light of the New Jersey Energy Master Plan, it is important to have an accurate LCA for New Jersey with different supply chains and offshore grids included.

Even though there currently exist software that can approximately calculate the amount of $CO_2$ released, there remains some limitations. One such carbon footprint calculator is developed by the Bureau of Ocean Energy Management called the 'BOEM Wind Energy Tool'. Even though the tool is user friendly and comes with a technical manual and a user manual, limitations exist in the potential for large error margins, including multiple variables for which data is difficult to obtain. Some of the variables include detailed information regarding transportation. SimaPro 9.1 is a LCA software which addresses some of these limitations, by adapting existing datasets to better represent specific case study type scenarios while also accounting for uncertainties is the data and emission calculation algorithms. SimaPro 9.1 also looks beyond $CO_2$ emissions and addresses environmental impacts from multiple perspectives including other environmental emissions and sustainability metrics such as human health and economic wellbeing.

Since it has focused objectives, it will certainly be able to help in the decision-making process for both the developers and the state of New Jersey. This chapter will provide results that will allow Ørsted to make informed decisions regarding estimated emissions from transportation and installation, operation and maintenance trips, and transportation after dismantling the farm. Furthermore, the State will be able to make decisions regarding smart grids and integrating them with the offshore power supply directly. Questions regarding electrical power delivery, its costs, grid connections, and transportation needs will all be answered through this LCA. Thus, allowing for policies to be made regarding the suggested wind power plant in a more accurate manner.

This chapter aims to quantify emissions from an offshore wind power plant, with floating and fixed turbines, on the New Jersey coastline using LCA. The LCA will focus on different scenarios such as type of turbine, grid connections with offshore substations, and different recycle options including 100% recycle. The wind farm in question will be located 15 miles from the coast and be capable of producing 1100MW from 92 turbines with a power rating of 12MW assumed to be operating at full capacity.

## Methods

### Life Cycle Assessment Model

The aim of this chapter, as mentioned above, is to estimate the cradle-to-grave emissions associated with offshore wind turbine farms operating off the coast of the New Jersey shore, and to analyze their environmental implications.

To conduct the LCA, we used Simapro Software version 9.1, a popular software in academia especially for wind turbine research. From onshore farms to floating turbines, LCA has been used extensively to conduct environmental analyses for wind farms (Ardente, Beccali, Cellura, & Lo Brano, 2008; Haapala & Prempreeda, 2014; Huang, Gan, & Chiueh, 2017; Sacchi, Besseau, Pérez-López, & Blanc, 2019; Wang, Wang, & Liu, 2019; Weinzettel, Reenaas, Solli, & Hertwich, 2009). Furthermore, ReCiPe framework was used which calculates environmental impact across 18 midpoint categories and 3 endpoint categories (Goedkoop et al., 2008). The midpoint indicators are given in table 1. Midpoint categories can be classified under the 3 endpoint categories which include long-term impacts such as environmental health, human health, and resource scarcity ("LCIA: the ReCiPe model | RIVM", 2020) as depicted in Figure 2. From the ReCiPe framework we chose hierarchist perspective which is based on the most common policy changes as opposed to individualist (I) which is for short term changes which are understood and undisputed and egalitarian (E) which is a precautionary perspective for long term changes not yet completely understood (Goedkoop, 2009).

*Table 1: ReCiPe Midpoint and Endpoint Impact Categories*

| **Midpoint Impact Category** | **Abbreviation** |
|---|---|
| Global warming | GWP |
| Stratospheric ozone depletion | ODP |
| Ionizing radiation | IRP |
| Ozone formation, human health | HOFP |
| Fine particulate matter formation | PMFP |
| Ozone formation, terrestrial ecosystems | EOFP |
| Terrestrial acidification | TAP |
| Freshwater eutrophication | FEP |
| Marine eutrophication | MEP |
| Terrestrial ecotoxicity | TETP |
| Freshwater ecotoxicity | FETP |
| Marine ecotoxicity | METP |
| Human carcinogenic toxicity | HTPc |
| Human non-carcinogenic toxicity | HTPnc |
| Land use | LOP |
| Mineral resource scarcity | SOP |
| Fossil resource scarcity | FFP |
| Water consumption | WCP |
| **Endpoint Impact Category** | |
| Human health | HH |
| Ecosystem health | ED |
| Resource scarcity | RA |

*Source: National Institute for Public Health and the Environment, RIVM Report 2016-0104a*

Our system boundary includes the production, transportation, installation, disassembly, and recycling of each component over 20 years depicted in Figure 1, using the functional unit 1 kilowatt-hour (kWh).

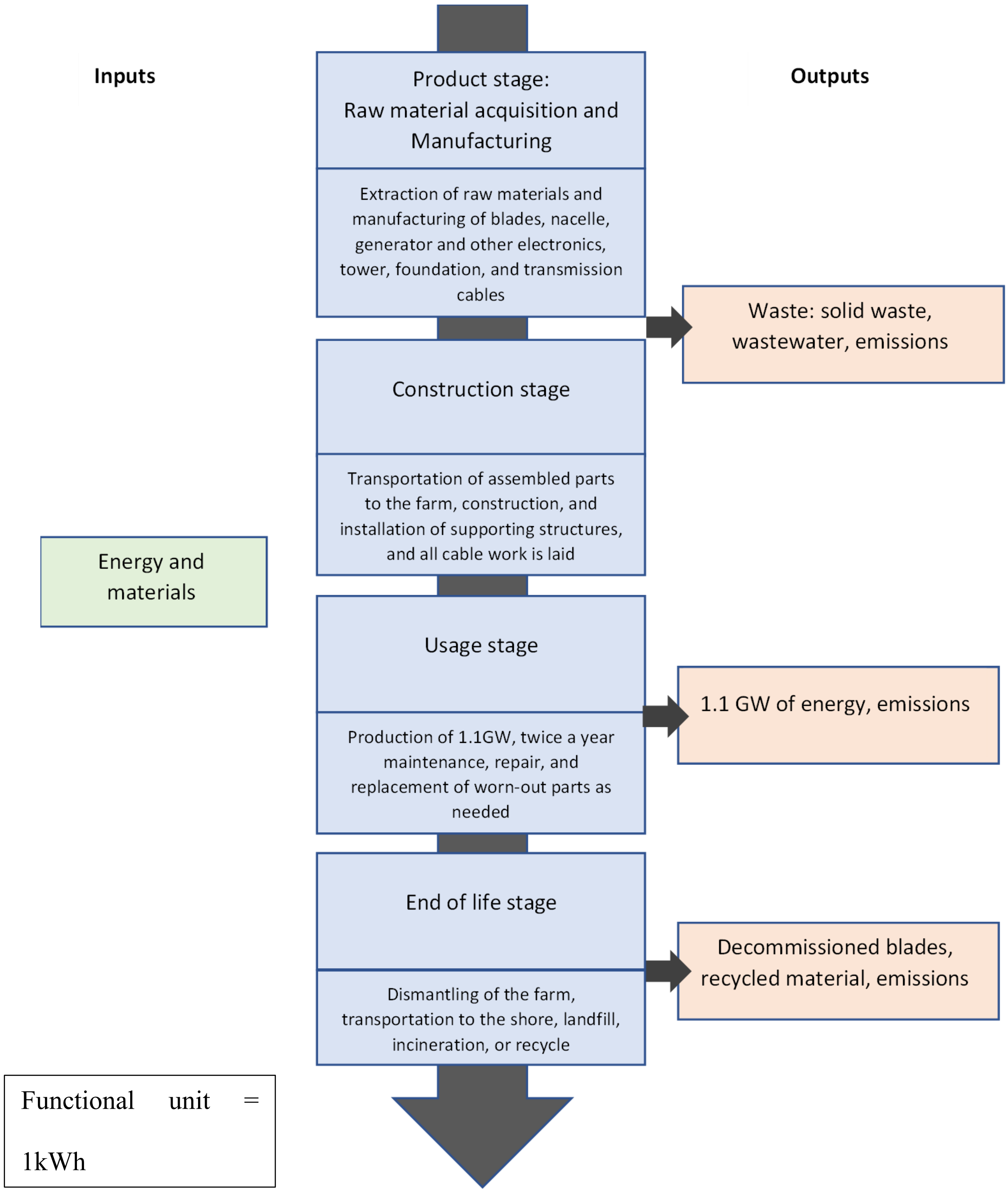



*Figure 1: System boundary for the hypothetical offshore wind farm*

The LCA model for this thesis is given in Figure 1. It includes all stages of the wind farm from raw material acquisition to end of life treatment after the farm is decommissioned in 20 years' time. EcoInvent 3.8. provides all raw material extraction, part of the product stage in the system boundary, data such as for iron and carbon which is then used for the manufacture of steel, an important material for the construction of wind turbine foundation and tower. All datasets used from EcoInvent 3.8 are given in *Table 2*. Transportation of raw materials for steel and the transportation of steel itself is provided by DataSmart database which provides fuel consumption for US. Transportation of any raw materials and productions before the construction stage is part of the product stage in the above system boundary. Same is the case with all other production materials of the turbine. Once materials have been processed, they are moved to manufacturing plants and are part of the construction stage. Transportation of such is calculated by the author. It is included in a separate unit process called 'Transportation' and is explained in detail below. The same process also includes the installation of turbines and the decommissioning phase. The construction of tower, nacelle, rotor blades, foundations, and transmission cables are all described below along with their calculations. Usage stage includes the operations and maintenance, while the end of life stage includes dismantling, transportation, recycling and/or incineration and landfilling of the turbine.

| Dataset | Citation |
|---|---|
| **Production** | |
| Rotor | NEEDs (2008); Ashuri, 2012 |
| Nacelle | |
| Tower | |
| Foundations | |
| Cables | |
| Cable Station | |
| Offshore Substation | |
| Construction | |
| Transportation | Arvesen, Birkeland, & Hertwich, 2013; Asgarpour, 2016; Tsai, Kelly, Simon, Chalat, & Keoleian, 2016 |
| Installation | |
| **Usage** | |
| O&M | Scheu, Matha, Hofmann, & Muskulus, 2012; Wang, Wang, & Smith, 2015 |
| **End of life** | |
| Recycle blades | Cherrington et al., 2012; Fox, 2016; J. P. Jensen & Skelton, 2018; Katerin Ramirez-Tejeda, 2016; A. Rahimizadeh, J. Kalman, R. Henri, K. Fayazbakhsh, & L. Lessard, 2019; Sommer & Walther, 2021; Yazdanbakhsh, Bank, Rieder, Tian, & Chen, 2018 |
| Recycle Steel | Norgate, 2013 |
| Recycle Aluminium | Grimaud, Perry, & Laratte, 2016; Norgate, 2013 |
| Recycle Glass | Haupt, Kägi, & Hellweg, 2018 |
| Recycle glass fibre | Karuppannan Gopalraj & Kärki, 2020; Shuaib & Mativenga, 2016 |
| Recycle carbon fibre | Karuppannan Gopalraj & Kärki, 2020 |
| Recycle plastics | Data from EcoInvent* |

*Table 2: Dataset citations for this LCA.*

**All the data from EcoInvent is in Appendix Table 15*

Furthermore, ReCiPe framework was used which calculates environmental impact across 18 midpoint categories and 3 endpoint categories. The midpoint indicators include particulate matter, troposphere ozone formation human impact, ionizing radiation, stratosphere ozone depletion, cancerous human toxicity, non-cancerous human toxicity, global warming, water use, freshwater eco toxicity, freshwater eutrophication, troposphere ozone formation due to ecosystems, terrestrial ecotoxicity, terrestrial acidification, land use/transformation, marine ecotoxicity, mineral resources, fossil resources. Midpoint categories can be classified under the 3 endpoint categories which include long-term impacts such as environmental health, human health, and resource scarcity ("LCIA: the ReCiPe model | RIVM", 2020) as depicted in Figure 2. From the ReCiPe framework we chose hierarchist perspective which is based on the most common policy changes as opposed to individualist (I) which is for short term changes which are understood and undisputed and egalitarian (E) which is a precautionary perspective for long term changes not yet completely understood (Goedkoop, 2009).

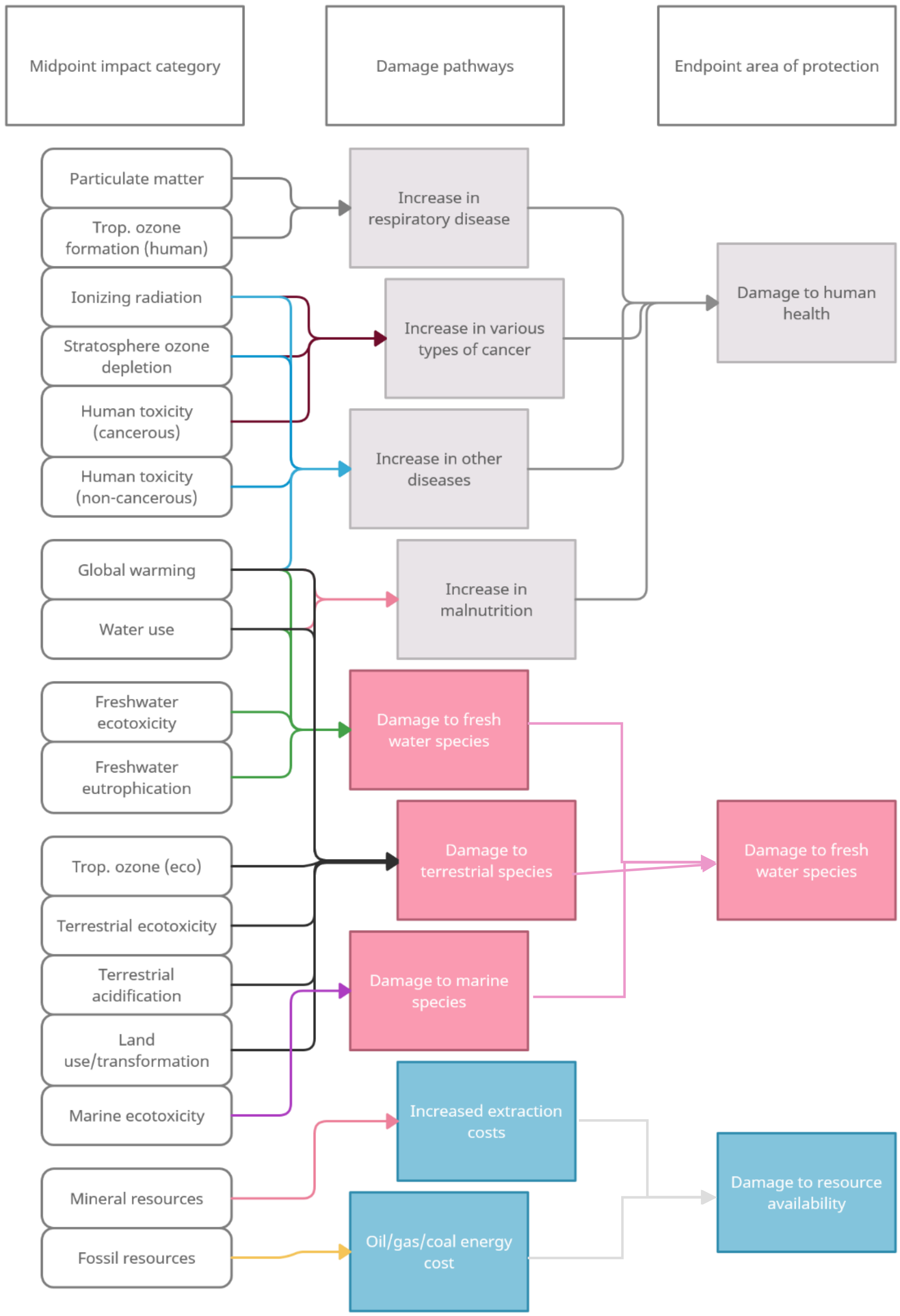



*Figure 2: ReCiPe midpoint and endpoint categories ("LCIA: the ReCiPe model | RIVM", 2020)*

**Study area**

This thesis is based on an upcoming offshore wind farm in New Jersey. In 2019 Ørsted announced the construction of their 1100MW wind farm 15 miles southeast of Atlantic City as shown in the figure below (Ocean Wind Ørsted, 2019). Since this fall well within the distance of 31miles (50km) suggested as the average distance by Weinzettel et al (2009) for using floating turbines, this thesis is comparing fixed foundation with floating to understand the environmental impacts associated with both. The hypothetical wind farm consists of 92, 12 MW turbines connected using inter-array cables in a radial topology as stated in the Strategic Plan 2019.

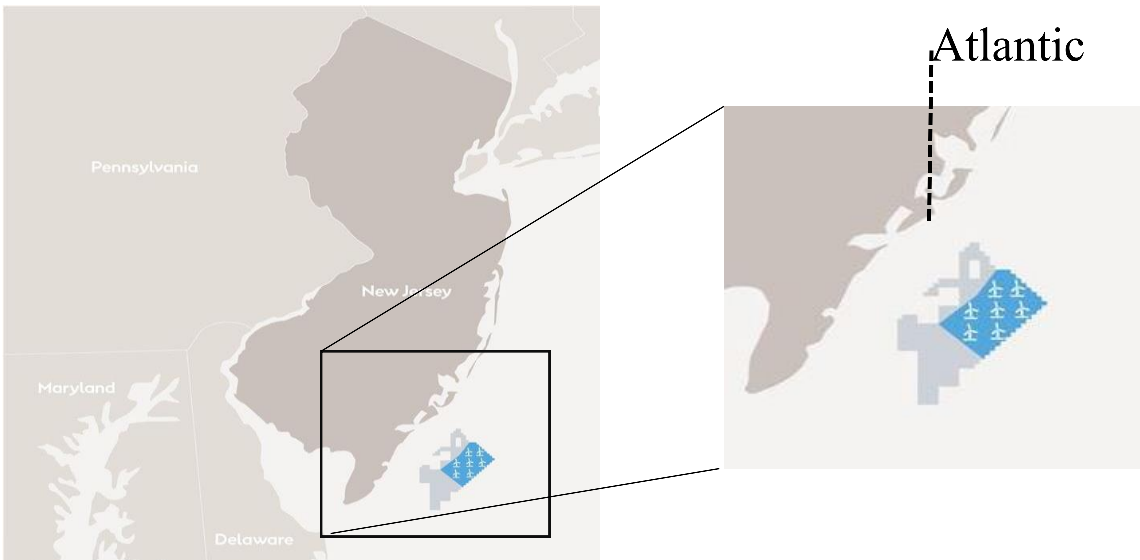



*Figure 3: Suggested location of the Ocean Wind project by Ørsted (Ocean Wind Ørsted, 2018)*

**Scenarios**

To compare impacts of different type of connections and turbines, we have 7 scenarios. S0 is our baseline which includes 92 fixed bottom turbines and radial topology inter-array 32kV cables. S1 consists of 92 floating turbines with radial topology inter-array 32kV cables. S2 has fixed bottom turbines, radial topology inter-array 32kV cables, and an offshore substation which is connected to the main grid using 150kV cables. Similar S3 has floating turbines with radial topology inter-array 32kV cables and an offshore substation connected to the main grid using 150kV cables. S4 contains recycling of rotor blades for S0. S5 includes S2 and recycling of rotor blades. S6 recycles blades for S1 and S7 recycles for S3.

| | S0 | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|
| **Turbine type** | Fixed | Floating | Fixed | Floating | Fixed | Fixed | Floating | Floating |
| **Substation** | Onshore | Onshore | Offshore | Offshore | Onshore | Offshore | Onshore | Offshore |
| **End of life** | BAU | BAU | BAU | BAU | Recycle | Recycle | Recycle | Recycle |

*Table 3: Description of scenarios*

## Calculations

### Functional Unit

All calculations are based on 1kWh of electricity produced. For all quantities in the inventory to be expressed in terms of the functional unit a conversion factor and Equation 1 provided by the EPA was used.

$$[avg\ nameplate\ capacity]\ x\ [avg\ US\ wind\ capacity\ factor]\ x\ 8{,}760\ hours/year\ x\ 1{,}000\ kWh/MWh$$

*Equation 1: electrical power generated by 1 turbine in 1 year (Green Power Equivalency Calculator, 2019)*

$$24\ hours\ x\ 360\ days = 8760\ hours/year$$

$$12\ x\ 0.3498\ x\ 8{,}760\ x\ 1{,}000\frac{kWh}{MWh} = 36770976\ kWh/year/turbine$$

$$36770976\ x\ 92 = 3382929792\ kWh/year/92\ turbines$$

$$3382929792\ x\ 20 = 67658595840\frac{kWh}{20year}$$

Since the 12MW GE Haliade X is still in the developmental phase, we do not have its average nameplate capacity. Hence, we use 12MW in our calculations. Average U.S. wind capacity factor, which is unitless ratio, is given by the EPA as 0.3498 (Green Power Equivalency Calculator, 2019). Using Equation 1 we determine annual green power purchase by 92 turbines to be 67,658,595,840 kWh (or 3382.93 GWh, ideally) for the 20-year lifetime of the wind farm.

### Manufacturing stage

#### *Rotor*

Attaining comprehensive inventories for rotor blades and other turbine components is difficult. Most of published data tends to be older and for much smaller turbines. In this thesis the inventory for rotor blades was obtained from a report published by Ørsted (formerly DONG Energy) in 2008. The inventory was then scaled using the blade mass found in Ashuri (2012) for rotor diameter 220m ("GE Renewable Energy", 2021). Total mass of the blade was then used to find masses for all materials in the “Rotor” unit process.

$$0.0571x^{2.64} = blade\ mass\ (ton)$$

*Equation 2*

Where x is the rotor diameter in meters.

#### *Tower*

Tower was scaled up exactly like rotor blades. Inventory was taken from NEEDS report which was then scaled using the total mass equation from Ashuri (2012). However, concrete was removed from the scaling process as wind turbine towers no longer use concrete.

$$0.609x^{3.22} = tower\ mass\ (ton)$$

*Equation 3*

Where x is the rotor diameter in meters.

#### *Nacelle*

Since the nacelle houses generators and all driving motors, its inventory and scaling needed to be precise. However, due to lack of availability of data, assumptions had to be made. NEEDS report (2008) provides materials required for nacelles for different dimensions of wind turbines. The 12 MW GE Haliade X this research is based upon has a 220m rotor diameter and a 150m hub height. The model is based on a 225m rotor diameter and 140m hub height 15MW turbine for the cover while the generators and other equipment housed inside the nacelle are modelled after a dimensionally smaller but 12MW turbine. To ensure that weight and mass of the nacelle cover matches the rest of the modelled turbine we use dimensions of 225m and 140m. However, the data provided for these dimensions use generators which produce 15MW. To rectify that we use generator inventory for the 12MW. Even though we cannot use the dimensions for the 12MW since they are smaller at 160m rotor diameter and 130m hub height, we can use the generator material inventory.

***Foundation***

Two types of foundation are used in this research. Fixed foundation is drilled into the seabed and consists of a cylindrical tower, transition piece and the foundation, other than the monopile (Myhr et al., 2014). While the floating foundation is anchored to the seabed using suction anchors made of steel and modelled after the wind farm Hywind II, Scotland ("How Hywind works", 2017).

*Fixed foundation*

This type of foundation is drilled into the seabed. Most of the foundation and transition piece are made of steel for which the amount is taken from NEEDS (2008) for 140m hub height and 225m diameter. All concrete has been eliminated from the inventory as manufacturers tend to use steel monopiles (Kapsali & Kaldellis, 2012). Other than that, grouting and scour protection were calculated using the following equations from (Energinet.dk, 2015; Sacchi et al., 2019)

*Grouting:*

$$Grouting\ [m^3] = 2.93x\ transition\ piece\ length\ [m] - 27.54$$

*Scour protection:*

$$Scour\ protection\ [m^3] = 0.192\ x\ nominal\ power\ [kW] + 1643$$

Furthermore, monopile was calculated following the same methods as the report by Energinet (2015) and Sacchi et al. (2019)

| Monopile | Dimension | Unit |
|---|---|---|
| Outer diameter at seabed level | 9.5 | m |
| Pile length | 80 | m |
| Pile weight | 1250 | t |
| Ground penetration (below mud line) | 29 | m |
| Transition piece | | |
| Length | 31 | m |
| Outer diameter | 7.5 | m |
| TP weight | 420 | t |
| Volume of grout | 65 | m3 |

*Table 4: Monopile and transition piece calculations. Units: [m]=meters, [t]=ton*

For the monopile height an additional 9m were added above the sea level to ensure the maintenance platform is above waves. Moreover, the latitude and longitude were chosen based on the offshore wind farm site mentioned in the Strategic Plan (Ocean Wind Ostead, 2019). The depth of -28,7m was determined based on the longitude and latitude (Ocean Wind Ostead, 2019). Furthermore, electricity and heat usage estimates for the construction of fixed foundation were taken directly from NEEDS (2008).

***Floating foundation***

Although floating foundations in the wind industry are very new, their concept has been around for some time. One of the first mentions of floating foundation concept dates back to 1972 where Professor William E. Heronemus introduced idea of commercial floating turbines (Heronemus, 1972). Weinzettel et al. (2009) is one of the more popular academic papers about the use, installation, and operation of floating turbines. It compares the floating turbine technology by Sway Floating and the Ecoinvent database 2MW floating turbine. Similarly Myhr et al. (2014) compares different types of floating platforms. However, neither of these focuses on using the technology for the USA. Figure 4 shows the structure of the type of floating turbine modelled in this chapter. Even though NEEDs (2008) report was used for the dataset of the floating turbine, the use of concrete was removed from the dataset. In the report the authors projected that turbine with the hub height of 140m would be using gravitation foundations, which use concrete. Hence, their inventory has a large amount of concrete. For this project, we use a floating turbine design similar to that used in the Hywind II farm, Scotland with steel suction anchors ("How Hywind works", 2021). Three equally distanced suction anchors placed around the floating turbine as shown in Figure 4. As their name suggests, the steel anchors generate a vacuum inside the cylinders securing the turbine platform in pace with moorings. Heat and electricity consumption were taken directly from the report.

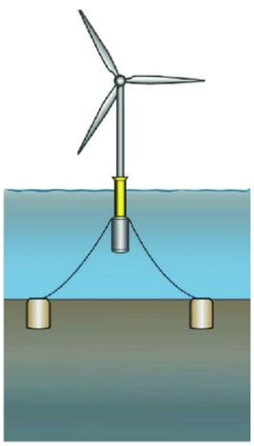


*Figure 4: suction anchor floating wind platform (Kazemi Esfeh & Kaynia, 2019)*

*Substation*

The dataset for offshore substation was taken from the NEEDS (2008) report without any modifications. Onshore substation that has been mentioned for use in the Strategic Plan (Ocean Wind Ostead, 2019) is already built and has been removed from the system boundary as depicted in Figure 1.

***Submarine cables***

Two type submarine cables were used in this study. For scenarios S1, S3, S5 and S7 where an offshore substation is considered in the calculation, we have to use 150kV cables from the offshore substation to the onshore substation. For the rest of the scenarios S0, S2, S4, and S6 where only an onshore substation is considered, we use the 32 kV cables. Although the cable sizes mentioned for use in Ocean Wind are 66 kV and 132kV to 245kV, we will be using 32 kV and 150 kV depending on the data available to us (Ocean Wind Ostead, 2019). For ease of calculations of submarine cables, the entire farm is assumed to be a single point 30km from the shore with all interconnecting array cables measuring 30km. 3km are added to account for estimation errors.

*32 kV cables*

The inventory used for submarine cables of 32kV is taken from NEEDs (2008). The functional unit for the original dataset is 1km. For scenarios S1, S3, S5 and S7 these array cables will be connected from the turbines to the offshore substation (Offshore substation of the Nordsee One wind park, 2015). For scenarios S0, S2, S4, and S6 these will bring the power generated to the shore.

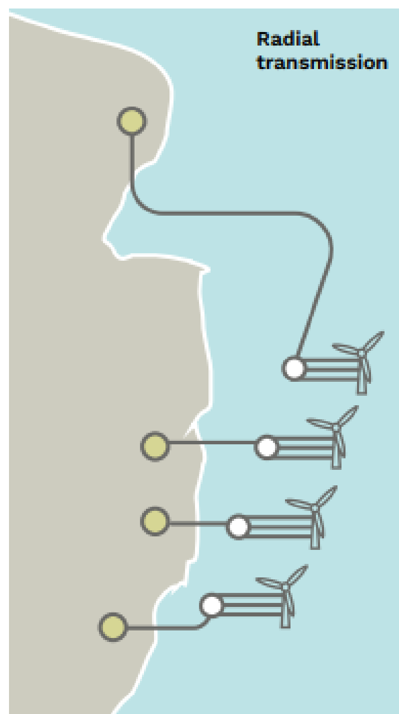



*Figure 5: radial transmission network as shown in the Strategic Plan (Ocean Wind Ostead, 2019*

As a rule of thumb, wind turbines are required to be placed 5 to 9 rotor diameters apart (Gaughan, 2018; "The Park Effect," 2003; Son, Lee, Hwang, & Lee, 2014). We followed the ring connection as stated in the Strategic Plan for array cable connections (Ocean Wind Ostead, 2019). In a ring or radial connection, we used 127.82km of array cables.

For S0, S2, S4, and S6, the total length of 32kV cables used was 157.82km, which includes array network as well as the distance to land. For scenarios S1, S3, S5 and S7 we only used 127.82km. Figure 5 shows the array network used in this thesis.

| | | |
|---|---|---|
| Distance 7 diameters apart | 220 x 7 = 1540 | m |
| 10 turbines in a straight line | 1540 x 9 = 13860 | m |
| 90 turbines | 13860 x 9 cables = 124740 | m |
| 2 turbines outside of the ring formation | (1540x2) +124740 = 127820 | m |
| Total | 127.82 + 30 = 157.82 | km |

*Table 5: array cable calculation for baseline S0*

*150 kV cables*

Similar to the 32kV cables, the dataset for 150kV cables has the functional unit of 1km. It is also taken from NEEDs (2008) without any modification. We use 25km of the cable.

***Cable station***

Under the assumption that a cable landing station will have to be built at the onshore grid connection, we use the inventory provided by NEEDs (2008) based on the grid connection of Horns Rev Offshore Wind Farm. Most cable stations serve the purpose of connecting the submarine cables to the onshore infrastructure. A cable station may be a point of connection to the onshore grid or the connection to onshore grid may take place several miles away in which case a landing station is simple a structure housing the submarine cables. This chapter models the station as the latter.

***Operation and maintenance***

Using the inventory for O&M from NEEDs (2008), we have scaled and built upon to meet the requirements of a 12MW turbine. According to GE the HALIADE X 12MW will not use a gearbox, which will significantly reduce maintenance of the nacelle (Bauer, n.d.; Gearbox vs.

direct drive: a comparison - ARADEX AG, 2021). Hence gear oil was removed from the inventory we built. The rest of the materials were scaled up linearly. Literature suggests blade and generator parts replacement to be 1/3 times over the 20-year life time of the farm or 2.5 days per turbine (Ardente et al., 2008; Arvesen et al., 2013; Tsai et al., 2016). Hence, we added these materials in our O&M dataset using 1/3 of the original blade and generator dataset while adding the 2.5-day time in our transportation dataset as explained below.

***Transportation***

As mentioned above the databases used to create the life cycle inventory are EcoInvent 3.8 and DataSmart. Hence emissions from any transportation required, during the production stage, is already calculated and included in the datasets provided by either of the databases. For this study we calculated the fuel usage during the construct stage to transport every part of the turbine from the production sites in Europe, as mentioned in the Ocean Wind Strategic Plan (2019), to the point of installation at Ocean Wind site.

Fuel consumption data for the construction stage is based on actual ships used for transportation of offshore wind turbines. Only the ships that have their data publicly available were used. None of the ships used in this study are in fact able to transport goods from the US under the Jones Act ("United States Code: Merchant Marine Act, 1920, 46 U.S.C. §§ 861-889 (1958)," 1958) which states that only ships sailing under the US flag can transport goods from the US. To keep true to this in our study we assume that all turbine parts are produced in Europe and are transported to Ocean Wind site directly for installation. Ships whose data are used are given in Table 6.

| | Type | Fuel consumption | Job | Source |
|---|---|---|---|---|
| Construction stage | Jack up vessel | 45ton per 24 hours | Transport rotor, nacelle, tower, foundations | (Fred Olsen Windcarrier, 2019) |
| | Tugboat | 150 gal per hour | Support vessel | (WeeksmarineINC, 2021) |
| | Freighter | EcoInvent 3.8 | Make cable station connections | EcoInvent 3.8** |
| | Dredger | 1558L/h = 1.37883 ton per 24 hours* | Lay submarine cables | (De Cuyper, Ansoms, & Verboomen, 2021) (Speight, 2011) |
| Usage stage | Jack up vessel (moving) | 11.7ton per 24 hour | Operation and maintenance | (Fred. Olsen Windcarrier, 2019) |
| | Jack up vessel (standing) | 9.3m$^3$ per 24 hour | Operation and maintenance | (Fred. Olsen Windcarrier, 2019) |
| End of life stage | Jack up vessel | 45ton per 24 hours | Transport rotor, nacelle, tower | (Fred Olsen Windcarrier, 2019) |

**Converted manually using the density of diesel = 0.85kg/l*

***Data from EcoInvent in Appendix* Table 15

*Table 6: Fuel consumption rates of different vessels used in the study*

Transportation need during the usage stage is for operation and maintenance. Data from the jack up vessel called Jill by Fred. Olsen Windcarrier (2019) is used to inform the life cycle inventory (LCI). The fuel consumption rates for Jill are given in Table 6 while the calculations for O&M are given in Table 9. Since O&M will be conducted from Paulsboro, all fuel consumption is calculated as such (Kummer, 2021). Similarly for the end of life stage of the theoretical wind farm in consideration, the same jack up vessel used for installation is used to inform the model for dismantling and decommissioning. As Table 10 shows, only the rotor, tower, and nacelle are brought back to the shore. Foundations are left standing in the ocean for artificial reef to grow leading to abundance in species that are associated with hard strata (Coolen et al., 2018; Glarou, Zrust, & Svendsen, 2020; Topham, Gonzalez, McMillan, & João, 2019) while the submarine cables and offshore substation having longer lives are also left in the ocean either for further use or as waste (Al-Sallami, 2021; Mahmoud, Fayad, & Dodds, 2021).

| Part | Origin | Destination | Km/per trip | Weight of load (ton) | Voyage Duration (hours) | Fuel Consumption (ton) |
|---|---|---|---|---|---|---|
| **Rotor** | Cherbourg | Ocean Wind | 5595.7 | 304.9 | 302.14 | 566.5 |
| **Nacelle/generators** | Saint nazaire | Ocean wind | 5640.8 | 261.8 | 304.58 | 571.1 |
| **Tower** | Germany | Paulsboro | 5815 | 2124.3 | 313.98 | 588.7 |
| **Foundation/transition** | Local/paulsboro | Paulsboro | 80.0 | 899.3 | 4.32 | 8.1 |

*Table 7:Transportation during the construction stage*

| Part | Origin | Destination | km/per trip | type of vehicle | weight of load (ton) | Tkm | voyage duration (hours) | fuel consumption (ton) |
|---|---|---|---|---|---|---|---|---|
| **rotor-nacelle-tower-foundation** | | | standing | jack up | | | 588 standing | 134.75 |
| **offshore substation** | Paulsboro | Ocean Wind | 80.5 | Freighter | 1500.2 | 1.78E-06 | -* | - |
| **cables 32kV** | Paulsboro | Ocean Wind | 80.5 | Dredger | 19.0 | 2.26E-08 | 4.34 | 3.69E-12/functional unit |
| **cables 150kV** | Paulsboro | Ocean Wind | 80.5 | Dredger | 66.9 | 7.96E-08 | 4.34 | 2.50E-01/functional unit |
| **cable station** | Paulsboro | Ocean Wind | 80.5 | Freighter | 140.057 | 1.67E-07 | -* | |
| | | | | Tugboats** | | | 4.34 | 0.87 |

*Table 8: Fuel consumption during the installation of wind turbines*

**Due to lack of data regarding the installation time of an offshore substation and the cable station it has not been included in the calculations.*
***Tugboats travel along with dredgers and freighters (Tran & Im, 2012)*

| Type of vehicle | distance (km) | speed travelled at kph | voyage hours | standing/crane hour | fuel consumption | Weight(ton) | Tkm/functional unit |
|---|---|---|---|---|---|---|---|
| **Jack up moving** | 80.5 | 11.1 | 7.24 | | 5.22E-11 | 60741 | 7.23E-05 |
| **Jack up standing** | | | | 2160* | 1.22E-08 | | |

*Table 9: Operation and maintenance fuel consumption*

**92 turbines will take about 3 months for maintenance according to private interview with a turbine operator.*

| Part | km/per trip | type of vehicle | weight of load (ton) | tkm | voyage duration (hours) | fuel consumption (ton) |
|---|---|---|---|---|---|---|
| **Rotor** | 64.4 | jack up | 304.9 | 19625.1 | 3.5 | 6.5 |
| **Nacelle** | 64.4 | jack up | 261.8 | 16855.2 | 3.5 | 6.5 |
| **Tower** | 64.4 | jack up | 2124.3 | 136749.9 | 3.5 | 6.5 |
| **Foundation** | Considered to be left in the ocean as the lifetime for these is known to be longer than a wind farm, marking it as outside the 20 year system boundary of the current study. | | | | | |
| **Offshore substation** | | | | | | |
| **Cables 32kV** | | | | | | |
| **Cables 150kV** | | | | | | |
| **Cable station** | | | | | | |

*Table 10: Fuel consumption during the decommission phase*

### *Uncertainty analysis*

Monte Carlo uncertainty simulation is used in SimaPro 9.1 to assess uncertainties in the data used. Monte Carlo simulation analyses using normal probability distributing giving final results as a probability distribution as well which can be read using standard deviation. The simulation was first applied to all 8 scenarios, including the baseline. Then, we applied it to any components of the system that lead to the most environmental impacts. The key impact components were cable station, fixed foundation, floating foundation, tower, transportation, and offshore substation.

## Results and Discussion

The results from each scenario are given below.

### Baseline Scenario Impact Analysis

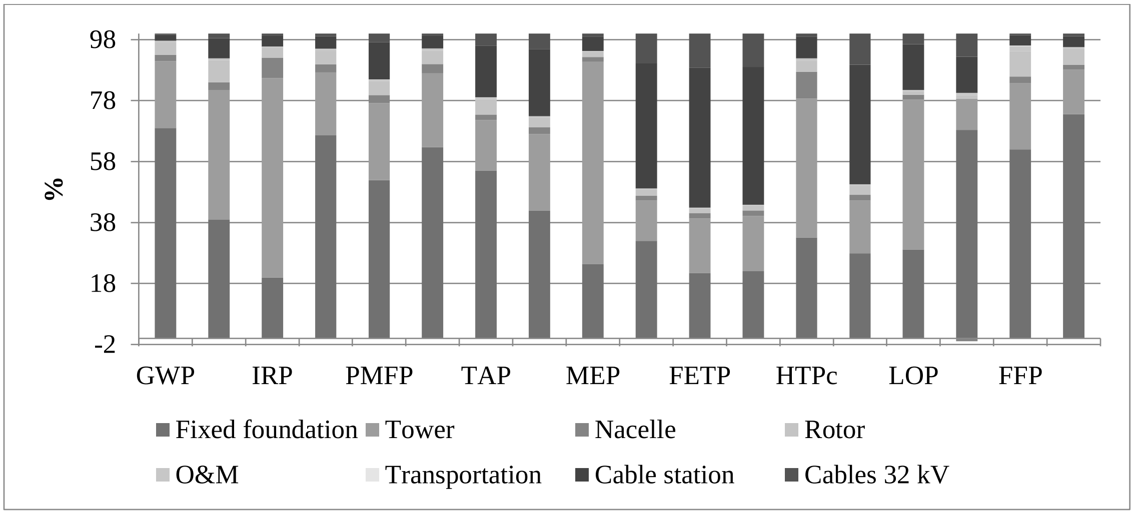



*Figure 6: Baseline impact assessment*

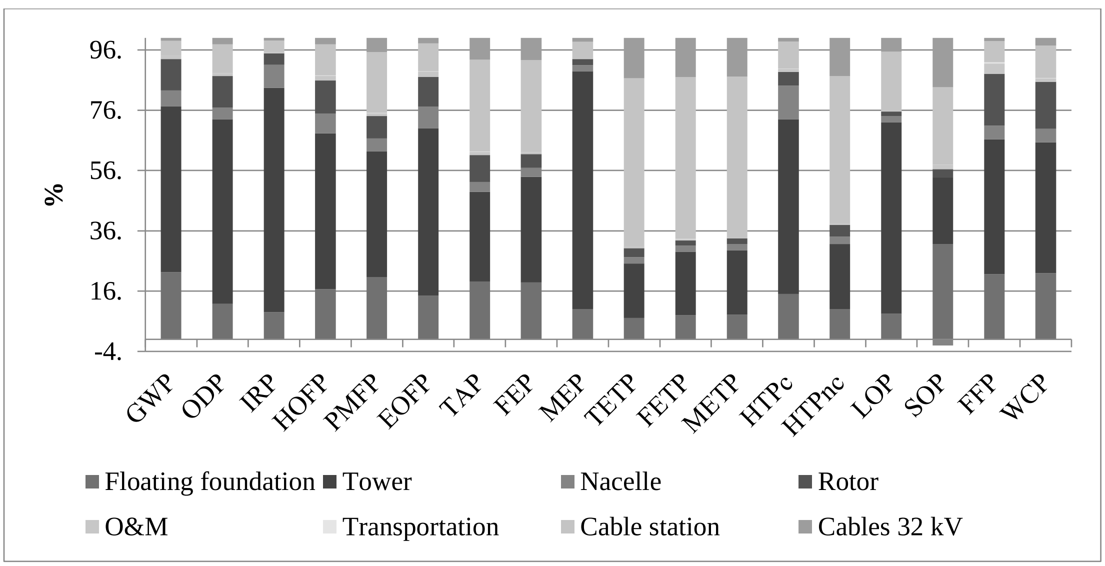



*Figure 7: S1 impact assessment*

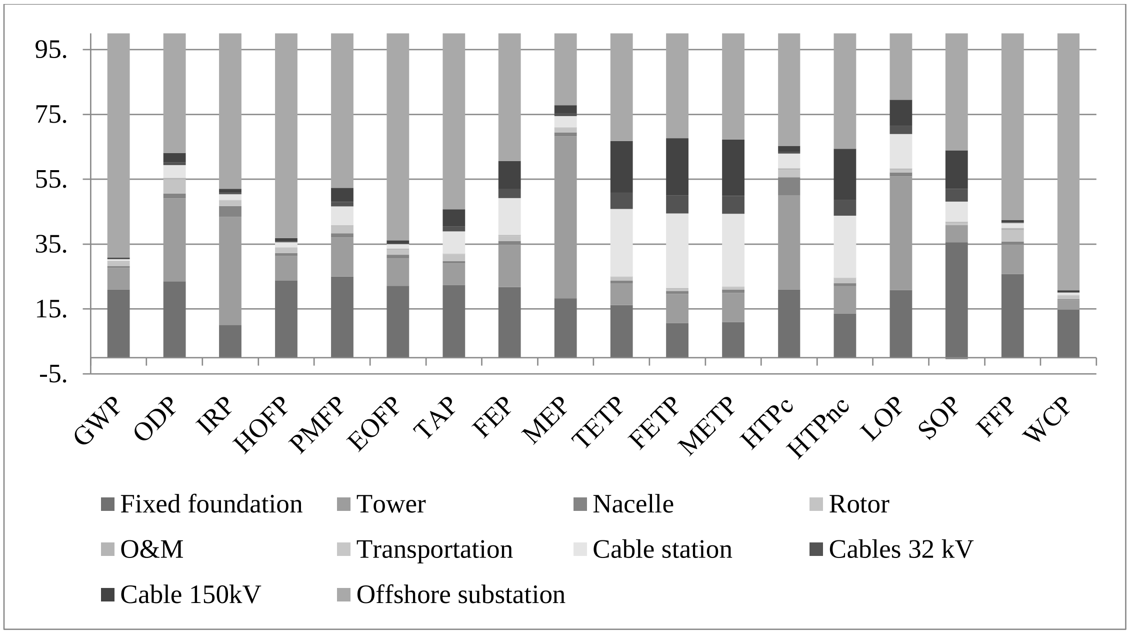



*Figure 8: S2 impact assessment*

For scenarios S0 and S4, where offshore substation is not within the system boundary, the most emissions are contributed to the constructions, transportation, and installation of the fixed foundation. Whereas when we look at scenarios S1 and S6 most emissions are from the construction, transportation, installation, and dismantling of the tower, not floating foundation. Floating foundation contributes significantly less when compared to fixed foundation. This is due to floating foundations not being embedded in the seabed, hence being less disruptive for the marine life than fixed foundation (Farr, Ruttenberg, Walter, Wang, & White, 2021). Floating foundations rank much lower than fixed in the categories associated with marine life: marine eutrophication and marine ecotoxicity.  Yang et al. (2019) also suggests that removal of a decommissioned floating turbine is easier and less emission intensive than fixed turbines. Furthermore, fixed foundations are, as their name suggests, embedded approximately 29m below the seabed; using more steel, floating foundations are moored to suction anchors at the seabed (Diaz et al., 2016; Sacchi et al., 2019).

For scenarios S1 and S6 the monopile/tower contributes to the most emissions across all categories. It contributes significantly to IRP, MEP, and LOP. However, for scenarios S0 and S4, where fixed foundation contributes the most to emissions, the significant categories are GWP, HoPF, and WCP. On the other hand, S2, S3, S5, and S7 where offshore substation is within the system, the offshore substation contributes almost 60% across all categories with GWP, HOFP, EOFP, FFP, and WCP being the most prominent.

| Impact category | Unit | S0 | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|---|
| GWP | kg $CO_2$ eq | 3.06E-04 | 1.22E-04 | 1.00E-03 | 8.21E-04 | 2.99E-04 | 9.98E-04 | 1.15E-04 | 8.14E-04 |
| ODP | kg CFC11 eq | 1.29E-10 | 8.95E-11 | 2.15E-10 | 1.75E-10 | 1.25E-10 | 2.10E-10 | 8.47E-11 | 1.70E-10 |
| IRP | kBq Co-60 eq | 3.13E-05 | 2.76E-05 | 6.17E-05 | 5.80E-05 | 3.13E-05 | 6.17E-05 | 2.76E-05 | 5.79E-05 |
| HOFP | kg NOx eq | 8.65E-07 | 3.47E-07 | 2.41E-06 | 1.90E-06 | 8.52E-07 | 2.40E-06 | 3.34E-07 | 1.88E-06 |
| PMFP | kg PM2.5 eq | 4.90E-07 | 2.97E-07 | 1.02E-06 | 8.26E-07 | 4.79E-07 | 1.01E-06 | 2.85E-07 | 8.15E-07 |
| EOFP | kg NOx eq | 9.35E-07 | 4.08E-07 | 2.65E-06 | 2.12E-06 | 9.22E-07 | 2.64E-06 | 3.95E-07 | 2.11E-06 |
| TAP | kg SO2 eq | 9.68E-07 | 5.38E-07 | 2.39E-06 | 1.96E-06 | 9.38E-07 | 2.36E-06 | 5.08E-07 | 1.93E-06 |
| FEP | kg P eq | 1.12E-07 | 7.99E-08 | 2.15E-07 | 1.83E-07 | 1.10E-07 | 2.14E-07 | 7.86E-08 | 1.82E-07 |
| MEP | kg N eq | 2.00E-08 | 1.68E-08 | 2.66E-08 | 2.34E-08 | 1.98E-08 | 2.64E-08 | 1.67E-08 | 2.32E-08 |
| TETP | kg 1,4-DCB | 2.70E-03 | 1.97E-03 | 5.30E-03 | 4.58E-03 | 2.67E-03 | 5.28E-03 | 1.95E-03 | 4.56E-03 |
| FETP | kg 1,4-DCB | 4.38E-05 | 3.75E-05 | 8.76E-05 | 8.13E-05 | 4.34E-05 | 8.72E-05 | 3.70E-05 | 8.08E-05 |
| METP | kg 1,4-DCB | 5.63E-05 | 4.78E-05 | 1.13E-04 | 1.04E-04 | 5.57E-05 | 1.12E-04 | 4.72E-05 | 1.04E-04 |
| HTPc | kg 1,4-DCB | 4.82E-05 | 3.80E-05 | 7.59E-05 | 6.57E-05 | 4.80E-05 | 7.57E-05 | 3.78E-05 | 6.55E-05 |
| HTPnc | kg 1,4-DCB | 6.32E-04 | 5.07E-04 | 1.30E-03 | 1.17E-03 | 6.22E-04 | 1.29E-03 | 4.97E-04 | 1.16E-03 |
| LOP | m2a crop eq | 1.46E-04 | 1.13E-04 | 2.04E-04 | 1.71E-04 | 1.45E-04 | 2.03E-04 | 1.12E-04 | 1.70E-04 |
| SOP | kg Cu eq | 4.35E-06 | 1.99E-06 | 8.39E-06 | 6.03E-06 | 4.28E-06 | 8.33E-06 | 1.92E-06 | 5.97E-06 |
| FFP | kg oil eq | 5.61E-05 | 2.72E-05 | 1.35E-04 | 1.06E-04 | 5.24E-05 | 1.31E-04 | 2.35E-05 | 1.02E-04 |
| WCP | m3 | 2.60E-06 | 8.83E-07 | 1.29E-05 | 1.12E-05 | 2.53E-06 | 1.28E-05 | 8.13E-07 | 1.11E-05 |

*Table 11: Midpoint environmental impacts of all 8 scenarios.*

Out of all 8 scenarios, Table 11 shows that S2 has the highest impact while S6 has the lowest across all categories. As mentioned in Table 3, S2 has fixed foundation, an offshore substation, and business as usual recycling while S6 has floating foundations, no offshore substation, and recycling as suggested in this paper. This is due to offshore substations having highest environmental impact and floating turbines having a lesser impact than fixed foundations.

Furthermore, for scenarios S4, S5, S6, and S7 where we tried to achieve 100% recycling, we see a negative contribution for nacelle and rotor. Since the results show emissions, a negative contribution signifies that recycling nacelle and rotor blades has a positive impact on the SOP. For this study we modelled both carbon and glass fiber to be recycled. Both of which are currently landfilled. Since both fibers need to be extracted from the nacelle and rotor blades, recycling these means that metals and plastics which could be recycled in S0, S1, S2, or S3 can now be recycled as well. Hence recycling these two has a strong impact on the overall system. While the impact from recycling nacelle is about 5% and about 17% for the rotor, it must be noted that the results are for every kWh. Figure 9 shows the difference between recycling rotor and nacelle. Similarly, other studies have found that recycling of wind turbine material which could lead to reduction in emissions amounting to 7351 ton $CO_2$, approximately equivalent to 52.5million km of driving a car (Jonas Pagh Jensen, 2019).

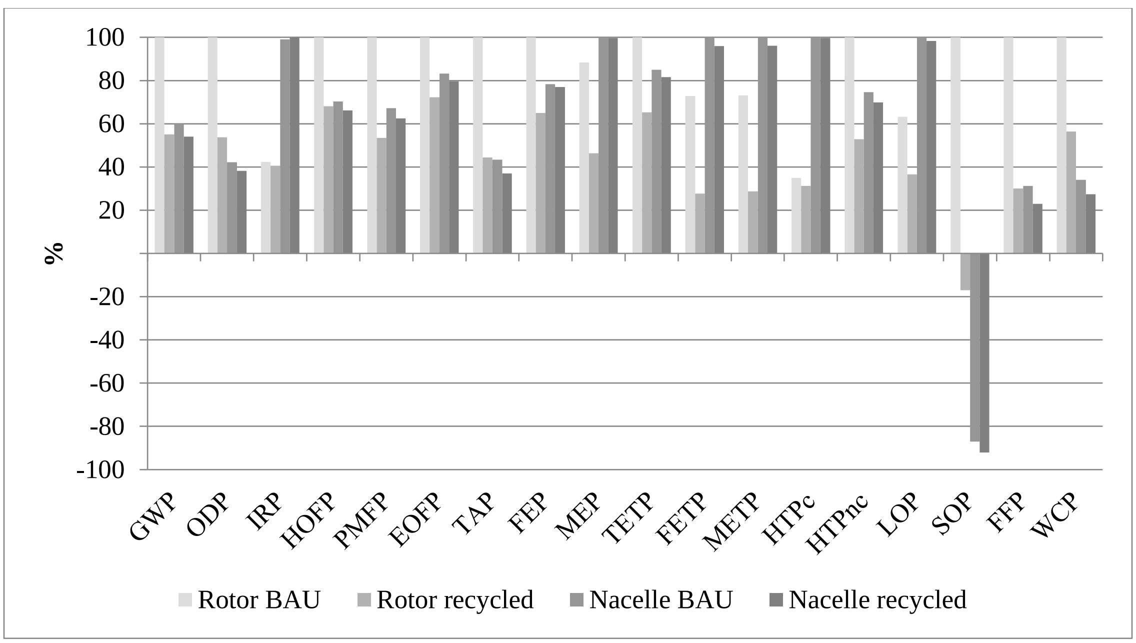



*Figure 9: Rotor blades and nacelle recycling has the greatest positive impact on mineral resource scarcity.*

Ocean wind will have anywhere from 276 to 297 blades to landfill at the end of its 20-year lifetime if recycling is not incorporated into the system. Recycling of blades can be achieved by extracting carbon and glass fibers through several mechanical and chemical processes (Sommer & Walther, 2021) and reusing them, or the entire blade can be recycled into other products such as

3D print ink (Amirmohammad Rahimizadeh, Jordan Kalman, Rodolphe Henri, Kazem Fayazbakhsh, & Larry Lessard, 2019), pavement concrete (Fox, 2016), or even urban furniture or playground material (J. P. Jensen & Skelton, 2018) as part of cross industry or closed loop recycling. While Fox (2016) establishes the use of wind blades in concrete, Yazdanbakhsh et al. (2018) state that concrete made using mechanically recycled blades have a higher energy absorption capacity making the concrete tougher than normal. Wind industry in Europe is currently exploring both options to reduce raw material costs and resource extraction as well as end of life waste (Mavrokefalidis, 2021; Richard, 2021; Sommer & Walther, 2021).

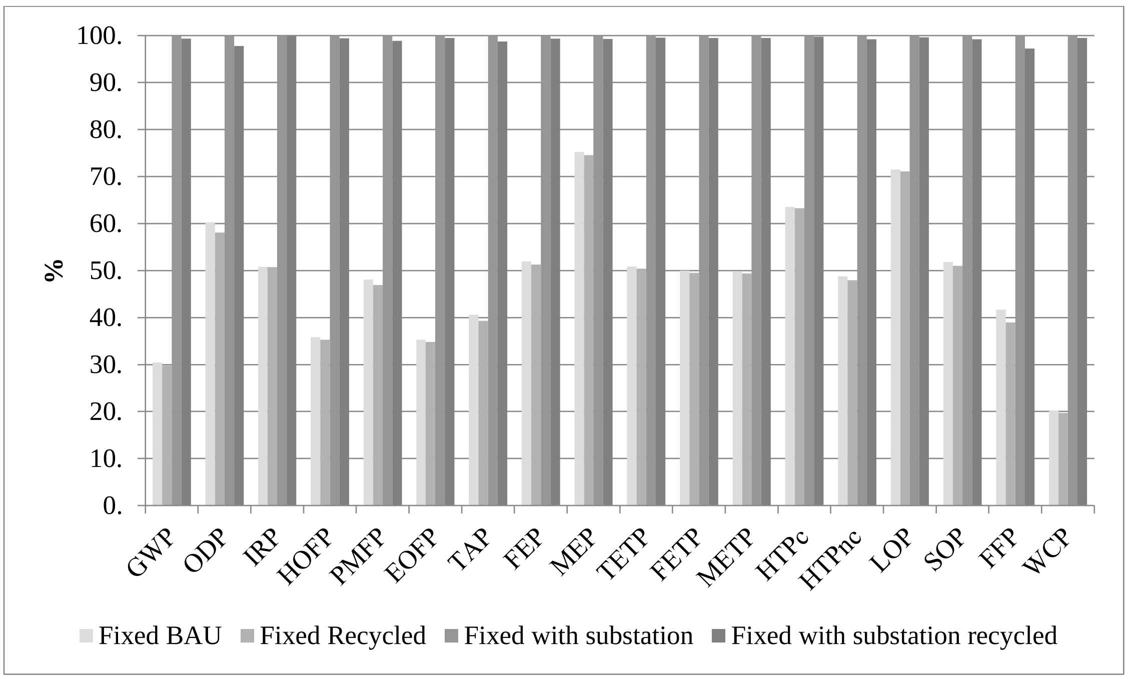



*Figure 10: Fixed turbine scenarios*

Figure 10 shows that while recycling has a positive impact for scenarios S4 and S6, an offshore substation will contribute to the most emissions. However, Offshore substations tend to decrease power loss while transmitting energy to the shore (Froese, 2016). Even though this study does not calculate power loss with or without an offshore substation, including one will convert low voltage produce from the turbine generators to high voltage at the substation which will reduces power losses significantly (Froese, 2016; Rizk, 2017). With several offshore wind farms being constructed in the north-eastern region of the USA, to name a few: Vinyard Wind, New England Wind, Park City Wind, Rhode Island Wind Farm, and Ocean Wind, one substation that can accommodate most or all farms in the vicinity is needed considering the large number of emissions from it. Substations will last 10-15 years longer than one wind farm(Arvesen, Nes, Huertas-Hernando, & Hertwich, 2014). The tristate area or north-eastern states can work toward an integrated grid and toward and cleaner future rather than building more substations than are necessary.

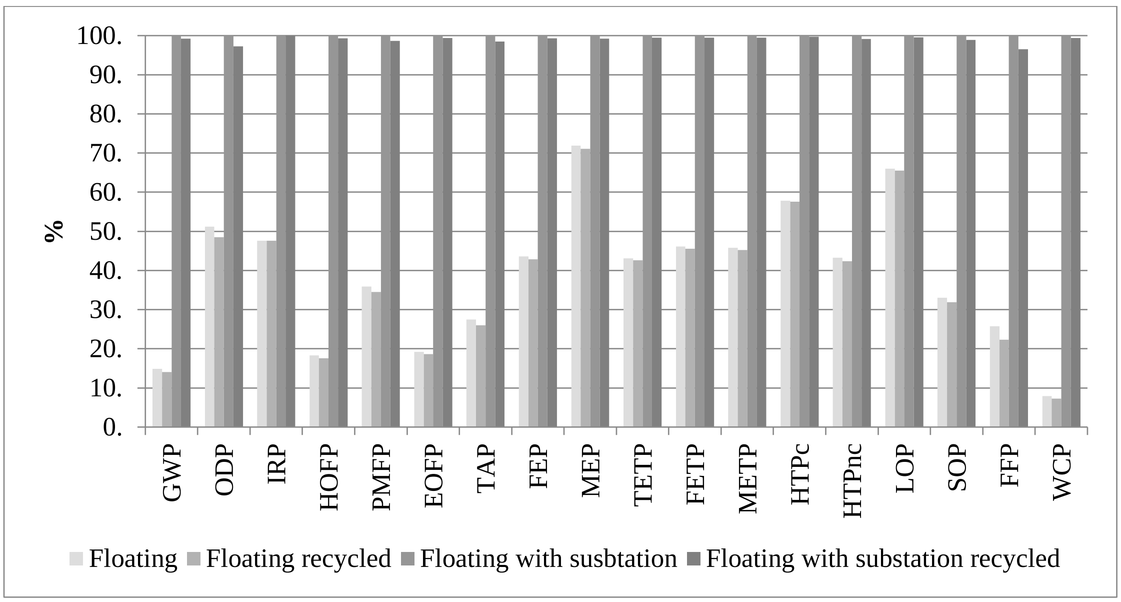



*Figure 11: Floating turbine scenarios*

Figure 11 shows all scenarios with floating foundations. Similar to Figure 10, offshore substation contributes to most emissions. Although recycling reduces the negative impact considerably, it is still significant in S3 and S6. In this study the capacity factory for floating turbines and fixed turbines was taken to be 35% due to availability of data. However, floating turbines can have higher capacity factors both due to larger generators and unobstructed access to wind energy in the deeper ocean (Lerch, De-Prada-Gil, & Molins, 2019; Weinzettel et al., 2009). This will impact the generator of power, power loses, and in turn impact the LCA conducted.

**Uncertainty analysis**

The Monte Carlos simulation used to calculate the uncertainty analysis in SimaPro 9.1. The simulation suns a fixed number of trails to generate uncertainty tables and graphs. Such a simulation helps understand if the results from different scenarios are reliable and comparable (Golsteijn, 2015). One important result from the Monte Carlo analysis is the coefficient of variance (CV). CV shows whether the data collected and used to inform the LCI is of high quality. CV $\leq$ 30 is important for the data used to be accurate and high quality. As shown in Table 12 CV associated with freshwater eutrophication (FEP), human carcinogenic toxicity (HTPc), ionizing radiation (IRP), terrestrial ecotoxicity (TETP), water consumption (WCP), for the baseline scenario is more than 30. Referring to the manual of the software tells us that the above-mentioned categories are listed as “recommended but in need of some improvement” and “recommended, but to be applied with caution”, while terrestrial ecotoxicity has no method of calculation listed.

Results from the uncertainty analysis of S0 are given in Table 12.

| Impact category | Unit | Mean | Median | SD | CV% | 5% | 95% | SEM |
|---|---|---|---|---|---|---|---|---|
| **PMFP** | kg PM2.5 eq | 4.87E-07 | 4.85E-07 | 3.30E-08 | 6.37 | 4.38E-07 | 5.46E-07 | 1.04E-09 |
| **FFP** | kg oil eq | 5.61E-05 | 5.59E-05 | 3.60E-06 | 6.6 | 5.03E-05 | 6.23E-05 | 1.14E-07 |
| **FETP** | kg 1,4-DCB | 4.40E-05 | 4.33E-05 | 6.75E-06 | 16.6 | 3.41E-05 | 5.60E-05 | 2.13E-07 |
| **FEP** | kg P eq | 1.14E-07 | 1.07E-07 | 4.37E-08 | 40 | 5.62E-08 | 1.91E-07 | 1.38E-09 |
| **GWP** | kg $CO_2$ eq | 0.000305 | 0.000303 | 2.13E-05 | 6.56 | 0.000274 | 0.000344 | 6.73E-07 |
| **HTPc** | kg 1,4-DCB | 4.81E-05 | 4.46E-05 | 1.81E-05 | 38.3 | 2.71E-05 | 8.23E-05 | 5.73E-07 |
| **HTPnc** | kg 1,4-DCB | 0.000629 | 0.000617 | 0.000122 | 90.4 | 0.00046 | 0.000837 | 3.87E-06 |
| **IRP** | kBq Co-60 eq | 3.10E-05 | 2.11E-05 | 3.59E-05 | 105 | 6.93E-06 | 8.59E-05 | 1.13E-06 |
| **LOP** | m2a crop eq | 0.000146 | 0.000143 | 2.09E-05 | 14.6 | 0.000119 | 0.000184 | 6.60E-07 |
| **METP** | kg 1,4-DCB | 5.65E-05 | 5.56E-05 | 8.36E-06 | 16.3 | 4.41E-05 | 7.13E-05 | 2.64E-07 |
| **MEP** | kg N eq | 2.01E-08 | 1.99E-08 | 1.97E-09 | 9.62 | 1.74E-08 | 2.35E-08 | 6.22E-11 |
| **SOP** | kg Cu eq | 4.32E-06 | 4.19E-06 | 8.56E-07 | 19.6 | 3.14E-06 | 5.92E-06 | 2.71E-08 |
| **HOFP** | kg NOx eq | 8.59E-07 | 8.56E-07 | 7.01E-08 | 8.31 | 7.52E-07 | 9.78E-07 | 2.22E-09 |
| **EOFP** | kg NOx eq | 9.28E-07 | 9.24E-07 | 8.37E-08 | 9.29 | 8.04E-07 | 1.07E-06 | 2.65E-09 |
| **ODP** | kg CFC11 eq | 1.29E-10 | 1.28E-10 | 1.13E-11 | 9.03 | 1.13E-10 | 1.49E-10 | 3.58E-13 |
| **TAP** | kg SO2 eq | 9.66E-07 | 9.62E-07 | 6.15E-08 | 6.11 | 8.69E-07 | 1.07E-06 | 1.94E-09 |
| **TETP** | kg 1,4-DCB | 0.002655 | 0.002398 | 0.000986 | 39.6 | 0.001722 | 0.004491 | 3.12E-05 |
| **WCP** | m3 | -5.91E-07 | 9.02E-06 | 9.96E-05 | 2600 | -0.00018 | 0.000142 | 3.15E-06 |

*Table 12: Baseline uncertainty analysis*

The components from the system with the highest environmental impacts in all scenarios went through an uncertainty analysis. Table 13 below lists them. Even though coefficient of variation (CV) for the tower, transportation, and offshore substation datasets are 12%, 11%, and 16%, respectively, they are less than 30%, which indicates that while they are not as precise as the cable station or floating foundation, they are acceptable. If they were greater than 30%, more data would have been needed to justify these results (Pre Sustainability, 2019).

| Product | mean | median | SD | CV | 5% | 95% | SEM |
|---|---|---|---|---|---|---|---|
| **Cable Station** | 3.02 | 3.01 | 0.16 | 5% | 2.78 | 3.29 | 0.00 |
| **Fixed foundation** | 4.87 | 4.82 | 0.41 | 8% | 4.31 | 5.61 | 0.01 |
| **Tower** | 2.15 | 2.13 | 0.25 | 12% | 1.76 | 2.58 | 0.01 |
| **Floating Foundation** | 0.37 | 0.37 | 0.02 | 5% | 0.34 | 0.40 | 0.00 |
| **Transportation** | 3370.00 | 3330.00 | 381.00 | 11% | 2860.00 | 4030.00 | 12.00 |
| **Offshore Substation** | 30.20 | 29.80 | 4.86 | 16% | 22.90 | 39.00 | 0.15 |

*Table 13: Uncertainty analysis for components of the system that contribute to the largest environmental impacts in every scenario*

## Conclusion

This study used LCA to find environmental impacts related to a hypothetical wind farm in New Jersey. The farm is assumed to be located 15 miles away from the shore of Atlantic City with 92 to 98 12MW fixed foundation wind turbines generating 1100MW. The cradle-to-grave LCA conducted is inclusive of raw material acquisition, transportation, installation, decommission, and recycling of the main components of the farm. The model spans the lifetime of 20 years of wind farm in consideration. Findings from this LCA are able to help make informed decisions based on the environmental impacts calculated.

Results of the scenario analysis shed light on some important factors. Floating turbines with suction anchors are less deteriorating to the environment than fixed turbines, working at the same capacity and generating an equal amount of power. Recycling of blades and nacelle covers will reduce mineral recourse scarcity by 17% and 5%, receptively. Ocean Wind will have anywhere from 92 to 99 turbines, each turbine will have 3 blades, giving a total of 276 to 297 blades at the end of the farm's lifetime to landfill in case the blades are not recycled. In an unlikely case of blade erosion or replacement during the lifetime of the farm, there will be that many more blades to landfill. Hence, recycling of carbon and glass fiber is essential for the industry. Furthermore, building offshore substation was found to have strong impacts on the environment, specifically contributing to global warming and water consumption. However, offshore substations are needed to ensure power loss while transmission is minimal. Hence, offshore substations need to be built for more than one project and the States neighbouring the Atlantic Ocean may need to establish a common grid.

While this study is comprehensive, there were some limitations to it. Data used to create the LCI is mostly based on a report from 2008. Wind industry has advanced drastically since 2008, newer more accurate data will lead to more accurate results. Secondly, energy loss during transmission is assumed to be negligible. Introducing energy loss into the LCA will make it more precise. When this project was in its data gathering phase, GE had not made the capacity factor of its Haliade X 12MW wind turbine publicly available. Since it is now available, it will improve the results greatly. Another major improvement to the LCA would be performance data of floating wind turbines in deeper US waters. For future work in this field, the researcher would recommend overcoming the above-mentioned limitations. Furthermore, primary data for floating wind turbines and their capacity factor would provide results of great use to policy makers in choosing floating turbines for eastern shore of the US. Similarly, LCAs of cross industry recycling of wind blades will prove beneficial as well the cross-industry recycling or reuse of submarine cables.

**References**

Al-Sallami, O. (2021). *CABLES DECOMMISSIONING IN OFFSHORE WIND FARMS: ENVIRONMENTAL AND ECONOMICAL PERSPECTIVE.* (Independent thesis Advanced level (degree of Master (One Year)) Student thesis). Retrieved from

Ardente, F., Beccali, M., Cellura, M., & Lo Brano, V. (2008). Energy performances and life cycle assessment of an Italian wind farm. *Renewable and Sustainable Energy Reviews, 12*(1), 200-217. doi:

Arvesen, A., Birkeland, C., & Hertwich, E. G. (2013). The Importance of Ships and Spare Parts in LCAs of Offshore Wind Power. *Environmental Science & Technology, 47*(6), 2948-2956. doi:10.1021/es304509r

Arvesen, A., Nes, R., Huertas-Hernando, D., & Hertwich, E. (2014). Life cycle assessment of an offshore grid interconnecting wind farms and customers across the North Sea. *International Journal of Life Cycle Assessment*, *19*(4), 826-837. doi:10.1007/s11367-014-0709-2

Coolen, J. W. P., van der Weide, B., Cuperus, J., Blomberg, M., Van Moorsel, G. W. N. M., Faasse, M. A., . . . Lindeboom, H. J. (2018). Benthic biodiversity on old platforms, young wind farms, and rocky reefs. *ICES Journal of Marine Science*, *77*(3), 1250-1265. doi:10.1093/icesjms/fsy092

Curran, M. A. (2013). Life Cycle Assessment: a review of the methodology and its application to sustainability. *Current Opinion in Chemical Engineering, 2*(3), 273-277. doi:

De Cuyper, J.-B., Ansoms, B., & Verboomen, B. (2021). Smart, sustainable: a life cycle approach to fuel economy as applied to dredging vessels. In I. A. o. D. Companies (Ed.): International Association of Dredging Companies.

Diaz, B. D., Rasulo, M., Aubeny, C. P., Fontana, C. M., Arwade, S. R., DeGroot, D. J., & Landon, M. (2016, 19-23 Sept. 2016). *Multiline anchors for floating offshore wind towers.* Paper presented at the OCEANS 2016 MTS/IEEE Monterey.

Energinet.dk. (2015). *Technical Project Description for Offshore Wind Farms (200 MW)* (13-97289-2 ). Retrieved from Fredericia:

Fox, T. (2016). *Recycling wind turbine blade composite material as aggregate in concrete.* (Master of Science). Iowa State University, Iowa, United States.

Froese, M. (2016). Making of the modern offshore substation. Retrieved from

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., . . . Rydberg, T. (2011). Life Cycle Assessment: Past, Present, and Future. *Environmental Science & Technology, 45*(1), 90-96. doi:10.1021/es101316v

Haapala, K. R., & Prempreeda, P. (2014). Comparative life cycle assessment of 2.0 MW wind turbines. *International Journal of Sustainable Manufacturing, 3*(2), 170-185. doi:10.1504/ijsm.2014.062496

Kapsali, M., & Kaldellis, J. K. (2012). 2.14 - Offshore Wind Power Basics. In A. Sayigh (Ed.), *Comprehensive Renewable Energy* (pp. 431-468). Oxford: Elsevier.

Kazemi Esfeh, P., & Kaynia, A. (2019). Numerical modeling of liquefaction and its impact on anchor piles for floating offshore structures. *Soil Dynamics and Earthquake Engineering, 127*. doi:10.1016/j.soildyn.2019.105839

Lerch, M., De-Prada-Gil, M., & Molins, C. (2019). The influence of different wind and wave conditions on the energy yield and downtime of a Spar-buoy floating wind turbine. *Renewable Energy, 136*, 1-14. doi:

Mahmoud, R. M. A., Fayad, H., & Dodds, P. E. (2021). *Repurposing of Offshore Oil and Gas Cables for Renewable Generation: Feasibility and Conceptual Qualification.* Paper presented at the Offshore Technology Conference.

Mavrokefalidis, D. (2021). Europe urged to ban landfilling wind turbine blades by 2025. Retrieved from

Son, E., Lee, S., Hwang, B., & Lee, S. (2014). Characteristics of turbine spacing in a wind farm using an optimal design process. *Renewable Energy, 65*, 245-249. doi:10.1016/j.renene.2013.09.022

Sourmehi, C. (2021). EIA projects nearly 50% increase in world energy use by 2050, led by growth in renewables. Retrieved from

Speight, J. G. (2011). 2 - Production, properties and environmental impact of hydrocarbon fuel conversion. In M. R. Khan (Ed.), *Advances in Clean Hydrocarbon Fuel Processing* (pp. 54-82): Woodhead Publishing.

Topham, E., Gonzalez, E., McMillan, D., & João, E. (2019). Challenges of decommissioning offshore wind farms: Overview of the European experience. *Journal of Physics: Conference Series, 1222*(1), 012035. doi:10.1088/1742-6596/1222/1/012035

Tran, V. L., & Im, N. (2012). A study on ship automatic berthing with assistance of auxiliary devices. *International Journal of Naval Architecture and Ocean Engineering, 4*(3), 199-210. doi:

Windcarrier, F. O. (2019). Specifications: Jack-up installation vessels Brave Tern and Bold Tern. In F. O. Windcarrier (Ed.).

Windcarrier, F. O. (2019). Specifications: Jackup vessel Jill. In F. O. Windcarrier (Ed.).

Yang, W., Tian, W., Hvalbye, O., Peng, Z., Wei, K., & Tian, X. (2019). Experimental Research for Stabilizing Offshore Floating Wind Turbines. *Energies, 12*(10), 1947. Retrieved from

Goedkoop, M. G., Heijungs, R. H., Huijbregts, M. H., Schryver, A. D. S., Struijs, J. S., & Zelm, R. V. Z. (2008). *ReCiPe 2008: a life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint levels* (No. 1). Ruimte en Milieu. https://www.leidenuniv.nl/cml/ssp/publications/recipe_characterisation.pdf

LCIA: the ReCiPe model | RIVM. Rivm.nl. (2020). Retrieved 24 June 2020, from https://www.rivm.nl/en/life-cycle-assessment-lca/recipe.

Ocean Wind LLC. (2019). Ocean wind application for offshore wind renewable energy certificates. https://www.bpu.state.nj.us/bpu/pdf/boardorders/2019/20190621/6-21-19-8D%20-%20Ørsted%20Public%20OREC%20Application.pdf

https://www.eia.gov/energyexplained/use-of-energy/electricity-use-in-homes.php

El Mokhi, C., & Addaim, A. (2020). Optimization of Wind Turbine Interconnections in an Offshore Wind Farm Using Metaheuristic Algorithms. *Sustainability, 12*(14), 5761. Retrieved from https://www.mdpi.com/2071-1050/12/14/5761

Goedkoop, M., et al (2009) ReCiPe 2008: A life cycle impact assessment method which comprises harmonized category indicators at the midpoint and endpoint levels. First edition.
Report i: Characterization. The Netherlands.

Ashuri, T. (2012). *Beyond Classical Upscaling.* Retrieved from http://resolver.tudelft.nl/uuid:d10726c1-693c-408e-8505-dfca1810a59a

World's Most Powerful Offshore Wind Platform: Haliade-X | GE Renewable Energy. (2021). Retrieved July 2021, from https://www.ge.com/renewableenergy/wind-energy/offshore-wind/haliade-x-offshore-turbine

DONG Energy (2008). Life cycle approaches to assess emerging energy technologies-Final report on offshore wind technology. Report by European Commission

How Hywind works. (2017). Retrieved 21 July 2021, from https://www.equinor.com/en/what-we-do/floating-wind/how-hywind-works.html

2015. *Offshore substation of the Nordsee One wind park*. [online] Available at: <https://www.nordseeone.com/engineering-construction/offshore-substation.html> [Accessed April 2020].

Bauer, L., n.d. *GE General Electric Haliade-X 12 MW - 12,00 MW - Wind turbine*. [online] En.wind-turbine-models.com. Available at: <https://en.wind-turbine-models.com/turbines/1809-ge-general-electric-haliade-x-12-mw>.

Heronemus, W. E. “Pollution-Free Energy From Offshore Winds”, 8th Annual Conference and Exposition Marine Technology Society, Washington D.C., September 11-13, 1972

U.S. Energy Information Administration (EIA). (2021). Retrieved 8 December 2021, from https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

Wind energy in Europe 2020 Statistics and the outlook for 2021-2025 | WindEurope. (2021). Retrieved 9 December 2021, from https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-in-2020-trends-and-statistics/

Moore, C., Brown, S., Alparslan, U., Cremona, E., & Alster, G. (2021). European Electricity Review. Retrieved 8 December 2021, from https://ember-climate.org/wp-content/uploads/2021/07/European-Electricity-Review-H1-2021.pdf

ARADEX AG. 2021. *Gearbox vs. direct drive: a comparison - ARADEX AG*. [online] Available at: <https://www.aradex.de/en/gearbox-vs-direct-drive-a-comparison/>.

Kummer, F. (2021). With offshore wind, New Jersey could be launching its biggest job creator ‘since the casinos’. Retrieved 11 April 2021, from https://www.inquirer.com/science/climate/new-jersey-offshore-wind-20210320.html

# Chapter 3: Energy tourism in New Jersey: multinomial regression analysis of tourist hotel view preference

## Introduction

In recent years, energy tourism has gained attention in the academic world. Although, a relatively unexplored topic in academia, it has been popular in what is called grey literature for some time now. Magazines and tourist boards have worked relentlessly to cover this topic mostly in European countries. Currently, German tour guidebooks contain about 200 green energy sites spread all over the country as tourist attractions. While Czech Republic offers coal safaris, where visitors are allowed to visit open mining pits and understand the processes involved with coal mines (Inmost, 2015). In US, there are several energy tourism sites as well, with guided and unguided tours to abandoned coal mines, solar and wind farms, and hydropower dams. In fact, the disaster site of Chernobyl has also been converted to a tourist attraction, with 60,000 visitors in 2018 (Weisberger, 2019). The unexpected popularity of this concept has led to a wider, more specific interest in energy tourism.

Although it is gaining a lot of interest, energy tourism lacks an unanimously agreed-upon definition. It is described as part of a segment of industrial tourism (Otgaar, 2012), as well as part of the cultural and heritage tourism (Frew, 2008). However, Frantál and Urbánková (2017) describe it as tourism that overlaps at least 3 tourism, industrial, cultural and heritage, and adventure tourism. While industrial tourism is described best for operational industrial sites where operation runs as usual and tourists are allowed to visit a specific portion of the site, energy tourism is where the visitors have specific services, and activities provided specifically for them. Although not true for all cultures, some cultures are deeply invested with events or activities which are energy related, such a coal mining or the ancient water wheel. Lastly, the overlap between energy tourism and adventure tourism is rather small. Diving from top of the wind turbines has been gaining interest in Germany and UK (Nabiyeva, 2014). Furthermore, energy tourism overlaps agriculture and rural tourism as it does industrial tourism. Most onshore wind farms are built in rural or remote areas, building tourist infrastructure such as roads as a result. The availability for such has been linked to an increase in tourism activity in rural or agricultural areas by Beer et al., (2018). Hence, in general, energy tourism can be described as any tourist activity relating, in one way or other, to energy.

Energy tourism is not only limited to providing consumer experience, but also of importance to vendors and the state as well. While acting as the source of income to many, from working in tourism related places such as restaurants, visitor centres, and hotels (Beer et al. 2018).

In the last decade, there has been a tremendous increase in tourism globally. Total contribution of global tourism increased from 7,444 billion USD in 2015 to 9,258 billion USD, 5% increase according to the Travel & tourism: global economic impact (2020). While person-trips in US, both domestic and international, increased from $2,256 million to $2,396 million in 2018 to 2019 (US Travel Association, 2020). Considering this, it only stands to reason that energy tourism also increased both worldwide and in the US. One of the wind and solar energy centre, Wild horse, in Washington has seen an increase from 14,800 visitors to 20,000 in 2015 to 2019 (Beer et al. 2018; Erickson, 2019). Wild horse has been so successful in attracting visitors as it offers several tourist activities, such as hunting, birdwatching, hiking, and horse riding, along with the guided tours to both the wind and solar farms. On the other hand, a more thrilling tourist attraction, the disaster site of the Chernobyl incident, saw a rise from 8,000 visitors in 2013 to 65,000 in 2018 (Llewelyn, 2019). Although there is a gradual rise in energy tourism, it must be noted that clean energy sites doing fairly well are the one offering more than just a visit to the facility.

**Problem statement**

As part of the New Jersey Energy Master Plan, there will be a 1100MW offshore wind farm built 15 miles off the coast of Atlantic and Worcester counties. Given that two of the more popular tourist destinations in New Jersey are in these two counties, hosting over 27 million visitors a year, it is worth noting the energy tourism opportunity for this city. Ocean City is one of these popular cities with attractions for people of all ages, most focusing on family staycations and getaways.

Although wind turbines have been blamed for reduction in tourist activity in certain areas, it is not always the case. Frantál and Kunc (2011) noted that there is no significant negative impact from wind turbines, making it ideal for New Jersey to develop this coming project as a tourist attraction. They also found that offshore turbines 7.5 miles away have no impact on tourism. If the turbines are within 7.5 miles than as long as other recreational activities are offered, there is not significant impact on tourism. Similarly, Broekel & Alfken (2015) found that there is a weak negative impact on tourism due to wind turbines. However, they also mentioned that 66% of the participants in their survey wanted to visit the wind farm. Interestingly so, in the paper for sustainable tourism Jiricka et al., (2010) claim that offering other tourist activities along with energy power plant attractions will increase the during of visitors' stay. Since Ocean City is an already established tourist destination, surveying its visitors and residents about their preference of view can be easily implemented.

As such, this chapter will explore the respondent's choice for a view with or without the wind turbines from their hotel room. Hotel room preference is measured along with awareness of wind turbines and the impact of wind industry on wind industry and its impact on 1) Jobs 2) Clean energy 3) Scenic beauty 4) Energy security 5) Local tourism 6) Marine environment 7) Property values 8) Boat navigation and 8) Commercial boating.

## Methods

### Sample size

The sample size for this survey was 800. We received responses from 813 surveyors which was reduced to 805 after eliminating responses from the residents of states farther than 100 miles of Ocean City, NJ. States of Alaska, Arkansas, Oregon, and South Dakota were removed from the responses leaving the states of New Jersey, Pennsylvania, Delaware, Maryland and New York. The above-mentioned states were removed to reduce data skewness as only 1 (one) response each was recorded for these states.

Sample is representative of the population when compared to the US census data. Analysis of the samples shows that 51.4% of the population is female while 48.3% identifies as male. The rest 0.2% identify as neither. Census data shows that 50.8% of the population identifies as female. Table 14 shows the age distribution of the sample. Respondents from the age of 18 to 34 make up for most of the responses. The highest age reported is more than 74 years old at 92 years of age.

| **Age group** | | | | |
|---|---|---|---|---|
| | Frequency | Percent | Valid Percent | Cumulative Percent |
| 18 to 24 years old | 136 | 16.9 | 16.9 | 16.9 |
| 25 to 34 years old | 129 | 16.0 | 16.0 | 32.9 |
| 35 to 44 years old | 137 | 17.0 | 17.0 | 49.9 |
| 45 to 54 years old | 108 | 13.4 | 13.4 | 63.4 |
| 55 to 59 years old | 45 | 5.6 | 5.6 | 68.9 |
| 60 to 64 years old | 74 | 9.2 | 9.2 | 78.1 |
| 65 to 74 years old | 127 | 15.8 | 15.8 | 93.9 |
| less than 18 years old | 2 | .2 | .2 | 94.2 |
| more than 74 years old | 47 | 5.8 | 5.8 | 100.0 |
| Total | 805 | 100.0 | 100.0 | |

*Table 14: Age distribution of the sample*

There were 463 respondents from the state of New Jersey of which only 9.4% were the residents of Ocean City. The second highest respondents were from Pennsylvania at 308, followed by Delaware at 26, then Maryland and New York at 4 respondents each. 582 respondents have visited Ocean City at some point and 205 said it was their primary destination for recreation. 32 of the respondents stated that they visit Ocean City weekly while the highest frequency of visitation is once a month.

**Regression analysis**

Multinomial logistic regression (MLR) model was used in this chapter to analyze the results using SPSS Statistics. Multinomial logistic regression is an extension of binomial logistic regression and allows for more than two dependent variables. In this study there are two different dependent variables each of which have several choice options presented to the respondent. Each choice is treated as a variable in two regression analyses. The independent variable in regression analysis (1) is the awareness of offshore wind turbines (OSW) while the dependent variable is the type of preferred accommodation. The dependent variable has three choice options 1) accommodation without a view of OSW turbines 2) indifference to OSW turbines 3) accommodation with a view of OSW turbines. For regression analysis (2) the independent variable is the impact OSW turbines have on 1) Jobs 2) Clean energy 3) Scenic beauty 4) Energy security 5) Local tourism 6) Marine environment 7) Property values 8) Boat navigation and 8) Commercial boating. While the dependent variable is the same as regression analysis (1).

The MLR model works as it extends the binary model. Hence, let i denote the predictors for response variable j, and let $y_{ij}$ be the value of the response, the equation becomes as following:

$$p_{ijc} = P\left(y_{ij} = c \middle| \beta\right) = \frac{\exp\left(z_{ijc}\right)}{1 + \sum_{h=1}^{C} \exp\left(z_{ijh}\right)}$$

where c= 2,3,…,C and β is the conditional random effect. (El-Habil, 2012; Hedeker, 2003)

## Results and discussion

### (1) Regression analysis: preference of accommodation type vs awareness of wind turbines

Dependent: Which accommodation type would you prefer?

| | |
|---|---|
| One without a view of offshore wind turbines | 0 |
| I am indifferent regarding the view of offshore wind turbines | 1 |
| One with a view of the offshore wind turbines | 2 |

Independent: Before today, were you aware of OSW turbines?

| | |
|---|---|
| I have heard about them from people I know | 0 |
| I have heard or read about them in the news | 1 |
| I have seen them from a distance | 2 |
| I have seen them up close | 3 |
| They are visible from my home | 4 |
| Other | 5 |

The likelihood ratio test is used to describe the probability of both observed parameters. In our case the joined probability of respondent's preference of accommodation and their awareness of wind turbines gives us the significance of 0.002 which shows a good fit.

**Parameter estimates**

For analyses to run smoothly, a baseline needs to be described. The baseline is usually a neutral value that suggests the respondent is undecided or does not have an opinion of any of the options provided. For the dependent variable in this regression the value of 1 which represents indifference to the view of offshore wind turbines from the respondents' hotel room is chosen. For the independent variable the option of 'Other' with a value of 5 is selected. For accommodation type level 0, awareness of offshore wind farm level 2 is the most significant with a value of less than 0.001 representing a good fit, tables with all estimates are provided in the appendix. Moreover, awareness of offshore wind farm level 1 with a significance value of more than 0.01 and the coefficient value of 0.719, which is both positive and high, suggests that people who have heard about wind turbines from news or other media have a formed opinion of not wanting a view of the turbines. For accommodation type level 2, awareness of offshore wind farm level 3 has the most significance and the highest relation from the B coefficient. It suggests that respondents who have seen the turbines up close have a preference of a view with an offshore wind farm. While awareness level 0 has a very strong positive coefficient there is a possibility of a halo effect regarding clean energy in this response. Since level 0 represents that the respondents have heard from other people about wind turbines rather than having seen them themselves, there is a chance of a bias, and a possibility of a change in response once the respondent has seen it up close. Nevertheless, it is not apparent from this regression.

**(2) Regression analysis: preference of accommodation type vs attributes**

Dependent: Which accommodation type would you prefer?

| | |
|---|---|
| One without a view of offshore wind turbines | 0 |
| I am indifferent regarding the view of offshore wind turbines | 1 |
| One with a view of the offshore wind turbines | 2 |

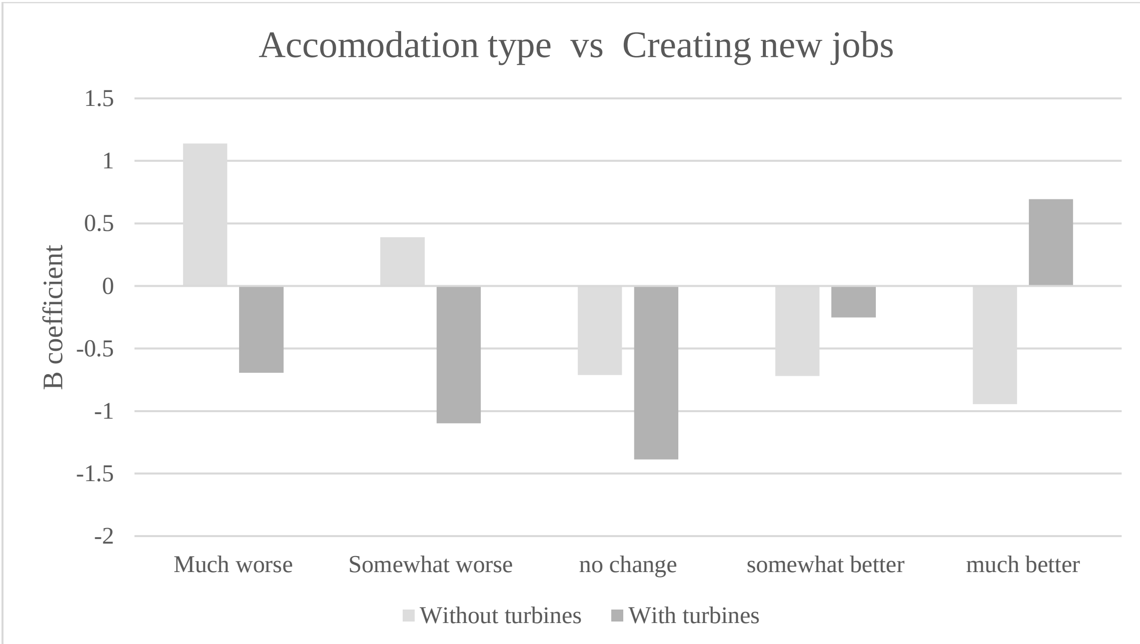
Independent: In your opinion, what impact will offshore wind farms 15 miles from Ocean City (New Jersey) have on the following?

| | |
|---|---|
| Much worse | 0 |
| Somewhat worse | 1 |
| no change | 2 |
| somewhat better | 3 |
| much better | 4 |

For this regression the likelihood ratio test shows the joined possibility of the opinion of respondents regarding wind farms and their preference to accommodation's view of the turbines. The test shows a good fit with the Chi-square value of 337.701 and significance of less than 0.001.

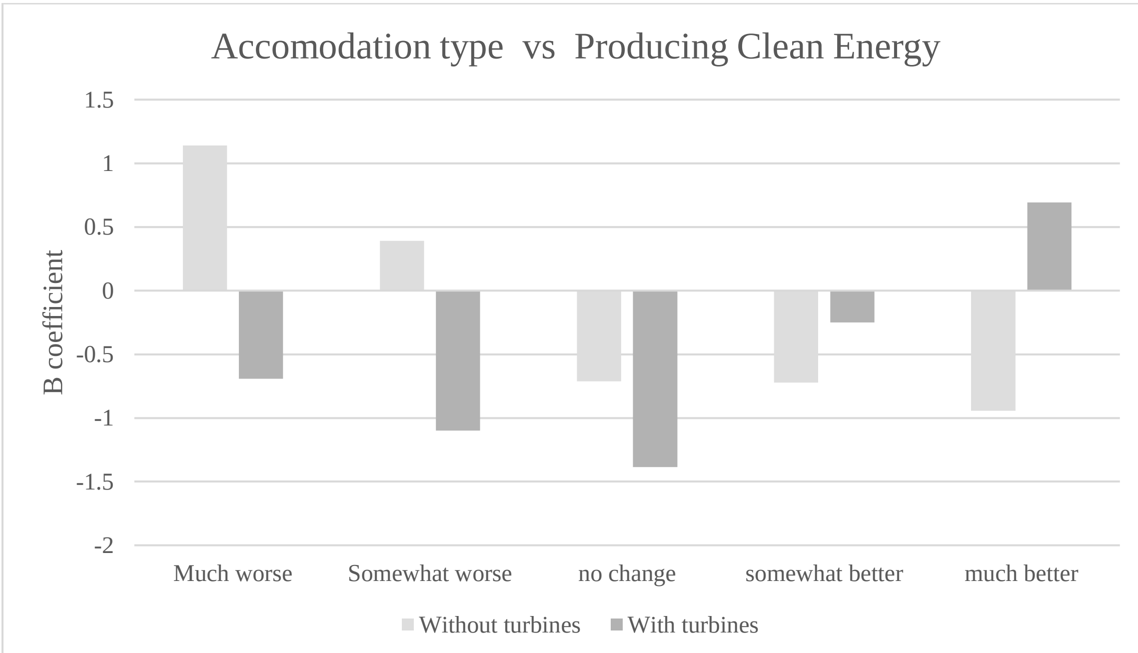
**Parameter estimates**

All parameters estimate tables are provided in the appendix.




From the regression analysis, level 1 for the option of wind turbines ‘creating job’ represents ‘much worse’. This option has the coefficient both positive and significant 1.194 and <0.001, respectively, suggesting that respondents who do not believe that wind industry is capable of promoting more jobs than other industries are more likely to change their preference to indifference in hotel room view. Similarly for level 3 and 4 of the same option which represents ‘somewhat better’ and ‘much better’, respectively, in regard to the creation of jobs due to the construction of wind farm is negative -.665, -1.160 and very significant <0.001, strongly suggests that respondents are less likely to change their preference to indifference. Hence participants that believe that wind industry will not create jobs are more likely to stay in accommodations without a view of the turbines.

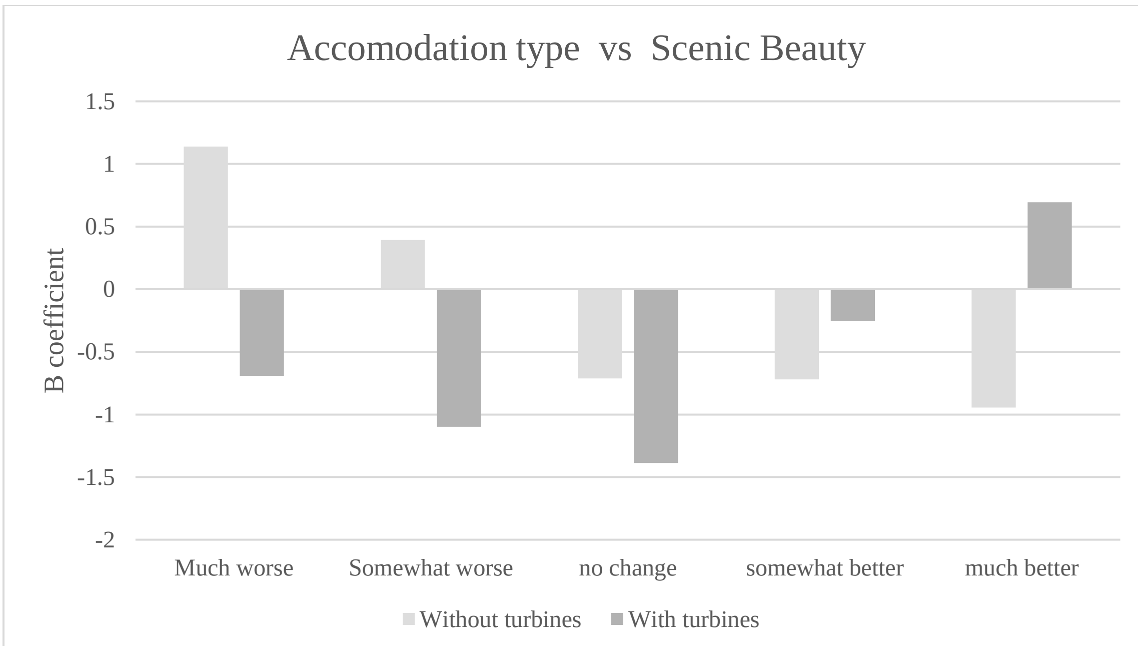
Furthermore, for accommodation type level 2 which represents respondents who do want to stay in rooms with a view of wind turbines, Creating Jobs (2) and (3) show negative and significant results at -.847 and -1.110 logit coefficient while the significance for both is less than 0.001. this suggests that respondents who believe that wind industry will have no change on job opportunities (2) or make it somewhat better (3) are less likely to change their hotel room preference from rooms with a view of turbines to indifference.



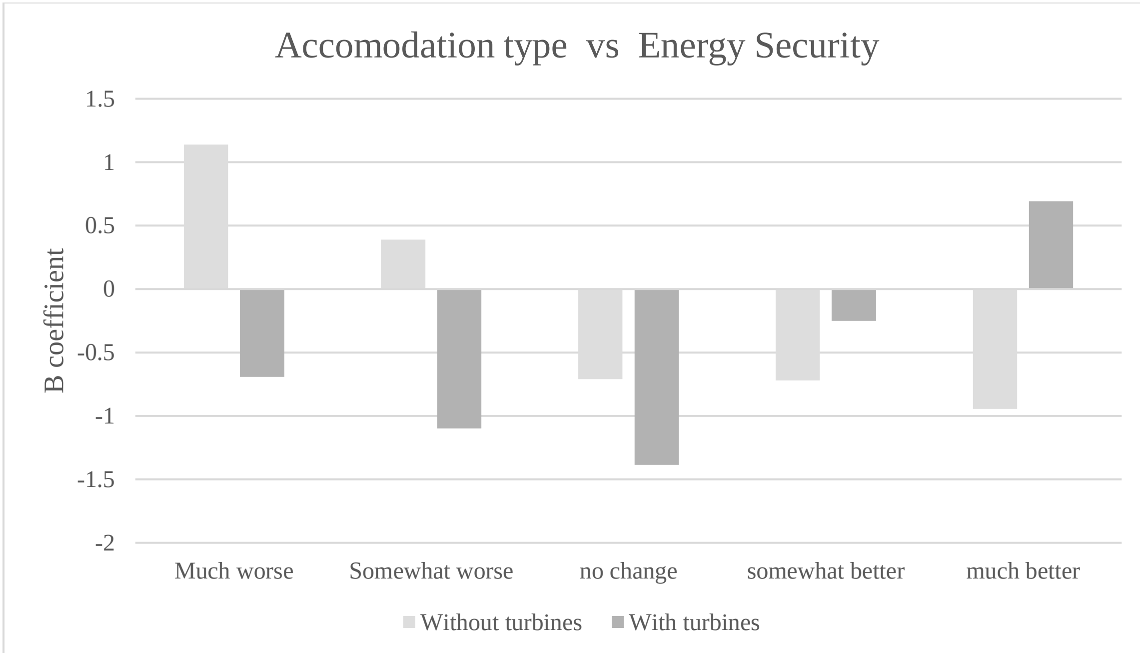

For the option of Producing Clean Energy (1) representing 'much worse' there is a positive and significant relationship of 1.288 and 0.001 respectively. This suggests that respondents who do not believe that wind farms are capable of producing cleaner energy than other technologies are more likely to change their preference of hotel room view to indifference. Similarly, Producing Clean Energy (3) and (4) are negative and significant at -.344, 0.010 and -1.196, <.001 respectively. Both these results suggest that respondents are less likely to change their hotel room preference to indifference. This finding is important as it suggests there is no 'halo effect' in this subject group and their preference does not change with clean energy production.

Moreover, for level 2 of accommodation type, Producing Clean Energy (2), (3) and (4) of the independent variable are negative and significant with logit coefficients at -.504, -.872, and

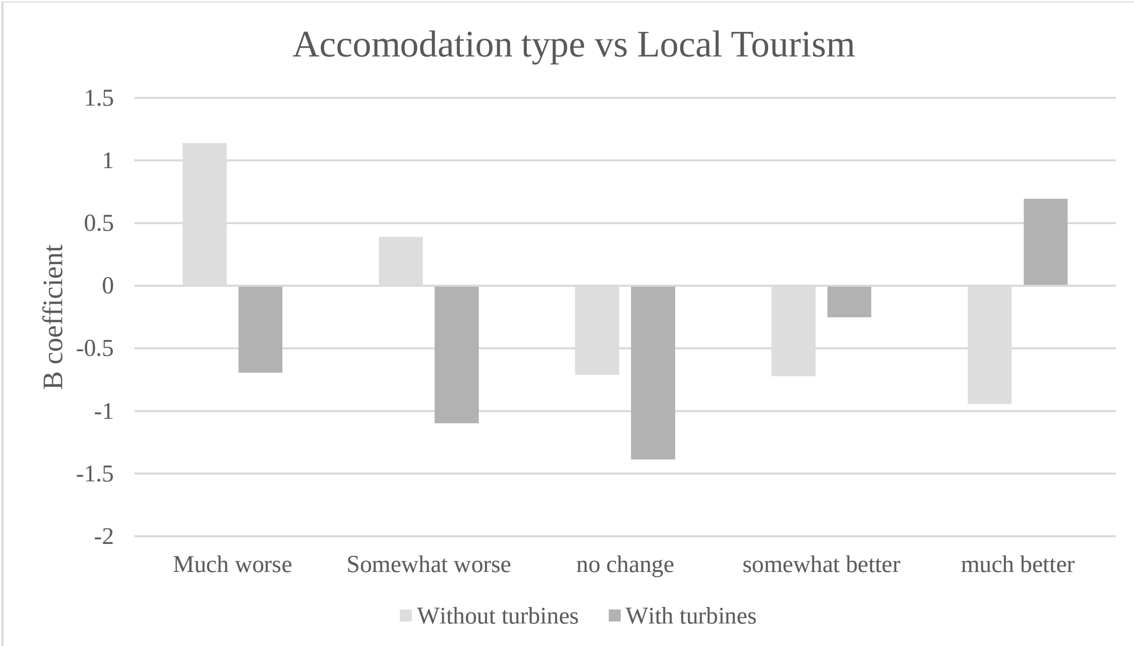
-.913. The results suggest that respondents with either preference for accommodation type do not consider wind industry to be capable of producing clean energy. These results suggest that respondents are less likely to change their preference of hotel room to indifference if they believe wind power is capable of producing clean energy. It also shows that clean energy holds value to them.



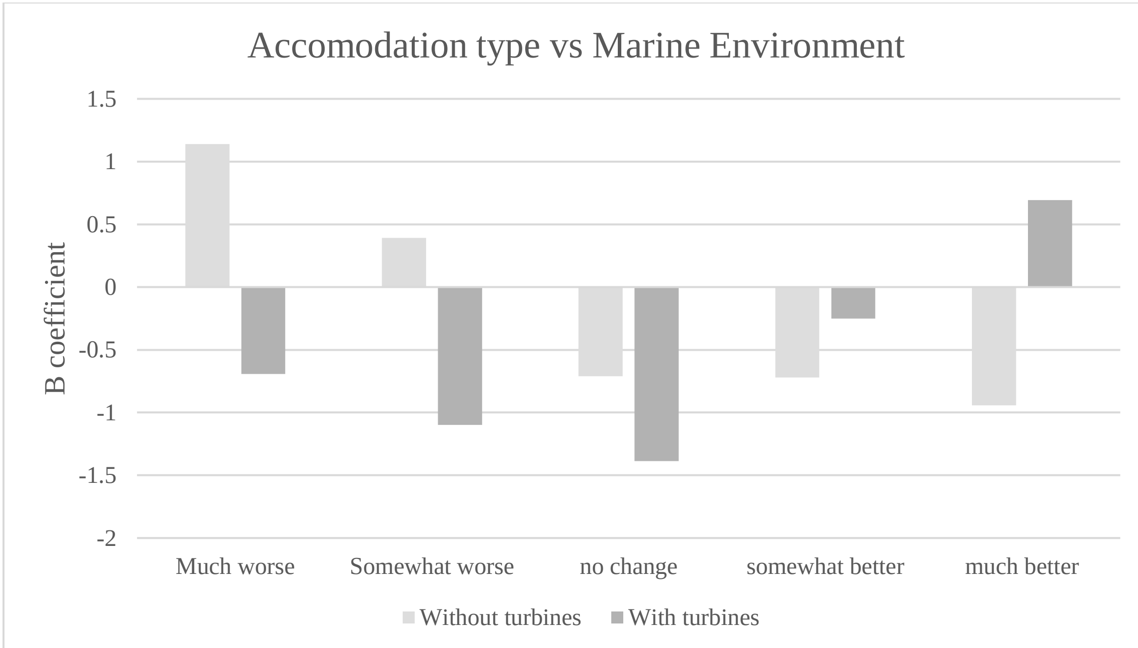

For Scenic Beauty (2), (3), and (4) results are significant, and the logit coefficient is negative with a value of -.840, -.822, and -1.099 respectively. These findings suggest that respondents are less likely to change their preference to indifference from wanting a room without a view of the turbines if they consider wind turbines to add to the scenic beauty of the surroundings. This suggests that their responses are not impacted by the visual appeal of wind turbines. On the other hand, for dependant variable Accommodation Type (2), Scenic Beauty (1), (2), and (4) are significant. (1) and (2) are negative -2.264 and -1.359 respectively. These findings suggest that respondents are less likely to change their hotel room view preference from one with a view of the turbines to indifference if they believe that wind turbines will negatively impact or have no impact on the scenic beauty of the surroundings. While (4) is positive .644 and suggests that respondents are more likely to change their preference to indifference if they believe that wind turbine will positively impact the image of the surroundings.



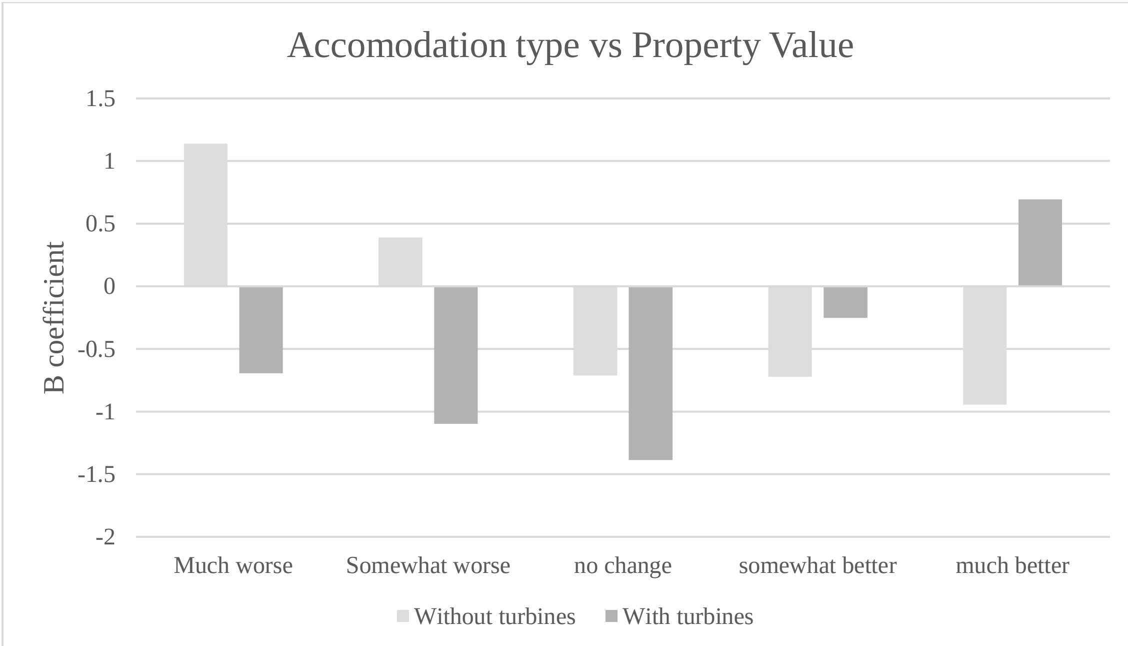

Energy Security (1), (3), and (4) are significant with logit coefficients of 1.417, -.502, and -1.224 respectively for Accommodation type (0). (1) is positive, suggesting that respondents who believe that wind power could make energy security somewhat worse compared to other energy technologies are more likely to change their preference of hotels rooms without wind turbines to indifference. Further, for (3) and (4) the logit coefficient is negative and high suggesting that respondents are less likely to change their preference to indifference if they think wind power could make energy security somewhat better or better. This also suggests that energy security does not impact their preference of hotel room. Conversely, for Accommodation type (2), Energy Security (2), (3), and (4) are significant with coefficients of -.989, -1.017, -.620, respectively. These coefficients are negative and high suggesting that respondents who consider wind turbines to be able to allow for energy security are less likely to change their preference from a hotel view with turbines to indifference.



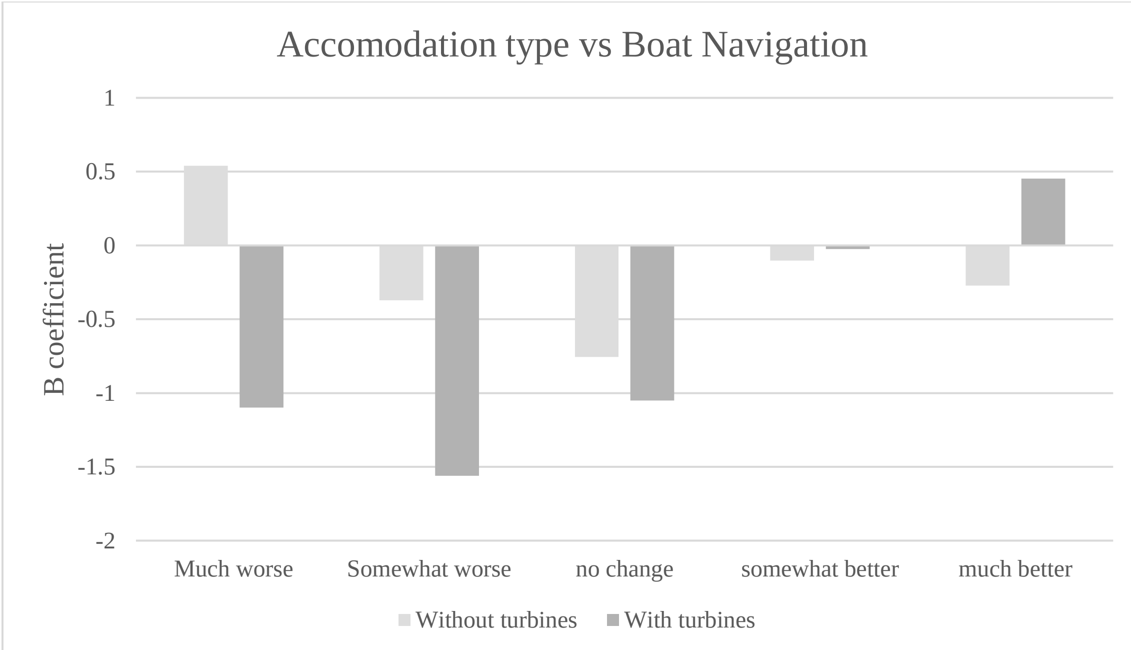

For Accommodation Type (0), Local Tourism (1), (2), and (3) are significant. (1) is positive with a logit coefficient of .934, suggesting that respondents are more likely to change their preference of hotel rooms without a view of the turbines if they believe that wind turbines will negatively affect the local tourism. However, (2) and (3) are negative and significant suggesting that respondents are less likely to change their preference to indifference if they believe that wind turbines will have no affect or will positively affect the local tourism. On the other hand, for Accommodation Type (2), Local Tourism (1), (2), and (4) are significant. (1) and (2) are negative with logit coefficients of -1.705 and -1.600, respectively. This implies that respondents who believe that local tourism will be negatively affected or not affected by the wind turbines are less likely to change their preference of hotel room views to indifference. However, (4) is positive with a logit coefficient of .616, implying that respondents are more likely to change their preference to indifference if they believe that local tourism will be greatly and positively affected by the offshore wind turbines.



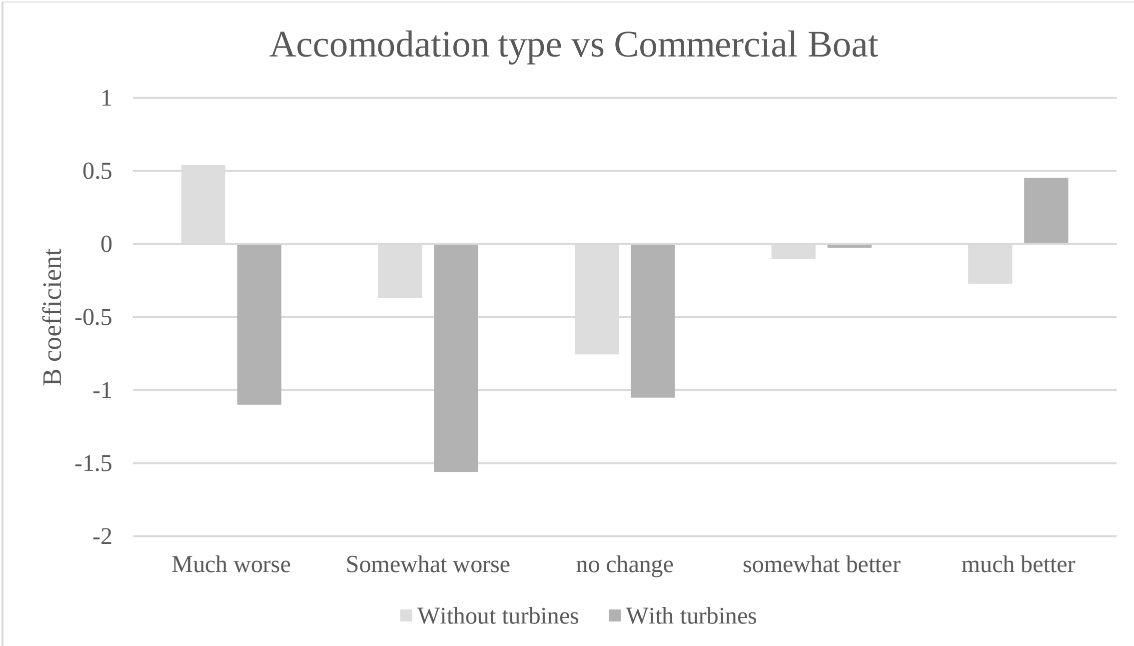

In the case of Marine Environment, (2), and (3) are significant for Accommodation Type (0). Both of the levels produce negative logit coefficients which signify respondents who believe that marine environmental will either have no change or be positively affected by offshore, as compared to other disturbances, wind turbines less likely to change their preference to indifference. While for Accommodation Type (2), Marine Environment (1), (2), and (3) levels are significant and negative. These findings suggest that respondents who believe that marine environments will be negatively impacted by offshore wind turbines are less likely to change their preference to indifference. However, level (3) suggests that respondents who believe that marine environments will be positively impacted by offshore wind turbines are less likely to change their preference to indifference too. Which suggests that marine environment do not impact the decision-making process of the respondents.




Moving on to Property Values, (0), (2), and (3) are significant for Accommodation Type (0). Level (0) is positive suggesting that respondents who believe that property values will be greatly negatively impacted by the introduction of wind turbines are more likely to change their preference to indifference. While (2) and (3) have a negative logit coefficient suggesting that people who believe that property values will have no change or will be somewhat positively impacted by the introduction of wind turbines are less likely to change their preference to indifference. On the other hand, Accommodation Type (1), produces significant results with Property Value (1) and (2). Both the levels have negative logit coefficients which suggests that respondents who think that property value will be adversely affected by wind turbines are less likely to change their preference of hotel room with a view of the turbines to indifference.




Next, Boat Nav (1) and (2) are significant with negative logit coefficients of -.370 and -.585, respectively. These findings suggest that respondents who believe that boat navigation will be negatively impacted or not impacted at all by the introduction of wind turbines are less likely to switch to indifference from their preference of a hotel room with no turbines. Similarly, for Accommodation Type (1), Boat Nav (1) and (2) are significant and negative with the logit coefficient of -1.504 and -.845, respectively. These findings suggest that respondents who believe that boat navigation will be negatively impacted or not impacted at all are less likely to switch their preference of a room with wind turbines to indifference.




Finally, Commercial Boat (1) and (2) are significant and negative with a logit coefficient of -.371 and -.755, respectively. These findings suggest that respondents who believe that Commercial boating will be negatively impacted or not impacted at all are less likely to change their preference of room without a view of wind turbines to indifference. On the other hand. For Accommodation Type (2), Commercial Boat (1) and (2) are negative and significant as well with a logit coefficient of -1.561 and -1.051, respectively. This suggests that respondents who believe that Commercial boating will be negatively impacted or not impacted at all are less likely to change their preference to indifference.

**Conclusion**

In this chapter the author surveys visitors and residents of Ocean City, New Jersey, to understand their preference of hotel view. The respondents are given 3 choices: room with a view of offshore wind turbines, room without a view of the offshore wind turbines, and indifference to either view. 'indifference' was used as the baseline for the analysis presented.

The results pointed out several important factors. Variables that affected the likelihood of change from without a view of offshore wind turbines to indifference for awareness as the dependent variable are when respondents have heard about turbines from other people, have seen them from a distance or seen them up close. This implies that respondents are more likely to want a room with a view of the turbines if they are visually exposed to it, while hearing about it from friends or family could be a 'halo effect'. To ensure growth of tourism in the area of the study as well as to make visitors and residents of Ocean City to be comfortable with wind turbines, visual exposure is necessary. On the other hand, respondents who have heard of turbines from their family and friends are more likely to change their preference to difference from wanting a room with a view. Which is mostly due to acquiescence bias and can be corrected with awareness and exposure.

Furthermore, Variables that affected the likelihood of change for the regression analysis with other attributes are creating jobs, producing clean energy, energy security, scenic beauty, marine environment, local tourism, property values. Out of these, for creating jobs, producing clean energy, energy security, local tourism, property values, respondents are more likely to change their preference to indifference if they believe these attributes of wind turbines are harming them or the environment. While respondents who believe that creating jobs, producing clean energy, energy security, marine environment will be positively affected by the wind turbines, they are more likely to stay with their preference.

The important take away from this analysis is that respondents will likely change to indifference if they are made more aware of the success of wind turbines in all the above-mentioned attributes. While for those who will stay their preference it is essential that positive impact of the attributes: creating jobs, producing clean energy, energy security, marine environment, are continuously seen and shown to the general public.

## References

Beer, M., Rybár, R., & Kaľavský, M. (2017). Renewable energy sources as an attractive element of industrial tourism. Current Issues In Tourism, 21(18), 2147-2159. https://doi.org/10.1080/13683500.2017.1316971

Board of Public Utilities. (2019). 2019 New Jersey Energy Master Plan pathway to 2050. Retrieved from http://d31hzlhk6di2h5.cloudfront.net/20200127/84/84/03/b2/2293766d081ff4a3cd8e60aa/NJBPU_EMP.pdf

Broekel, T., & Alfken, C. (2015). Gone with the wind? The impact of wind turbines on tourism demand. Energy Policy, 86, 506-519. https://doi.org/10.1016/j.enpol.2015.08.005

El-Habil, A. M. (2012). "An Application on Multinomial Logistic Regression Model." Pakistan Journal of Statistics & Operation Research **8**(2): 271-291.

Erickson, A. (2019). Wild Horse Wind Facility generates clean energy and visitor curiosity. King 5 Evening. Retrieved 20 August 2020, from https://www.king5.com/article/entertainment/television/programs/evening/wild-horse-wind-facility-generates-clean-energy-and-visitor-curiosity/281-428072153.

Franta´l, B. & Kunc, J. (2011). Wind turbines in tourism landscapes: Czech Experience. Annals of Tourism Research, 38(2), 499–519.

Frantál, B., & Urbánková, R. (2014). Energy tourism: An emerging field of study. Current Issues In Tourism, 20(13), 1395-1412. https://doi.org/10.1080/13683500.2014.987734

Frew, E. A., & Shaw, R. N. (1995, February). Industrial tourism: The experience and the motivation to visit. In R. N. Shaw (Ed.), CAUTHE 1995: Proceedings of the national tourism and hospitality conference (pp. 88–104). Canberra: Bureau of Tourism Research. Retrieved from http://search.informit.com.au/documentSummary;dn¼619442738712611;res¼IELBUS

Hedeker, D. (2003). "A mixed-effects multinomial logistic regression model." Statistics in Medicine **22**(9): 1433-1446.

Inmost, J. (2015). Czech coal safari offers excavators instead of giraffes - USA - Chinadaily.com.cn. Global.chinadaily.com.cn. Retrieved 14 July 2020, from http://global.chinadaily.com.cn/a/201509/17/WS5a30b0a0a3108bc8c672d9a0.html.

Jiricka, A., Salak, B., Eder, R., Arnberger, A., & Pröbstl, U. (2010). Energetic tourism: exploring the experience quality of renewable energies as a new sustainable tourism market. Sustainable Tourism IV. https://doi.org/10.2495/st100061

Kahan, A. (2019). EIA projects nearly 50% increase in world energy usage by 2050, led by growth in Asia. Eia.gov. Retrieved 21 August 2020, from https://www.eia.gov/todayinenergy/detail.php?id=41433#:~:text=Worldwide%20renewable%20energy%20consumption%20increases,growth%20in%20natural%20gas%20consumption.

Kahneman, D., & Knetsch, J. L. (1992). Valuing public goods: The purchase of moral satisfaction. Journal of Environmental Economics and Management, 22(1), 57-70. doi:https://doi.org/10.1016/0095-0696(92)90019-S

Llewelyn, A. (2019). Chernobyl: The incredible number of tourists that visit nuclear disaster site revealed. Express.co.uk. Retrieved 19 August 2020, from https://www.express.co.uk/news/world/1148593/chernobyl-nuclear-disaster-tourism-tourist-ukraine-hbo-drama-series-sky-atlantic-spt.

Nabiyeva, K. (2014). Renewables as Tourist Attractions? Only in Germany. Climatecentral.org. Retrieved 2 August 2020, from https://www.climatecentral.org/news/renewable-energy-as-tourist-attractions-in-germany-17558.

Sousa, A. J. G., & Kastenholz, E. (2015). Wind farms and the rural tourism experience – problem or possible productive integration? The views of visitors and residents of a Portuguese village. Journal of Sustainable Tourism, 23(8–9), 1236–1256. Retrieved from https://doi.org/10.1080/09669582.2015.1008499

US Travel Association. (2020). U.S. Travel and Tourism Overview (2019) [Fact sheet]. U.S Travel.https://www.ustravel.org/system/files/media_root/document/Research_Fact-Sheet_US-Travel-and-Tourism-Overview.pdf

Weisberger, M. (2019). Is It Safe to Visit Chernobyl?. livescience.com. Retrieved 19 August 2020, from https://www.livescience.com/65673-is-visiting-chernobyl-safe.html.

## Appendix i

| Dataset | Citation |
|---|---|
| **Rotor** | **Production** |
| | Glass fibre {GLO}\| market for \| APOS, U |
| | Chemical, organic {GLO}\| market for \| APOS, U |
| | Epoxy resin, liquid {RoW}\| market for epoxy resin, liquid \| APOS, U |
| | Polyvinylchloride, bulk polymerised {GLO}\| market for \| APOS, U |
| | Nylon 6-6, glass-filled {RoW}\| market for nylon 6-6, glass-filled \| APOS, U |
| | Aluminium, wrought alloy {GLO}\| market for \| APOS, U |
| | Synthetic rubber {GLO}\| market for \| APOS, U |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| | Cast iron {GLO}\| market for \| APOS, U |
| | Copper {GLO}\| market for \| APOS, U |
| | **End of life** |
| | Inert waste {RoW}\| treatment of, sanitary landfill \| APOS, U |
| | Waste rubber, unspecified {RoW}\| treatment of, municipal incineration \| APOS, U |
| | Recycling steel and iron avoided burden |
| | Scrap steel {RoW}\| treatment of, inert material landfill \| APOS, U |
| | Recycling non-ferro |
| **Nacelle** | **Production** |
| | Reinforcing steel {GLO}\| market for \| APOS, U |
| | Aluminium, wrought alloy {GLO}\| market for \| APOS, U |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |

| | |
|---|---|
| | Cast iron {GLO}\| market for \| APOS, U |
| | Acrylonitrile-butadiene-styrene copolymer {GLO}\| market for \| APOS, U |
| | Polyvinylchloride, bulk polymerised {GLO}\| market for \| APOS, U |
| | Epoxy resin, liquid {GLO}\| market for \| APOS, U |
| | Glass fibre {GLO}\| market for \| APOS, U |
| | Zinc {GLO}\| market for \| APOS, U |
| | Nylon 6-6, glass-filled {RoW}\| market for nylon 6-6, glass-filled \| APOS, U |
| | Synthetic rubber {GLO}\| market for \| APOS, U |
| | Polyethylene, high density, granulate {GLO}\| market for \| APOS, U |
| | Polycarbonate {GLO}\| market for \| APOS, U |
| | Polyethylene terephthalate, granulate, amorphous {GLO}\| market for \| APOS, U |
| | Lubricating oil {RoW}\| market for lubricating oil \| APOS, U |
| | **End of life** |
| | Recycling steel and iron avoided burden |
| | Scrap steel {RoW}\| treatment of, inert material landfill \| APOS, U |
| | Recycling aluminium |
| | Waste rubber, unspecified {RoW}\| treatment of, municipal incineration \| APOS, U |
| | Waste polyvinylchloride {RoW}\| treatment of waste polyvinylchloride, municipal incineration \| APOS, U |
| | Inert waste {RoW}\| treatment of, sanitary landfill \| APOS, U |
| | Recycling zinc |
| **Tower** | **Production** |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| | Steel, unalloyed {GLO}\| market for \| APOS, U |
| | Steel, unalloyed {GLO}\| market for \| APOS, U |

| | |
|---|---|
| | Copper {GLO}\| market for \| APOS, U |
| | Welding, arc, steel {GLO}\| market for \| APOS, U |
| | Powder coat, steel {GLO}\| market for \| APOS, U |
| | Polyvinylchloride, bulk polymerised {GLO}\| market for \| APOS, U |
| | Alkyd resin, long oil, without solvent, in 70% white spirit solution state {RoW}\| market for alkyd resin, long oil, without solvent, in 70% white spirit solution state \| APOS, U |
| | **End of life** |
| | Recycling steel and iron avoided burden |
| | Recycling aluminium |
| | Recycling non-ferro |
| | Waste polyvinylchloride {RoW}\| treatment of waste polyvinylchloride, sanitary landfill \| APOS, U |
| | Waste plastic, mixture {GLO}\| treatment of waste plastic, mixture, unsanitary landfill, dry infiltration class (100mm) \| APOS, S |
| | Scrap steel {CH}\| treatment of, inert material landfill \| APOS, U |
| **Fixed foundation** | **Production** |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| | Steel, unalloyed {GLO}\| market for \| APOS, U |
| | Aluminium, wrought alloy {GLO}\| market for \| APOS, U |
| | Copper {GLO}\| market for \| APOS, U |
| | Lead {GLO}\| market for \| APOS, U |
| | Alkyd resin, long oil, without solvent, in 70% white spirit solution state {RoW}\| market for alkyd resin, long oil, without solvent, in 70% white spirit solution state \| APOS, U |
| | Tap water {RoW}\| market for \| APOS, U |
| | Concrete, normal {RoW}\| market for \| APOS, U |
| | Gravel, crushed {RoW}\| market for gravel, crushed \| APOS, U |

| | |
|---|---|
| | Electricity, medium voltage {US}\| market group for \| APOS, U |
| | Heat, district or industrial, natural gas {GLO}\| market group for \| APOS, U |
| **Floating foundation** | **Production** |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| | Steel, unalloyed {GLO}\| market for \| APOS, U |
| | Aluminium, wrought alloy {GLO}\| market for \| APOS, U |
| | Copper {GLO}\| market for \| APOS, U |
| | Lead {GLO}\| market for \| APOS, U |
| | Alkyd resin, long oil, without solvent, in 70% white spirit solution state {RoW}\| market for alkyd resin, long oil, without solvent, in 70% white spirit solution state \| APOS, U |
| | Tap water {RoW}\| market for \| APOS, U |
| | Electricity, medium voltage {US}\| market group for \| APOS, U |
| | Heat, district or industrial, natural gas {GLO}\| market group for \| APOS, U |
| **Cables 150kV** | **Production** |
| | Copper {GLO}\| market for \| APOS, U |
| | Polyethylene, high density, granulate, recycled {US}\| market for polyethylene, high density, granulate, recycled \| APOS, U |
| | Zinc coat, pieces {GLO}\| market for \| APOS, U |
| | Reinforcing steel {GLO}\| market for \| APOS, U |
| | Lead {GLO}\| market for \| APOS, U |
| **Cables 32kV** | **Production** |
| | Copper {GLO}\| market for \| APOS, U |
| | Polyethylene, high density, granulate, recycled {US}\| market for polyethylene, high density, granulate, recycled \| APOS, U |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| | Lead {GLO}\| market for \| APOS, U |
| **Cable Station** | **Production** |
| | Copper {GLO}\| market for \| APOS, U |

| | |
|---|---|
| | Aluminium, wrought alloy {GLO}\| market for \| APOS, U |
| | Zinc coat, pieces {GLO}\| market for \| APOS, U |
| | Ceramic tile {GLO}\| market for \| APOS, U |
| | Sulfur hexafluoride, liquid {RoW}\| market for sulfur hexafluoride, liquid \| APOS, U |
| | Cast iron {GLO}\| market for \| APOS, U |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| | Lubricating oil {GLO}\| market for \| APOS, U |
| **Cable Station** | **Production** |
| | Reinforcing steel {GLO}\| market for \| APOS, U |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| | Aluminium, wrought alloy {GLO}\| market for \| APOS, U |
| | Concrete, normal, at plant/US* US-EI U |
| | Reinforcing steel {GLO}\| market for \| APOS, U |
| | Zinc coat, pieces {GLO}\| market for \| APOS, U |
| | Copper {GLO}\| market for \| APOS, U |
| | Cast iron {GLO}\| market for \| APOS, U |
| | Polyethylene, high density, granulate, recycled {US}\| market for polyethylene, high density, granulate, recycled \| APOS, U |
| | Epoxy resin, liquid {GLO}\| market for \| APOS, U |
| | Alkyd resin, long oil, without solvent, in 70% white spirit solution state {RoW}\| market for alkyd resin, long oil, without solvent, in 70% white spirit solution state \| APOS, U |
| | Sulfur hexafluoride, liquid {RoW}\| market for sulfur hexafluoride, liquid \| APOS, U |
| | Lubricating oil {RoW}\| market for lubricating oil \| APOS, U |
| | Stone wool {GLO}\| market for stone wool \| APOS, U |
| **Transportation** | |
| Jack up vessel | Diesel, at regional storage/US-US-EI U |
| Tugboat | Diesel, at regional storage/US-US-EI U |
| Dredger | Diesel, at regional storage/US-US-EI U |

| **Usage** | |
|---|---|
| O&M | |
| | Lubricating oil {GLO}\| market for \| APOS, U |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| Nacelle replacement part | Reinforcing steel {GLO}\| market for \| APOS, U |
| | Aluminium, wrought alloy {GLO}\| market for \| APOS, U |
| | Steel, low-alloyed {GLO}\| market for \| APOS, U |
| | Cast iron {GLO}\| market for \| APOS, U |
| | Acrylonitrile-butadiene-styrene copolymer {GLO}\| market for \| APOS, U |
| | Polyvinylchloride, bulk polymerised {GLO}\| market for \| APOS, U |
| | Epoxy resin, liquid {GLO}\| market for \| APOS, U |
| | Glass fibre {GLO}\| market for \| APOS, U |
| | Zinc {GLO}\| market for \| APOS, U |
| | Nylon 6-6, glass-filled {RoW}\| market for nylon 6-6, glass-filled \| APOS, U |
| | Synthetic rubber {GLO}\| market for \| APOS, U |
| | Polyethylene, high density, granulate {GLO}\| market for \| APOS, U |
| | Polycarbonate {GLO}\| market for \| APOS, U |
| | Polyethylene terephthalate, granulate, amorphous {GLO}\| market for \| APOS, U |
| | Lubricating oil {RoW}\| market for lubricating oil \| APOS, U |
| Blade replacement parts | Glass fibre {GLO}\| market for \| APOS, U |
| | Chemical, organic {GLO}\| market for \| APOS, U |
| | Epoxy resin, liquid {RoW}\| market for epoxy resin, liquid \| APOS, U |
| | Polyvinylchloride, bulk polymerised {GLO}\| market for \| APOS, U |
| | Nylon 6-6, glass-filled {RoW}\| market for nylon 6-6, glass-filled \| APOS, U |

| | |
|---|---|
| | Aluminium, wrought alloy {GLO}\| market for \| APOS, U |
| **End of life** | |
| Recycle steel | Pig iron, at plant/GLO US-EI U |
| | Iron scrap, at plant/US- US-EI U |
| | Electricity, medium voltage, at grid, New Jersey/US US-EI U |
| Recycle zinc | Zinc {GLO}\| market for \| APOS, U |
| | Electricity, medium voltage, at grid, New Jersey/US US-EI U |
| Recycle Copper | Copper {GLO}\| market for \| APOS, U |
| | Copper {RoW}\| treatment of scrap by electrolytic refining \| APOS, U |
| | Electricity, medium voltage, at grid, New Jersey/US US-EI U |
| Recycle aluminium | Aluminium, primary, cast alloy slab from continuous casting {GLO}\| market for \| APOS, U |
| | Aluminium scrap, old, at plant/US- US-EI U |
| | Electricity, medium voltage, at grid, New Jersey/US US-EI U |
| Recycle glass | Packaging glass, white {GLO}\| packaging glass production, white, without cullet \| APOS, U |
| Recycle carbon fibre | Carbon black {GLO}\| market for \| APOS, U |
| | Electricity, medium voltage, at grid, New Jersey/US US-EI U |
| Recycle plastics | Polyethylene, high density, granulate {GLO}\| market for \| APOS, U |
| | Polyethylene terephthalate, granulate, amorphous {GLO}\| market for \| APOS, U |
| | Polypropylene, granulate {GLO}\| market for \| APOS, U |
| | Polyvinylchloride, bulk polymerised {GLO}\| market for \| APOS, U |
| | Electricity, medium voltage, at grid, New Jersey/US US-EI U |
| Recycle ABS | Acrylonitrile-butadiene-styrene copolymer {GLO}\| market for \| APOS, U |
| | Electricity, medium voltage, at grid, New Jersey/US US-EI U |

*Table 15: Data from EcoInvent*

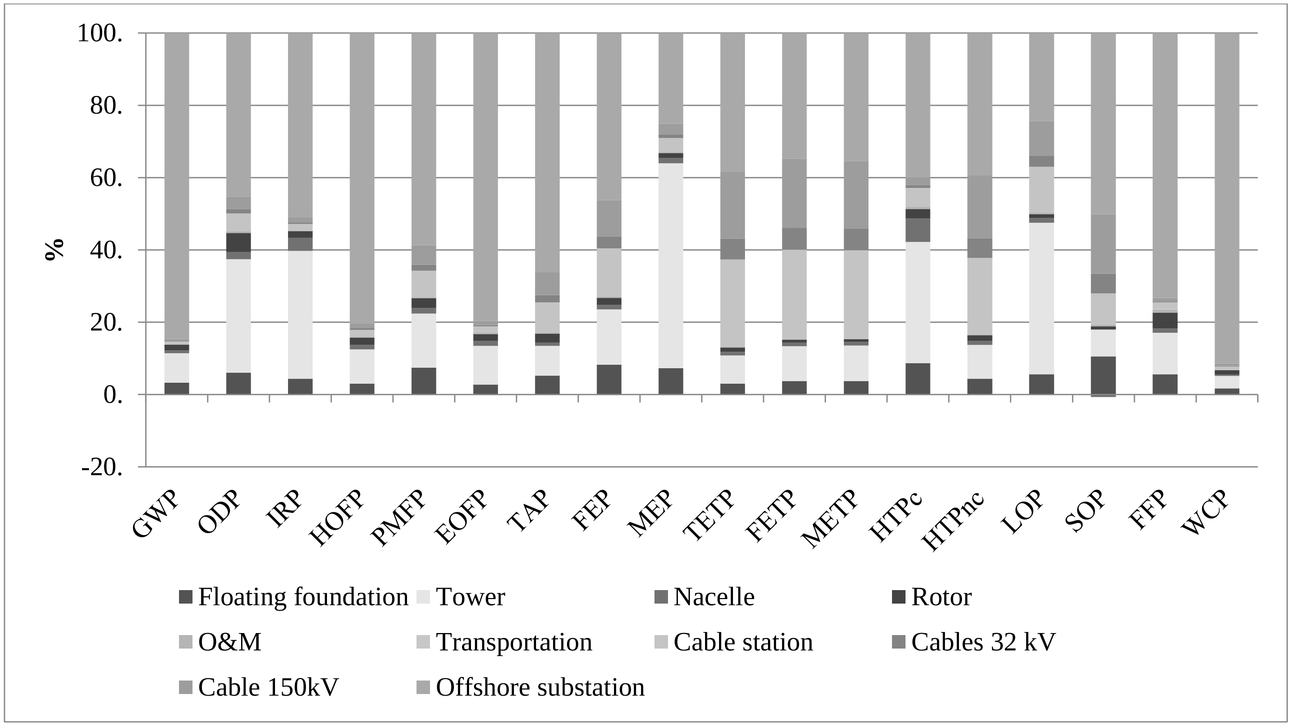
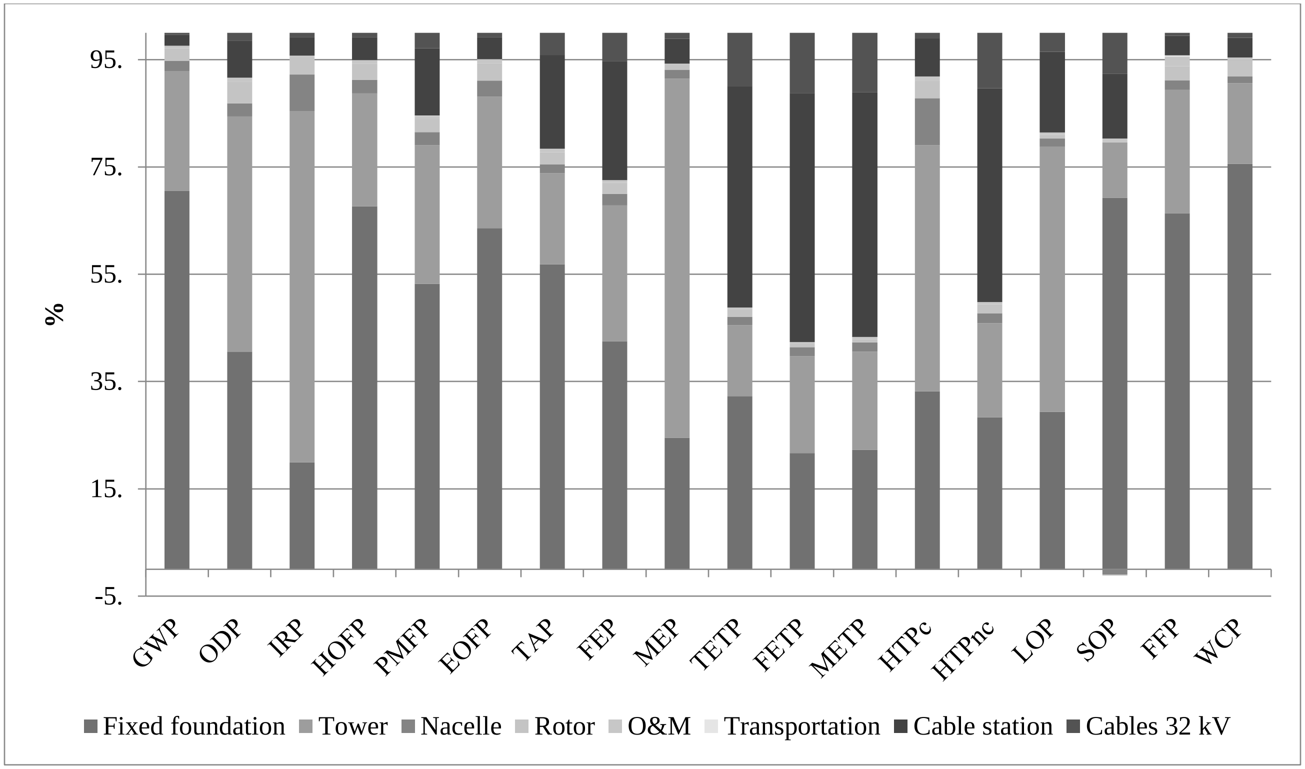

100.
80.
60.
40.
20.
0.
-20.
%
GWP
ODP
IRP
HOFP
PMFP
EOFP
TAP
FEP
MEP
TETP
FETP
METP
HTPc
HTPnc
LOP
SOP
FFP
WCP
Floating foundation
Tower
Nacelle
Rotor
O&M
Transportation
Cable station
Cables 32 kV
Cable 150kV
Offshore substation

*Figure 12:S3*



95.
75.
55.
35.
15.
-5.
%
GWP
ODP
IRP
HOFP
PMFP
EOFP
TAP
FEP
MEP
TETP
FETP
METP
HTPc
HTPnc
LOP
SOP
FFP
WCP
Fixed foundation
Tower
Nacelle
Rotor
O&M
Transportation
Cable station
Cables 32 kV


*Figure 13:S4*

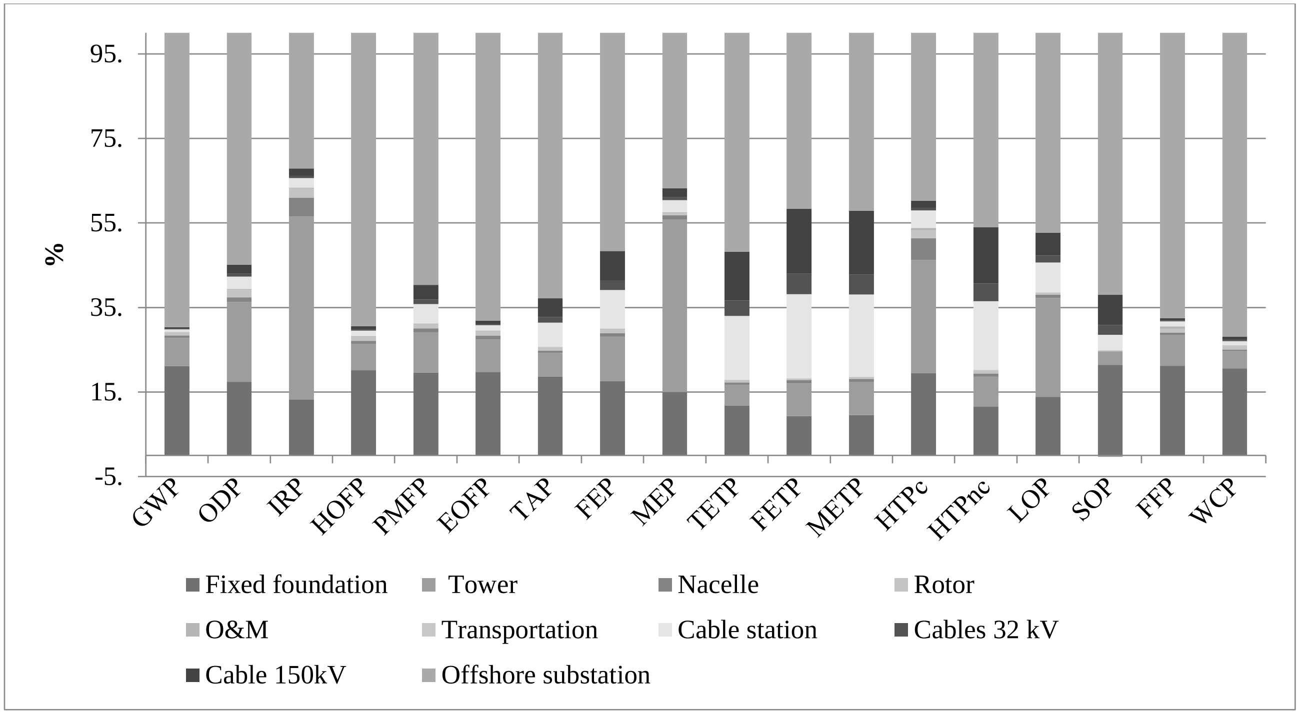
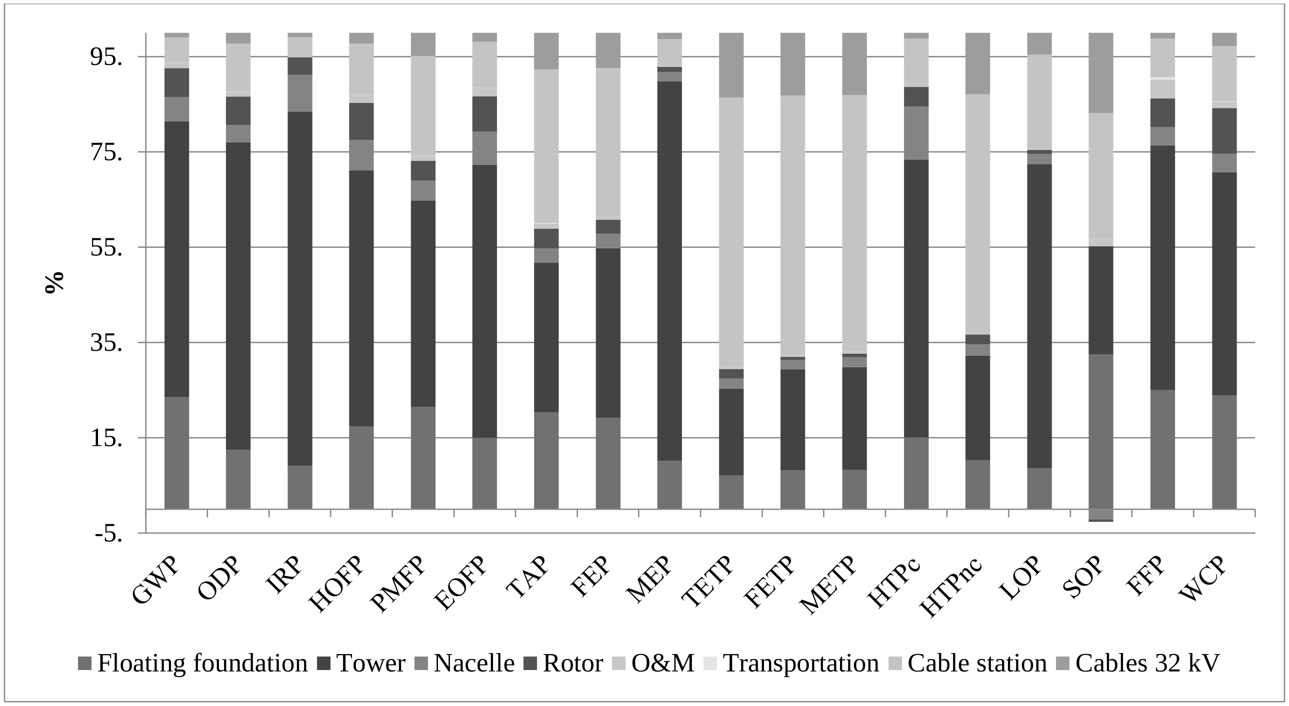

95.
75.
55.
35.
15.
-5.
%
GWP
ODP
IRP
HOFP
PMFP
EOFP
TAP
FEP
MEP
TETP
FETP
METP
HTPc
HTPnc
LOP
SOP
FFP
WCP
Fixed foundation
Tower
Nacelle
Rotor
O&M
Transportation
Cable station
Cables 32 kV
Cable 150kV
Offshore substation

*Figure 14:S5*



%
95.
75.
55.
35.
15.
-5.
GWP
ODP
IRP
HOFP
PMFP
EOFP
TAP
FEP
MEP
TETP
FETP
METP
HTPc
HTPnc
LOP
SOP
FFP
WCP
Floating foundation
Tower
Nacelle
Rotor
O&M
Transportation
Cable station
Cables 32 kV


*Figure 15:S6*

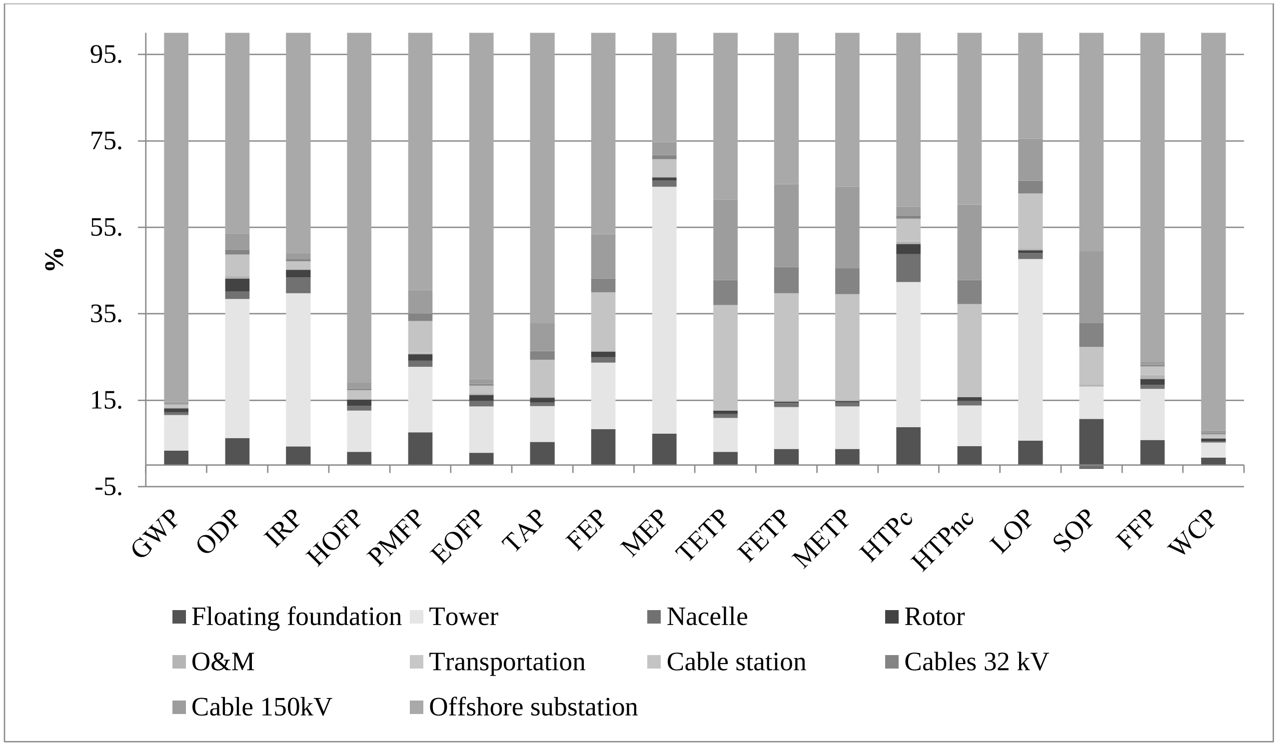

95.
75.
55.
35.
15.
-5.
%
GWP
ODP
IRP
HOFP
PMFP
EOFP
TAP
FEP
MEP
TETP
FETP
METP
HTPc
HTPnc
LOP
SOP
FFP
WCP
Floating foundation
Tower
Nacelle
Rotor
O&M
Transportation
Cable station
Cables 32 kV
Cable 150kV
Offshore substation

*Figure 16:S7*

**Appendix ii**

## Parameter Estimates

| Accommodation Type[a] | | B | Std. Error | Wald | df | Sig. | Exp(B) | 95% Confidence Interval for Exp(B) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Lower Bound | Upper Bound |
| 0 | [Creating New Jobs=0] | .916 | .418 | 4.798 | 1 | .028 | 2.500 | 1.101 | 5.676 |
| | [Creating New Jobs=1] | 1.194 | .361 | 10.940 | 1 | <.001 | 3.300 | 1.626 | 6.695 |
| | [Creating New Jobs=2] | -.300 | .145 | 4.281 | 1 | .039 | .741 | .558 | .984 |
| | [Creating New Jobs=3] | -.665 | .130 | 25.961 | 1 | <.001 | .514 | .398 | .664 |
| | [Creating New Jobs=4] | -1.160 | .250 | 21.521 | 1 | <.001 | .313 | .192 | .512 |
| 2 | [Creating New Jobs=0] | .318 | .465 | .470 | 1 | .493 | 1.375 | .553 | 3.418 |
| | [Creating New Jobs=1] | .095 | .437 | .048 | 1 | .827 | 1.100 | .467 | 2.590 |
| | [Creating New Jobs=2] | -.847 | .173 | 24.122 | 1 | <.001 | .429 | .306 | .601 |
| | [Creating New Jobs=3] | -1.110 | .153 | 52.848 | 1 | <.001 | .329 | .244 | .444 |
| | [Creating New Jobs=4] | -.443 | .195 | 5.151 | 1 | .023 | .642 | .438 | .941 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | [Producing Clean Energy=0] | .000 | .577 | .000 | 1 | 1.000 | 1.000 | .323 | 3.101 |
| | [Producing Clean Energy=1] | 1.288 | .399 | 10.400 | 1 | .001 | 3.625 | 1.657 | 7.929 |
| | [Producing Clean Energy=2] | .272 | .192 | 2.015 | 1 | .156 | 1.312 | .902 | 1.911 |
| | [Producing Clean Energy=3] | -.344 | .134 | 6.577 | 1 | .010 | .709 | .545 | .922 |
| | [Producing Clean Energy=4] | -1.196 | .158 | 57.138 | 1 | <.001 | .302 | .222 | .412 |
| 2 | [Producing Clean Energy=0] | .000 | .577 | .000 | 1 | 1.000 | 1.000 | .323 | 3.101 |
| | [Producing Clean Energy=1] | .118 | .486 | .059 | 1 | .808 | 1.125 | .434 | 2.916 |
| | [Producing Clean Energy=2] | -.504 | .235 | 4.590 | 1 | .032 | .604 | .381 | .958 |
| | [Producing Clean Energy=3] | -.872 | .159 | 30.065 | 1 | <.001 | .418 | .306 | .571 |
| | [Producing Clean Energy=4] | -.913 | .143 | 41.084 | 1 | <.001 | .401 | .303 | .530 |
| 0 | [Scenic Beauty=0] | .647 | .263 | 6.037 | 1 | .014 | 1.909 | 1.140 | 3.198 |
| | [Scenic Beauty=1] | .122 | .156 | .609 | 1 | .435 | 1.130 | .831 | 1.535 |
| | [Scenic Beauty=2] | -.840 | .135 | 38.938 | 1 | <.001 | .432 | .332 | .562 |
| | [Scenic Beauty=3] | -.822 | .223 | 13.625 | 1 | <.001 | .439 | .284 | .680 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | [Scenic Beauty=4] | -1.099 | .436 | 6.336 | 1 | .012 | .333 | .142 | .784 |
| 2 | [Scenic Beauty=0] | -1.012 | .413 | 6.004 | 1 | .014 | .364 | .162 | .817 |
| | [Scenic Beauty=1] | -2.264 | .371 | 37.158 | 1 | <.001 | .104 | .050 | .215 |
| | [Scenic Beauty=2] | -1.359 | .164 | 69.100 | 1 | <.001 | .257 | .186 | .354 |
| | [Scenic Beauty=3] | -.015 | .175 | .008 | 1 | .930 | .985 | .699 | 1.387 |
| | [Scenic Beauty=4] | .644 | .269 | 5.717 | 1 | .017 | 1.905 | 1.123 | 3.230 |
| 0 | [Energy Security=0] | 1.386 | .645 | 4.612 | 1 | .032 | 4.000 | 1.129 | 14.175 |
| | [Energy Security=1] | 1.417 | .394 | 12.930 | 1 | <.001 | 4.125 | 1.905 | 8.930 |
| | [Energy Security=2] | -.164 | .159 | 1.061 | 1 | .303 | .849 | .621 | 1.160 |
| | [Energy Security=3] | -.502 | .132 | 14.448 | 1 | <.001 | .605 | .467 | .784 |
| | [Energy Security=4] | -1.224 | .192 | 40.504 | 1 | <.001 | .294 | .202 | .429 |
| 2 | [Energy Security=0] | .288 | .764 | .142 | 1 | .706 | 1.333 | .298 | 5.957 |
| | [Energy Security=1] | .405 | .456 | .789 | 1 | .374 | 1.500 | .613 | 3.670 |
| | [Energy Security=2] | -.989 | .207 | 22.794 | 1 | <.001 | .372 | .248 | .558 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | [Energy Security=3] | -1.017 | .157 | 41.734 | 1 | <.001 | .362 | .266 | .493 |
| | [Energy Security=4] | -.620 | .155 | 16.010 | 1 | <.001 | .538 | .397 | .729 |
| 0 | [Local Tourism=0] | 1.253 | .567 | 4.883 | 1 | .027 | 3.500 | 1.152 | 10.633 |
| | [Local Tourism=1] | .934 | .252 | 13.788 | 1 | <.001 | 2.545 | 1.554 | 4.168 |
| | [Local Tourism=2] | -.640 | .115 | 30.795 | 1 | <.001 | .528 | .421 | .661 |
| | [Local Tourism=3] | -.981 | .195 | 25.188 | 1 | <.001 | .375 | .256 | .550 |
| | [Local Tourism=4] | -.160 | .284 | .319 | 1 | .572 | .852 | .488 | 1.486 |
| 2 | [Local Tourism=0] | .560 | .627 | .797 | 1 | .372 | 1.750 | .512 | 5.978 |
| | [Local Tourism=1] | -1.705 | .544 | 9.836 | 1 | .002 | .182 | .063 | .528 |
| | [Local Tourism=2] | -1.600 | .165 | 93.759 | 1 | <.001 | .202 | .146 | .279 |
| | [Local Tourism=3] | -.390 | .161 | 5.894 | 1 | .015 | .677 | .494 | .928 |
| | [Local Tourism=4] | .616 | .239 | 6.657 | 1 | .010 | 1.852 | 1.160 | 2.957 |
| 0 | [Marine Environment=0] | .405 | .304 | 1.776 | 1 | .183 | 1.500 | .826 | 2.723 |
| | [Marine Environment=1] | .056 | .168 | .113 | 1 | .737 | 1.058 | .761 | 1.470 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | [Marine Environment=2] | -.616 | .132 | 21.714 | 1 | <.001 | .540 | .417 | .700 |
| | [Marine Environment=3] | -.682 | .185 | 13.580 | 1 | <.001 | .506 | .352 | .727 |
| | [Marine Environment=4] | -.762 | .324 | 5.545 | 1 | .019 | .467 | .247 | .880 |
| 2 | [Marine Environment=0] | -1.099 | .471 | 5.431 | 1 | .020 | .333 | .132 | .840 |
| | [Marine Environment=1] | -1.344 | .265 | 25.777 | 1 | <.001 | .261 | .155 | .438 |
| | [Marine Environment=2] | -1.123 | .158 | 50.480 | 1 | <.001 | .325 | .239 | .443 |
| | [Marine Environment=3] | -.554 | .177 | 9.741 | 1 | .002 | .575 | .406 | .814 |
| | [Marine Environment=4] | .288 | .242 | 1.419 | 1 | .234 | 1.333 | .831 | 2.141 |
| 0 | [Property Values=0] | 1.139 | .406 | 7.869 | 1 | .005 | 3.125 | 1.410 | 6.928 |
| | [Property Values=1] | .391 | .187 | 4.389 | 1 | .036 | 1.479 | 1.026 | 2.133 |
| | [Property Values=2] | -.711 | .117 | 36.671 | 1 | <.001 | .491 | .390 | .618 |
| | [Property Values=3] | -.721 | .206 | 12.254 | 1 | <.001 | .486 | .325 | .728 |
| | [Property Values=4] | -.944 | .445 | 4.496 | 1 | .034 | .389 | .162 | .931 |
| 2 | [Property Values=0] | -.693 | .612 | 1.281 | 1 | .258 | .500 | .151 | 1.660 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | [Property Values=1] | -1.099 | .289 | 14.483 | 1 | <.001 | .333 | .189 | .587 |
| | [Property Values=2] | -1.386 | .151 | 84.560 | 1 | <.001 | .250 | .186 | .336 |
| | [Property Values=3] | -.251 | .178 | 1.990 | 1 | .158 | .778 | .549 | 1.103 |
| | [Property Values=4] | .693 | .289 | 5.765 | 1 | .016 | 2.000 | 1.136 | 3.522 |
| 0 | [Boat Nav=0] | .470 | .285 | 2.719 | 1 | .099 | 1.600 | .915 | 2.797 |
| | [Boat Nav=1] | -.370 | .139 | 7.060 | 1 | .008 | .690 | .525 | .907 |
| | [Boat Nav=2] | -.585 | .137 | 18.249 | 1 | <.001 | .557 | .426 | .729 |
| | [Boat Nav=3] | -.416 | .231 | 3.235 | 1 | .072 | .660 | .419 | 1.038 |
| | [Boat Nav=4] | -.773 | .349 | 4.908 | 1 | .027 | .462 | .233 | .915 |
| 2 | [Boat Nav=0] | -1.050 | .439 | 5.715 | 1 | .017 | .350 | .148 | .828 |
| | [Boat Nav=1] | -1.504 | .209 | 51.826 | 1 | <.001 | .222 | .148 | .335 |
| | [Boat Nav=2] | -.845 | .149 | 31.972 | 1 | <.001 | .430 | .320 | .576 |
| | [Boat Nav=3] | -.267 | .221 | 1.449 | 1 | .229 | .766 | .496 | 1.182 |
| | [Boat Nav=4] | .176 | .266 | .437 | 1 | .508 | 1.192 | .708 | 2.008 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | [Commercial Boat=0] | .539 | .275 | 3.853 | 1 | .050 | 1.714 | 1.001 | 2.936 |
| | [Commercial Boat=1] | -.371 | .157 | 5.622 | 1 | .018 | .690 | .508 | .938 |
| | [Commercial Boat=2] | -.755 | .131 | 33.362 | 1 | <.001 | .470 | .364 | .607 |
| | [Commercial Boat=3] | -.103 | .227 | .205 | 1 | .651 | .902 | .579 | 1.407 |
| | [Commercial Boat=4] | -.272 | .332 | .672 | 1 | .413 | .762 | .398 | 1.460 |
| 2 | [Commercial Boat=0] | -1.099 | .436 | 6.336 | 1 | .012 | .333 | .142 | .784 |
| | [Commercial Boat=1] | -1.561 | .240 | 42.271 | 1 | <.001 | .210 | .131 | .336 |
| | [Commercial Boat=2] | -1.051 | .145 | 52.337 | 1 | <.001 | .350 | .263 | .465 |
| | [Commercial Boat=3] | -.025 | .222 | .012 | 1 | .912 | .976 | .631 | 1.508 |
| | [Commercial Boat=4] | .452 | .279 | 2.622 | 1 | .105 | 1.571 | .909 | 2.716 |
| | | | | | | | | | |