OFFSHORE WIND ENERGY’S ROLE IN THE UNITED STATES’ ENERGY TRANSITION

MNR Capstone

Krisa Erdesz
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I. Abstract

As the human population grows, the need for alternative and clean forms of energy is greater. The installation of offshore wind energy has been on the rise over the past decade, however the fossil fuel energy generation sectors, such as coal and natural gas, are still major players in the energy supply markets. Wind turbines emit sound and electromagnetic energy, whereas fossil fuel burning activities discharge large quantities of carbon dioxide into the atmosphere, which is absorbed by the ocean. Many species are sensitive to auditory and electromagnetic disturbances caused by the different stages of offshore wind development, but many of the effects caused by the wind turbines appear to be less impactful and destructive compared to the formation of carbonic acid and rising ocean acidity levels. Marine species and ecosystems can display unique biological responses to different impacts. The goal of this research is three-fold: To inform the public of the environmental issues surrounding fossil fuel energy generation; to describe what is required to phase fossil fuels out, and to summarize the status of offshore wind energy as a resource to offset fossil fuels and its potential impacts.

II. Introduction

The human population is increasing at such a rate that the carrying capacity of the earth has been a topic of concern since at least the late 1960s (Ehrlich, 1968). The current average population increase is estimated at 81 million people per year (US Census Bureau, 2020). As our numbers continue to increase, our energy consumption and greenhouse gas emission rates or CO_2 levels are escalating. This creates the need to implement alternative forms of energy. Utilizing cleaner forms of energy will help reduce CO_2 levels.

In 2019, the U.S. total primary energy consumption, including industrial and residential use, was about 100.2 quadrillion British Thermal Units (BTU) or roughly 29.3 trillion Kilowatt-hours (kWh) (U.S. Energy Information Administration (EIA), 2020). During this same year, only 29.6 trillion kWh of electricity were generated within the electricity generation facilities within the U.S, making this the first time in U.S. history since 1957 that we consumed less than we produced (U.S. Energy Information Administration (EIA), 2020). The proportions of energy consumption by source; 80% generation from fossil fuels, 8% from nuclear energy, and only 11% from renewable energy sources (U.S. Energy Information Administration (EIA), 2020). The original energy generators, industrial and commercial operations that rely on the burning of fossil fuels such as coal, oil, and natural gas are still heavy hitters in the energy game. The U.S. remains the largest emitter of greenhouse gas emissions, on a per capita basis. Unfortunately, the U.S. has remained the largest emitter of emissions even though, as seen in Figure 1, the levels have been decreasing slowly since 1970 (Tiseo, 2020).

These older generators of energy have fulfilled their role, but it is now time to start phasing out these "iron giants" and start preparing for a post-fossil energy movement. The future we are already preparing for includes diversification of energy sources, including transitioning from fossil fuels partially to offshore wind. If the transition is carried out in an environmentally informed and economically feasible way, the energy future of the U.S. will be diverse and sustainable for the days ahead.

A. Fossil Fuel Generation: Future and Impacts

Fossil fuel energy generation relies on the burning of fossil fuels--coal, oil, or natural gas--which releases the stored energy trapped within the resources as heat energy. The heat energy is used to create steam, which flows at a high-pressure through tightly packed metal blades, or a turbine. The turbine is designed to convert the steam's energy into kinetic energy that can eventually be used by a generator to create electricity (Figure 2). This energy can be stored and utilized, but most power plants that burn fossil fuels are not very efficient (Woodford, 2006). Most of the fuel is not converted into usable energy, as it must be refined and purified into a useable form, leaving the remaining excess waste material requiring some form of disposal (National Research Council, 2010). The energy or power that is being transferred from station to station is slowly lost from each transfer, with only 20% of the energy being usable (Greenpeace, 2005) (Figure 3). The U.S. consumes over 29 trillion kWh worth of energy annually (U.S. Energy Information Administration (EIA), 2020), while the average household in the U.S. uses over 877 kWh per month, or 10,649 kWh per year (U.S. Energy Information Administration, 2021). As a nation, we have been increasing this fossil fuel consumption to respond to the growing population for decades (Figure 4) (International Energy Agency, 2020). Of our reserves of fossil fuels, coal, in particular, was projected to be the single fossil fuel left in the world after 2042 if the consumption rates kept increasing as they did (Shafiee & Topal, 2009). Reserves of oil and natural gas have been prolonged through the use of new applied technologies (Kirsch, 2020), but the fear of "running out" of resources has been overtaken by the concerns associated with the formation and emission of harmful CO_2 gases, rather than the rates at which these fuels will be depleted.

There has been a long battle between the fossil fuel industry and environmental representatives regarding the use of fossil fuels. The impacts associated with fossil fuels stem from extraction and processing methods, as well as the emissions of greenhouse gases including carbon dioxide from combustion. The emissions also include short-lived but highly toxic air pollutants like sulfur dioxide (SO_2) (Shinall & Smith, 2019). Our largest natural resource, the ocean, is greatly affected by these large quantities of emissions because the burning of fossil fuels accumulates in the atmosphere. The high levels of CO_2 are being absorbed by the ocean, reacting with the seawater to form carbonic acid (H_2CO_3). "In the past 200 years alone, ocean water has become 30 percent more acidic—faster than any known change in ocean chemistry in the last 50 million years" (Smithsonian, 2019). These increases in acidity and changes in the ocean's carbonate chemistry can cause numerous adverse effects on marine organisms and their habitats. The decrease in carbonate, caused by the increase in acidity, can affect marine organisms that form carbonate-based shells, like organisms from the phylum Mollusca and other benthic invertebrates. "Ocean acidification could result in a "global osteoporosis," harming not only commercially important shellfish, such as lobster, crabs, and mussels, but also key species in marine food webs" (Natural Resources Defense Council, 2009).

Issues related to the increased CO_2 gas absorption rates are not limited to the changes in the oceans' chemistry, but the heat content and thermostatic sea level rise as well. The escalation in greenhouse gas emissions affects the atmosphere causing an imbalance in the ability of natural processes to absorb the excessive emissions (U.S. Energy Information Administration, 2020). This imbalance is also referred to as the radiative force (RF) and has been increasing exponentially. (Figure 5) (Larson et al., 2019) This radiative force has been causing the oceans' heat content to rise, and "this lasting effect is due to the slow response of the oceans to thermally equilibrate" (Larson et al., 2019). The heat content of the ocean is the amount of heat stored and can affect the water surface temperatures, sea levels, and currents. This heat content has been slowly increasing within the upper 2000m layer since 1958 and has been increasing exponentially more after the 1980s (Figure 6) (Cheng et al., 2021). An increase in water temperature can have adverse effects on marine species and the surrounding ecosystems. Particular species and environments rely on a specific range of water temperatures and complications can arise if these ranges are altered too excessively. These complications can include changes in metabolic rates, life cycles, and behavioral responses. Rising water temperatures can be seen visually as the bleaching of coral reefs. Unfortunately, there is not enough knowledge on whether or not these species will ever possess the potential to adapt to the rising CO_2 levels and temperatures, but they should be considered a high priority in the research domain (Doney et. al., 2019).

Rising ocean heat content not only affects the water temperature but an increase in ocean heat contributes to rising sea levels. The temperature changes are causing a rise in water volume due to the glacier melting and the thermal expansion of seawater (Figure 7) (Lindsey, 2021). The rising sea levels will not only affect the ecosystems and the organisms that rely on them, but this will affect human activities as well. Loss of coastal areas increases in flooding, and saltwater flowing into groundwater and causing the coastal infrastructure to be more susceptible to storm damage are some of the effects that could be caused by rising sea levels. With this increase in radiative force, the melting of glaciers and permafrost could also potentially release ancient microbes or viruses that have been dormant within the ice. A study released in 2020 by Dr. Zhi-Ping Zhong, from The Ohio State University's Byrd Polar and Climate Research Center (BPCRC) revealed 33 samples of dormant viral populations were obtained from glacier core samples. These samples were meta genomically sequenced from ~520 and ~15,000 years old from The Guliya ice cap

(Northwestern Tibetan Plateau, China). The results indicated that the ice was serving as an archive and the viruses had the potential to revive. “In a worst-case scenario, this ice melt could release these pathogens into the environment” (Zhong et al., 2020, p. 18). We have already begun to destroy the planet’s atmosphere, these changes to our ocean’s chemistry and temperature will signal a massive disruption to our waters, and that may be our final warning from nature. Supplementing global temperature goals with firm limits on atmospheric CO_2 concentrations could reduce the risk of high-impact weather changes, such as disruption of weather patterns, storm frequency, droughts, and flooding (Baker et al., 2018).

Before the late 19th century, wood and watermills were used as the predominant form of energy and were extremely important to the early industrial sectors. These sources eventually gave way to the utilization of coal and other petroleum-based products as a source of energy. As our nation’s energy consumption patterns changed, we have had to escalate our extraction and processing of fossil fuels to keep providing energy to the country (Figure 8) (U.S. Energy Information Administration, 2021A). The increase in extraction and processing of fossil fuels is accompanied by a surge in various costs and increased environmental impacts. The methods used to extract fossil fuels can be highly invasive to the surrounding environment. Underground and surface mining, strip mining, and mountaintop removal are the main method used to extract solids such as coal. Drilling is the preferred method to extract liquid fuels such as oil. These methods of extraction can produce negative impacts on the environment, each with its hefty price tag.

Mines have the potential to collapse and affect surface infrastructure as well as subsurface water flow. Abandoned mines, if not properly dismantled and disposed of, can cause fires and acid drainage, leaching heavy metals into a nearby water supply. Many of the costs associated with fossil fuel extraction are health and safety costs, from fatalities caused by mining accidents and chronic health disorders developed by the workers years after leaving the mines. The other large cost associated with fossil fuels is transportation costs. Needing to transport fossil fuels from point A to point B can be quite expensive, especially if importing from overseas. The costs and impacts related to fossil fuel production and converting them to a "usable" product may pose a question if they are worth the "value" we think they hold.

An energy revolution was started in the U.S. when the very first commercial offshore wind farm began operation in December 2016, approximately 3 miles southeast of Block Island, RI (Orsted, 2016). To date, the U.S. has procured a total offshore wind pipeline worth 28,000 MW, spread out among 15 federal leases and with the wind potential of more than 2,000 GW, almost double the nation's current energy use (American Clean Power Association, 2021). Eight states have been behind the driving the offshore wind demand force; Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Rhode Island, and Virginia. Collectively, they have established targets to secure over 30,000 MW of offshore wind energy by 2035 (American Clean Power Association, 2021). Each state set specific offshore wind energy procurement goals, approved contracts for pilot demonstration projects, and outsourced many requests for proposals (RFPs) to contractors to assist in reaching their wind energy goals. On February 19, 2021, the U.S. rejoined the Paris Agreement, under new Presidential elect Joe Biden, as we once again accepted the terms and conditions to assist the rest of the world in becoming carbon neutral by 2050 (Chemnick, 2021). Transitioning away from fossil fuels is no longer an ideal, it is happening and if the U.S. can keep surpassing these major energy procurement milestones, there is hope for that carbon-neutral future.

Costs associated with converting from fossil fuels to renewables are the main focus, but it is still important to thoroughly analyze these costs versus the benefits. Many of the costs are centered around the related infrastructure and operation of offshore wind facilities. An increase in the demand for offshore wind energy will in turn cause an increase in these related costs and materials (Lesser, 2020). The cost of capturing wind energy has become more cost-effective than obtaining fossil fuels for energy use, which “means that it can be less expensive to build climate-friendly infrastructure than it is to construct new fossil-fuel plants that will release planet-warming pollution for decades to come” (Peach, 2020).

There are many benefits associated with adapting and utilizing newer technologies in the energy sector, including the potentially lower costs. Aside from the possible local economic growth and countless new jobs that would be created, the improvements in our nation’s health would bring a more positive light to the renewable division. Drew Shindell, a professor from Duke University, provided testimony in a House committee hearing “The Devastating Impacts of Climate Change on Health” on August 5, 2020. The results of new research shed light on the transitioning to alternative energy, with Shindell explaining that if we were to phase out fossil fuels in the next 50 years it would amount to “over $700 billion per year in benefits to the U.S. from improved health and labor alone, far more than the cost of the energy transition” (House Committee on Oversight and Reform, 2020). This transition can lead to a decrease in warming rates within two decades of the start of the fossil-fuel phase-out (Shindell & Smith, 2019).

B. Offshore Wind Energy: Status, Future, and Impacts

Energy is generated from offshore wind in a manner that is comparable to that of the fossil fuel burning generators; turbine blades spin around a large rotor and create electricity. The difference is that the source of fuel for these turbines is wind. The wind is derived from the sun heating the earth's atmosphere unevenly, as well as the rotation and irregularities of the earth and its surface (Office of Efficiency & Renewable Energy, 2019). The allocation of this source of "fuel" for offshore turbines can be unlimited and may cause less burden on the economy to use it, compared to fossil fuels, (and no emissions), aside from the initial costs involved with the building and installation of the turbines. Offshore wind turbine technology first became significant in 1991, with the first successfully operating offshore wind farm, encompassing eleven 450kW turbines. (Kurian, Sambu, & Ganapathy, 2010). A collection of more than five offshore wind turbines is considered an offshore wind farm (OWF), with the largest farm in operation totaling eighty-seven turbines, located in the Irish Sea (Walney Extension, 2018).

There are four main parts to an offshore wind turbine: the hub, the blades, the nacelle, and the tower Figure 9 (NYSERDA, 2018). The hub and tower are the main support for the blades, while the nacelle is the housing unit for the components that convert the mechanical energy into electrical energy. As the blades turn, they capture the energy expended by the wind, generating electricity. The blades must have a clearance of up to 75 to 100 feet from the waterline, to avoid disturbances from waves. Turbines are secured to the seafloor by a foundation, usually concrete infrastructure, but can include other types such as jackets, monopiles, and gravity-based foundations also referred to as floating foundations (Figure 10) (Bailey, Brookes, & Thompson, 2014). Connected to the base of the turbine is a multitude of array cables, which transfer the collected electrical energy to an offshore substation (Figure 11, left) (NYSERDA, 2018). The offshore substation transmits all power allocated from the turbine to an onshore connection, which houses the electricity until it can be transferred into the existing network by the service provider (Figure 11, right) (NYSERDA, 2018).

The site selection process for each offshore wind turbine involves many factors and is based on marine spatial planning techniques and associated parameters (Figure 12 & 13) (Diaz et al., 2018). The key factor used to determine where an offshore wind turbine will be placed is the availability of the wind source. Any area where the wind speed is below 4.5 m/s is considered unfavorable and unprofitable for a turbine site location (Latinopoulos and Kechagia, 2015). Tide levels and the current strength also factor in the site selection, as well as if there is a high enough demand for power in that region. Other considerations used to determine the location of a site can include permitting, site control, and verifying that the site in question is not located within the parameters of an opposing country's Exclusive Economic Zone (EEZ). A Geographic Information System is a tool used in the site selection and implementation planning of an offshore wind turbine. By mapping out the offshore obstacles that can hinder the placement of a site, GIS can assist in avoiding prohibited areas like Marine and Environmentally Protected Areas (Saleous, Issa, & Al Mazrouei, 2016). The GIS-based selection methods are also combined with other site-selection methodologies to ensure proper location and placement of the turbines.

Offshore wind turbines have advanced technologically compared to the original offshore turbines that were commissioned in 1991. There is still have much to learn in this sector, regarding ecological safety and overall protection for all surrounding marine ecosystems. Wind turbines can impact the ecosystem surrounding them, some of these being positive, but others can be considered a negative impact on these marine ecosystems and their inhabitants (Figure 14) (Bergström et al., 2014). The foundations of the wind turbines can act as artificial reefs, also referred to as "secondary artificial reefs." These foundations increase the amount of hard substrate that is available for epibenthic species, providing a new habitat and probable shelter from impending predators (Inger et al., 2009). There is a downfall associated with the introduction of a "secondary artificial reef": these new substrates can promote the spread of invasive species, which could affect the current populations and species that resign in the area, which can be witnessed with any type of man-made infrastructure that has been introduced into a marine environment (Inger et al., 2009). "These structures should not be regarded as surrogates for natural substrates since epibenthic assemblages on artificial surfaces were shown to differ compared to assemblages on natural hard substrates" (Andersson et al., 2009, p. 254).

In addition to the artificial reefs, fishery exclusion can also be considered a positive effect that offshore wind turbines have on the surrounding ecosystem, but only from an environmental standpoint. The exclusion of these commercial fishing vessels from the area surrounding an offshore wind turbine farm could assist in controlling the harvest rates (Fayram & de Risi, 2007). There is much perceived and potential conflict between the offshore wind and commercial fisheries, due to the fishing vessels not being permitted to enter offshore wind farm perimeters. Obstruction to the navigation routes that fisheries used most commonly can lead to a decrease in harvest rates and profits losses. Larger commercial operations may not be affected as much as the smaller, traditional operations that would not be able to compensate for these losses (European MSP Platform, 2019).

The negative impacts associated with offshore wind are arguably more pervasive compared to the positive of artificial reef/habitat creation. There are three classifications of negative impacts that could be associated with offshore wind turbines: water pollution, noise or acoustic disturbance and electromagnetic frequency disturbance, and water pollution from the infrastructure, which includes the leaching of chemicals or biofouling from paints and or finishes from the foundation can affect the surrounding areas and its inhabitants. The installation of offshore wind turbines also causes an increase in vessel traffic, as the turbines are monitored and visited regularly, requiring a vessel to transport staff to the site. With this increase in vessel traffic, the release of contaminants and other harmful substances are leached into the water column (Bailey, Brookes, & Thompson, 2014) and also increased underwater sound, itself a pollutant.

Acoustic disturbances are another potential effect that offshore wind turbines have on marine ecosystems. Most of the acoustic disturbances happen during construction when the foundation of the wind turbine is being pile-driven into the seafloor. This process can take hours to complete, depending on the substrate type (Anderson, 2011). This classification of anthropogenic noise can emit a sound level of 180 decibels, which can cause auditory injury if the affected individual is within 100m of the pile driving activity and could occur up to 50km away. This is also common with seismic surveys that are conducted for site selection data (Bailey et al., 2010). With a staggering total of almost 31,900 different species of fish, along with an unknown number of species we have yet to discover, there are very few that have been studied in terms of their abilities to detect sounds and vibration (Frose and Pauly, 2010). Other noise disturbances can be caused by the blades of the turbine, which could increase the stress level of the marine organism or harm internal communication by masking the sound signals that the fish emits (Bergström, Sundqvist, & Bergström, 2013).

The electromagnetic disturbance caused by offshore wind turbines can have a substantial impact on the marine ecosystem. Electromagnetic fields have been known to affect a wide array of electrosensitive species. As the electricity is transported from the offshore substation to the onshore connection, which houses the electricity for later use, this creates an electromagnetic field. The artificial electromagnetic fields produced are 70 times higher than the natural values that are measured in areas without offshore wind turbines (Bochert and Zettler, 2004). A top concern associated with the EMFs is that the organisms that migrate may orient themselves towards the EMF, being emitted from the cables, and could move inshore or offshore and stray from their normal migratory path (Klimley et al., 2016). The subsea power cables that are used to transport the electricity to the onshore connection can have different effects, based on the location of the cable, being buried or laying on the seafloor. If the cables are buried under the substrate, this can assist in the dispersal of the EMFs, lowering the effect they have versus if the cable is left to lie on the seafloor, which would emit the full EMF force into the water column (CMACS, 2003).

C. The Effects at Individual Stages of Offshore Wind Development

There are three different stages associated with the implementation of OWF's: construction, operational, and decommission or post-operation stage. During each of these three stages, the effects that are caused by the OWFs can vary, some being more detrimental than others, which can be summarized in Figure 15.

1. Construction Phase

The first stage of implementing an offshore wind turbine is called the construction stage, which involves the creation of the foundation to support the turbine and layout of array cables used to transport the energy to the offshore or onshore connections. The disturbances common to the construction phase include sediment removal, cable laying and routing, structure building (pile driving), and the timing of these activities (Gill, 2005). The removal of sediment from the seafloor or the substrate that is there before the construction of the turbine can be considered habitat destruction or degradation. With this loss of habitat, there will be a significant decrease in biodiversity and there is a decrease in shoreline protection (Inger et al., 2009). From these effectors, there is a trickle-down effect that alters other aspects of the marine ecosystem. Along with the habitat loss from the construction, there is increased turbidity, the release of contaminants, an increase in biological oxygen demand, and an increased level of noise or vibration (Gill, 2005). The aftermath of the construction phase can trigger potential ecological responses to organisms depending on their life histories or behavior; the sedentary species typically show reduced biodiversity and an increase in opportunistic species while the mobile species are affected by temporary or long-term displacement and hearing loss (Gill, 2005). The construction phase can affect many organisms on a different level, as NYSERDA performed a Sensitivity Analysis on the different stages of the implementation of the turbines; see Figures 16 & 17 for the ranges of sensitivity each type of marine organism had during the construction phase (NYSERDA, 2017a).

2. Operational Phase

The second phase of implementation of an offshore wind turbine is called the operational phase, which is the time frame that the turbine is in full operation and is providing a steady output of electric energy to the service provider. The disturbances associated with this phase can include cable rating, or the size based on the maximum amount of voltage that is required to transport and array configurations, the frequency and quantity of electricity flowing through the cables, and any additional moving parts of the rig (Gill, 2005). During this phase of the turbine operation, additional complications can arise; increased noise and vibration within the water column, the release of EMFs, collisions above or below the water between structures or equipment and organisms, an increase in habitat heterogeneity, and the transportation of foreign sediment to an isolated area (Gill, 2005). As with the construction phase, there are potential ecological responses of affected organisms. Species that are sensitive to acoustic and EMF are affected the most during this phase. EMF can cause potential interference with communication or defenses of different species that are either attracted to or repelled by the EMF areas. As a result, EMF can cause organisms to alter migratory patterns with the possibility of injury or fatalities (Gill, 2005). This phase is rated by sensitivity, regarding each type of marine organism (Figure 18), showcasing how each category of an organism and how much of a risk or stress is put on them (NYSERDA, 2017a).

3. Decommission/Post-Construction Phase

The final phase of the implementation of offshore wind turbines is called the decommission or post-construction phase. With the removal of the turbine and all the parts that are associated with it, there is an increased disturbance to the sediment once again, as well as substrate degradation from the removal of the cables buried under the seafloor. Many of the effects resulting from the decommissioning and removal of a turbine structure are similar to the initial construction phase; habitat removal, increased turbidity, the release of contaminants, new colonization opportunities, and increased noise or vibration (Gill, 2005). The potential ecological responses produced by this final phase can affect the sedentary and mobile species, reduced diversity, an increase in opportunist abundance, temporary or long-term displacement, and a possible reduction in biomass. This phase is rated by sensitivity, regarding each type of marine organism (Figure 19), showcasing how each category of an organism and how much of a risk or stress is put on them (NYSERDA, 2017a). An overall assessment of the stress level that these three phases can put on different categories of marine organisms (Figure 20) can be compared and shows that the construction phase, on average, puts the most amount of stress on any individual. (NYSERDA, 2017a)

D. Sensitive Species

The ability to sense sound vibrations and changes within the water column, sense and use the earth's magnetic fields is present for marine mammals, sea birds, many groups of fishes (including elasmobranchs), and for several other invertebrate groups (Normandeau et al., 2011). There are naturally occurring electromagnetic fields, a direct current (DC), within the oceans, emitted by undersea cables that are commonly used for energy or power transfers. Undersea communication cables also generate an alternating current (AC) (BOEM, 2020). Reduction of emitted EMFs can be obtained by burying the cable under the seafloor at a certain depth and also providing a metallic covering around the cable (Figure 21) (BOEM, 2020). These classes of species are also greatly affected by auditory disturbances emitted from the construction and operational phases of the offshore wind turbines. Erdesz (2019) summarizes the impacts caused by these varying forms of disturbance, which can be seen in Table 1.

E. Future of Offshore Wind for the US

The idea of transitioning away from fossil fuel energy generation is still not an ideal that the entire U.S. can agree on together. We are far behind Europe's grasp of the offshore wind energy sector, as they have been utilizing this source of energy for a longer period. European nations have been operating and employing offshore wind energy for the last 20 years, already having installed over 18GW of wind capacity. We can learn from the data and acquired experience they possess to make better energy-related decisions. Our main lesson to learn from countries that have implemented offshore wind energy into their grids is how can the U.S. prepare and implement offshore wind facilities in an effective and environmentally conscious way that is specific to our coastlines. Compared to European coastlines, the U.S. possesses more potential areas to place offshore wind farms, giving way to larger areas to utilize for maximum wind energy collection and generation. Having more areas for potential wind capability would increase the U.S. future wind capacity, but we would require different research tactics to map turbine placements, as our ecosystems and coastlines are slightly different from Europe's. Planning will necessitate environmental studies of the diverse substrates and marine ecosystems making up U.S. coastal waters (Figure 22). For example, as the west coast waters have a narrow shelf, steeper slopes, and deeper waters, perhaps floating turbine sites would fit best. Fixed platform turbine sites are better suited for shallower waters, similar to the waters off the east coast. Being able to use the floating turbine sites would be less expensive than having to build them in the deeper waters and would be cost-effective as they can be assembled in nearby ports, then towed out to their location (Barter et al., 2020). To maximize wind power and potential capacity amounts for the future, we must continue to progress in our efforts towards the exploration and research of newer wind technologies. "The footprint is minimal compared to the vast area of the sea. The impacts are very localized and small, especially compared to the effects of fishing or warming of the oceans," (Bray et al., 2016, p. 18). The reduction of our energy demand will be the key to improving our prospects for a successful transition (Floyd, 2015).

III. Discussion

To generate sufficient energy to fulfill the supply and demand of the public, the burning of fossil fuels has had repercussions. These repercussions have started to greatly affect our atmosphere and our oceans. With the implementation of offshore wind into the U.S.'s energy grid, the phasing out of fossil fuel generation would produce many benefits to not just our country, but the globe itself. To comply with the terms and conditions laid out in the Paris Agreement, to be able to achieve true sustainability, there has to be a balance, a balance of three factors. We must balance the economic, environmental, and social factors, to attain true sustainability in our country. This is referred to as the three pillars of sustainability: economic viability, environmental protection, and social equity (Purvis et al., 2018), and none can exist without the other. As seen in Table 2, the three pillars of sustainability and how they can be applied to the fossil fuel and offshore wind energy sectors are summarized.

The first pillar, economic viability, requires that resources are used efficiently and responsibly, with an end goal of consistently producing an operational profit (Purvis et al., 2018). Fossil fuel generation can seem to have the upper hand within this factor, as the cost for new infrastructure would not be needed, creating convenience for this energy source. Offshore wind platforms and structures would need to be built in the U.S., yielding increased costs. By providing incentives for the implementation of renewable energy sources, offshore wind could provide offset costs to these other costs associated with beginning the renewables movement in the U.S. Another viable way to offset costs and still maintain an operating profit is the creation of jobs for the public. As reported in American Wind Energy Association's *U.S. Offshore Wind Power Economic Impact Assessment*, the development of offshore wind in the U.S. could create up to 83,000 jobs and produce 25 billion dollars in annual economic output by the year 2030 (AWEA, 2020).

The second pillar, environmental protection, meaning that to achieve balance in this factor we must live within the means of our natural resources (Purvis et al., 2018). The consumption of natural resources must be held at a specific sustainable rate and the damage caused by the use or extraction of these natural resources must be considered. Fossil fuel generation releases large amounts of CO_2 and highly toxic amounts of SO_2 into the atmosphere, which is absorbed by the oceans. These emissions are playing a huge role in the amount of air and water quality issues we are facing in the U.S. In 2019, over 70 million tons of pollution were emitted into the atmosphere in the U.S., composed of CO_2, SO_2, and Nitrogen Dioxide (NO_2) (US EPA, OAR, 2020). Introducing offshore wind could improve the air and water quality and assist in the reduction of greenhouse gas emissions. Transitioning away from fossil fuels will aid in the preservation of natural habitats and ecosystems, as the extraction of energy for offshore wind does not cause such extreme outcomes as fossil fuel requirements do.

The final pillar of sustainability, social equity, is where a social system must persistently achieve good social well-being and maintain this for the long term (Purvis et al., 2018). Fossil fuel burning releases large quantities of greenhouse gases into the air, causing an environmental health hazard. Pollutants like particulate matter (PM 10), black carbon (BC), nitrogen oxides (NO, NO_2), ozone (O_3), and sulfur dioxide (SO_2) can cause adverse effects if exposed for long periods (Environmental Defense Fund, 2020). Some of these effects can include heart attacks, stroke, respiratory diseases, and varying types of cancer (CDC, 2021). Allowing offshore wind to take over the energy sector in the U.S., the improvement of air quality could be directly tied to communal health improvement and overall decreased health-related costs. If the U.S. is to stay on the path of "business as usual" and maintain the burning of fossil fuels as the main source of energy, we will never gain energy independence if we keep relying on other countries' exports. With offshore wind, the strive for energy independence in the U.S. has never been greater, being able to create revenue and stabilize the energy sector for our own country would fulfill the requirements of all three pillars of sustainability.

Considering the complexities of implementing offshore wind, a comparison with terrestrial based wind energy facilities should also be examined. With 40% of the U.S. population residing in coastal counties and over 44% living within 93 miles of the coasts (Office of Coastal Management, NOAA, 2021), there is a large energy demand but fewer opportunities for siting wind farms compared to the central United States. Since the energy grid is not connected throughout the entire US, electricity generated by wind energy in the center of the country cannot be exported to the coasts (US EPA, OAR, 2017). Utilizing the same pillars of sustainability, terrestrial and offshore wind turbines each possess their strengths and weaknesses, the question is which is best suited for the U.S.?

The cost per unit of energy associated with terrestrial wind turbines are much lower than that of offshore wind which can be seen in Figure 23. (U.S. Energy Information Administration, 2021B). The land-based versions are cheaper and require fewer transportation logistics. Offshore wind turbine infrastructure is more expensive, and a more complex logistic plan is needed to transport them to the intended site (Hevia-Koch et al., 2019).

Another cost that can be associated with these wind turbines is maintenance and repair. The land-based require less maintenance and repair, as they are not as vulnerable to hurricanes and other ocean-related weather patterns like the offshore wind versions are. The capacity factor, or how much potential wind power can be created, between the two types turbines can also affect the costs. Land-based turbines have a lower capacity, due to obstructions and nearby landscapes, while the offshore types are not hindered by any obstructions. In WindEurope's *Wind Energy in Europe: 2019*, the capacity factor from the land-based models was 24%, compared to the offshore capacity of 38% in 2019. (WindEurope, 2019)

A concern associated with land-based turbines is the amount of required space that is needed to implement a turbine, also known as the project's footprint. With the potential of increased urban land and population expansion, utilizing the open ocean is perhaps a more attractive option in this case. There are potentially unlimited areas that offshore wind turbines and farms can be placed, given that they are placed safely and strategically to accommodate for the multitude of factors that can alter the planning and installation of turbines. Placing offshore wind facilities out of sight from shore and utilizing floating turbines could lower residents' opposition compared with the controversy often encountered with land-based turbines. The land-based turbines have a location limit, they can only be placed in particular areas and must abide by the regulations and standards, such as distance from residential areas. View obstruction and noise emissions are some of the issue's residents have that many associate with wind turbines in general. Offshore wind turbines may be more expensive to construct and operate, at the moment, but utilizing the land for wind-based turbines may not be the best option, when the oceans can possibly provide unlimited offshore turbine sites instead.

IV. Conclusion

Researchers agree there is still a knowledge gap regarding ecological effects of offshore wind. There is also a gap in the US about public acceptability. This gap needs to be filled before the U.S. can decide if this process of renewable energy generation will help or hinder our goals towards becoming energy efficient. It has also become apparent that the fossil fuel energy generation is reaching its endpoint in engineering lifespan and practicality due to emissions. As these resources we once thought we could be reliant on, are causing more harm than they are worth. The harvesting of energy from offshore wind is still new to the U.S. A vast amount of data is still needed. There is still more time that must pass to collect sufficient data, especially for long-term effects. The main focus should be on the assessment of long-term impacts.

As the demand for offshore wind energy grows, technological advances will guide us to better implement farms more effectively and in a more environmentally responsible way. Utilizing accurate mapping techniques, to properly plot the most effective sites for turbine facility locations is a start. Proper planning would identify highest wind resources while to avoiding shipping, fishing, and whale migration. Utilizing wind farms as anchors to aquaculture installations could also offset costs by supplementing other economic sectors (Buck et al., 2008).

It is evident that mitigating the noise being emitted by the different stages of construction is of the highest priority. The independent technology think tank, RethinkX, releasing a groundbreaking study this past February 2021, concludes that, CO_2 emissions are not the only worry associated with fossil fuels. The new report reveals that traditional power plants' Levelized Cost of Electricity (LCOE), which is the average cost to generate electricity during the entire lifespan of the plant, was grossly overvalued (Dorr & Seba, 2021). They discovered the calculations associated with power plant LCOEs were distorted and show that fossil fuels costs more than we originally thought. The overall costs were calculated to be higher, while the capacity factors were calculated to be lower. For example, a coal power plant's capacity factor, given a forty-year lifespan, was calculated at 80%. This calculation was actually lower in reality, yielding only 67% capacity for coal plants in 2010, plummeting to almost 40% capacity ten years later (Dorr & Seba, 2021). This means the real cost of electricity produced by these plants is higher, with corrected values at 32.4 cents per KWh compared to the 7.6 cents per KWh originally calculated (Dorr & Seba, 2021). The report projects that the cost of electricity over the next ten years will be nine times higher for coal, five times higher for gas, fourteen times higher for nuclear and nine times higher for hydro than currently estimated due to these corrected calculations (Dorr & Seba, 2021).

The installation of offshore wind turbines has been gaining momentum within the clean energy sector since the first U.S. wind farm was put into operation in 2016 (Orsted, 2016). With the introduction of any new power technologies, there are bound to be pitfalls and lessons to learn for the future. Offshore wind turbines and the energy they produce assist in greenhouse gas reduction to promote the clean energy future we hope to see.

Reducing the potential negative impacts of the new technologies will be a process informed by scientific studies done here and abroad. Numerous lessons have already been learned regarding the noise and electromagnetic emissions; what is left to do is to rectify them and find alternative ways of reducing the number of decibels that are emitted and discovering ways of lessening the number of EMFs that are released from the array cables. “Little was known about potential ecological effects or impacts from EMFs, and that with the proliferation of offshore renewable energy facilities, exposure of marine organisms to EMFs will significantly increase" (Hutchinson et al., 2018, p. 1). Funding is urgently needed for research on the effects of artificial EMFs and how they affect each type of species of marine organisms, as well as the mechanisms that the organisms utilize to process the sound and vibrations. "It will be of importance to establish sound emission levels from all of the phases of wind farm development and give consideration to their consequences and their mitigation." (Dolman et al., 2003). The effects on tourism and recreation will also need to be studied, as there is little existing literature regarding this possible issue. The public’s perception of visual impacts will diminish over time as they have elsewhere such as Denmark. For example, the Middelgrunden Offshore Wind Farm located off the coast of Copenhagen (Sørensen et al.,2002), the local Danish were polled after the construction with more than 70% of the population being in favor of the farm (Danish Energy Authority, 2003).

Local acceptance is necessary for structures built to this magnitude. The key to public acceptance of structures similar to the ones built in Denmark are local ownership of the farms, not utilities installing and controlling the farms. Some research suggests that support is gradually growing from tourism and related recreation sectors (Smythe et al., 2020), giving new light to this alternative form of energy. The U.S. may need to make a drastic cultural and economic change, not just a technological one, for this transition from fossil fuel dependency to cleaner forms of energy generation to ever be successful.

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VI. Appendix

Figure 1: ***U.S. fossil CO_2 emissions per capita 1970-2019*** **(Tiseo, 2020)**

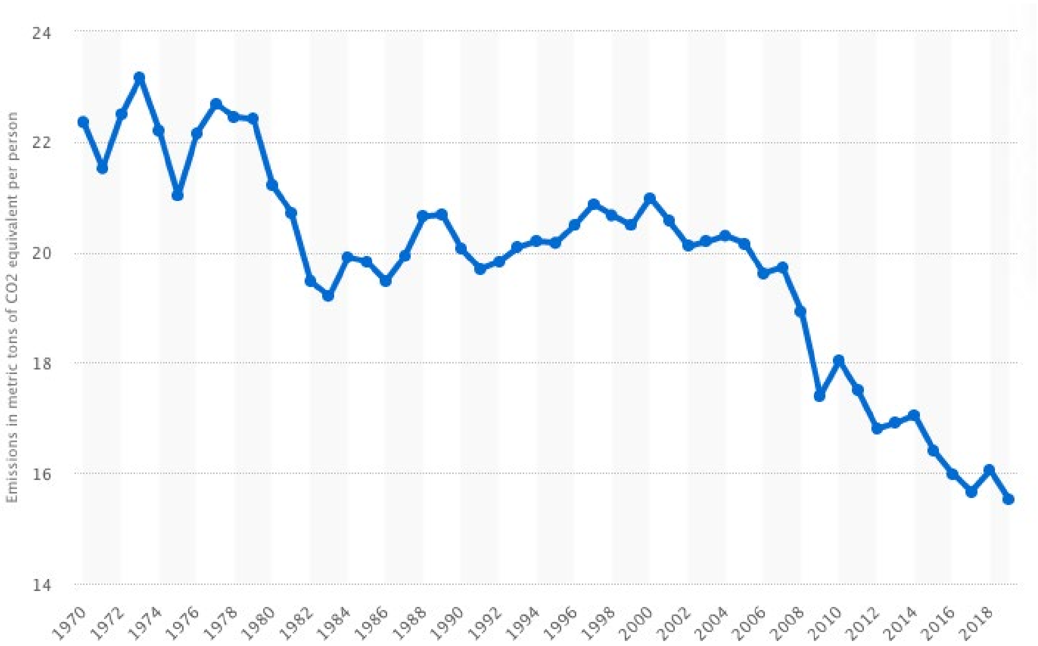


Figure 2: ***General power plant energy transfer sequence.*** **(Woodford, 2006)**

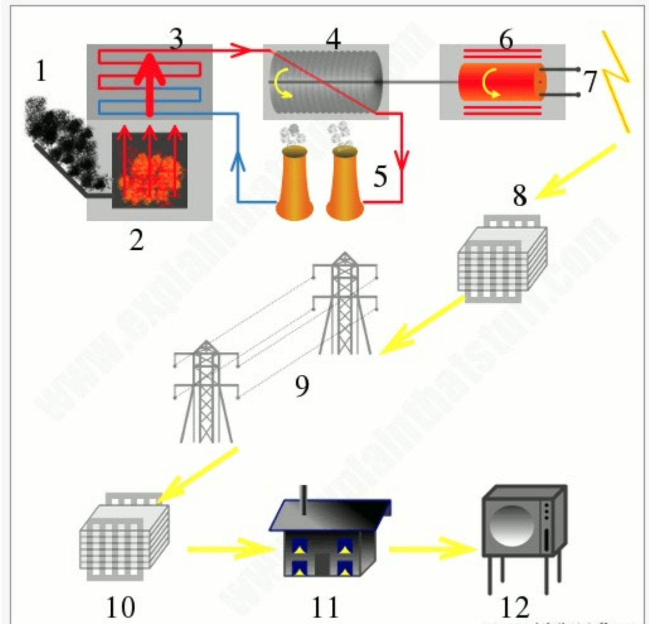


Figure 3: Inefficiency of centralized fossil fueled power plants. (Greenpeace, 2005)

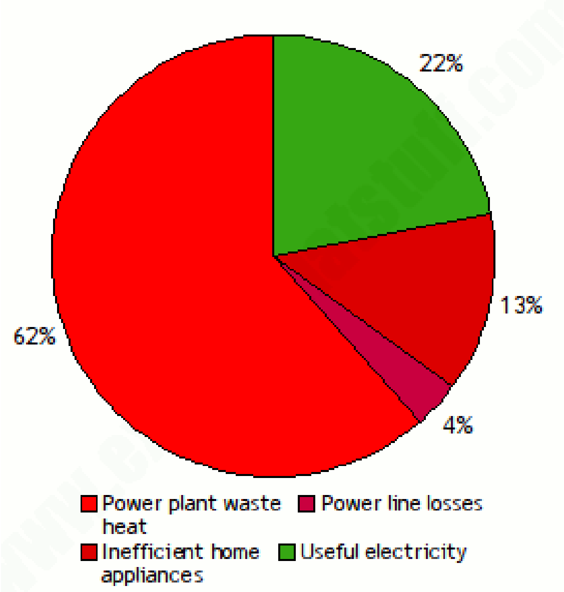


Figure 4: ***Total World Coal Production, 1971-2019.*** **(International Energy Agency, 2020)**

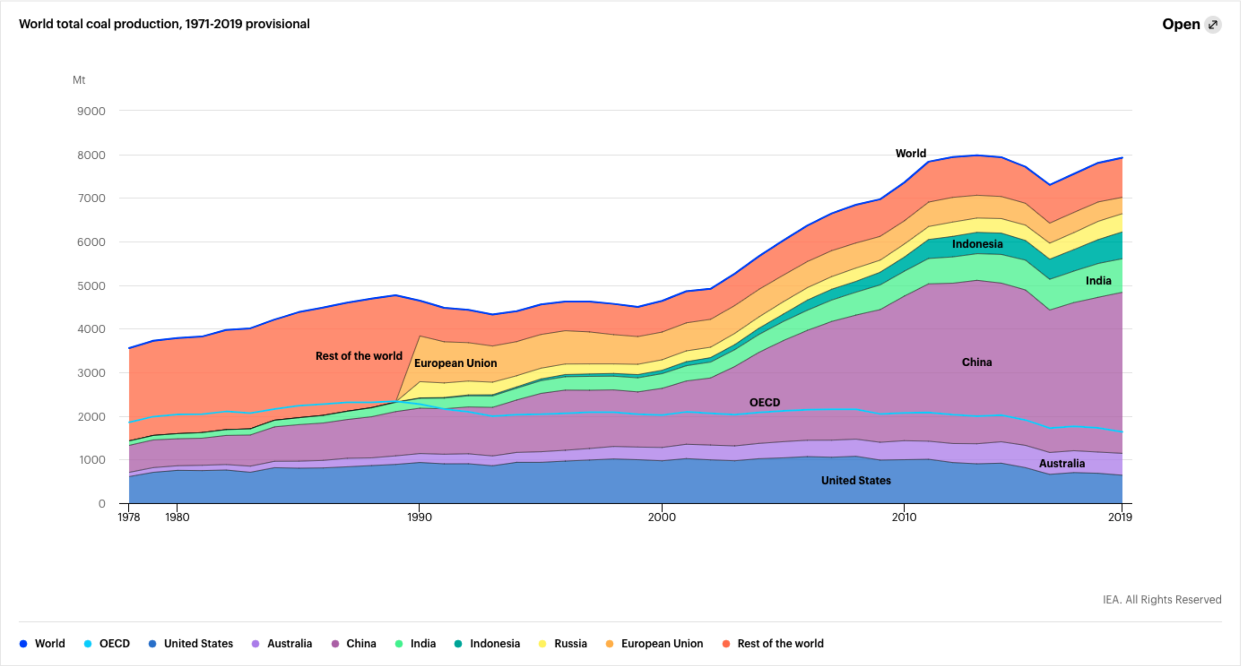


Figure 5: ***Instantaneous radiative force of greenhouse gases.*** **(Larson et al., 2019)**

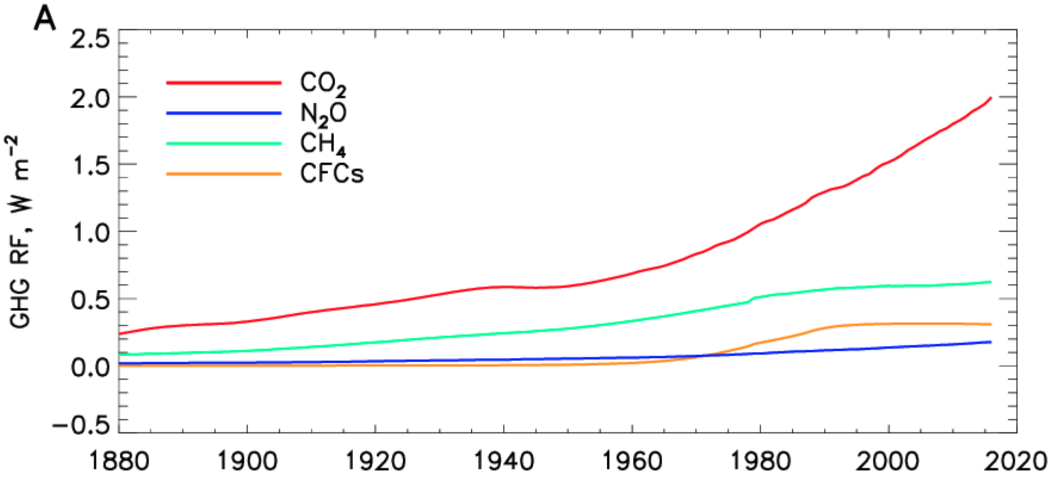


Figure 6: ***Upper Ocean Temperatures Hit Record High in 2020.*** **(Cheng et al., 2021)**

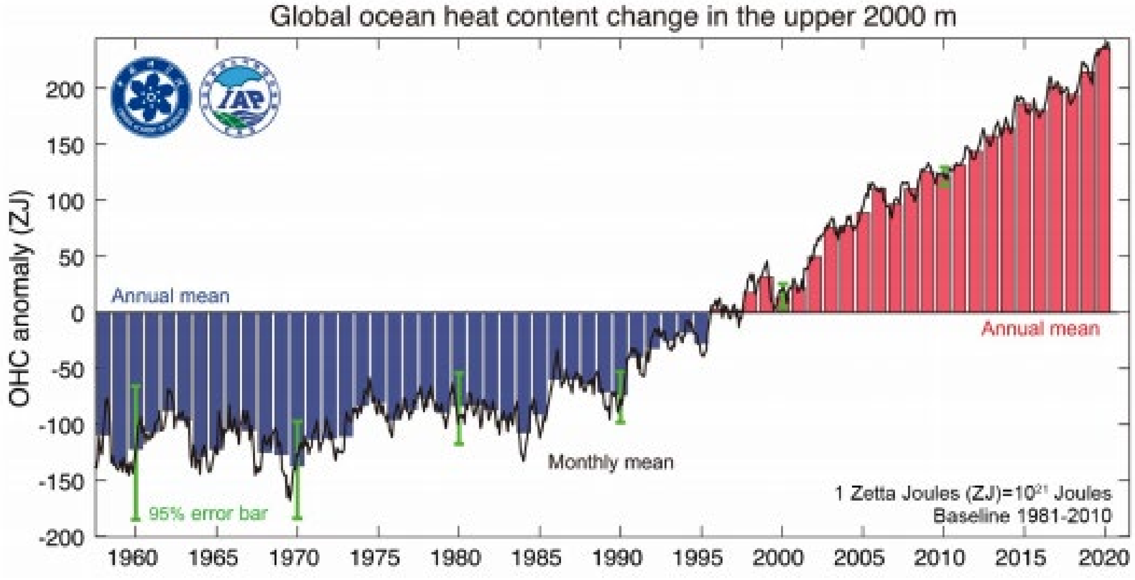


Figure 7: ***Contributors to Global Sea Rise Levels (1993 – 2018)*** **(Lindsey, 2021)**

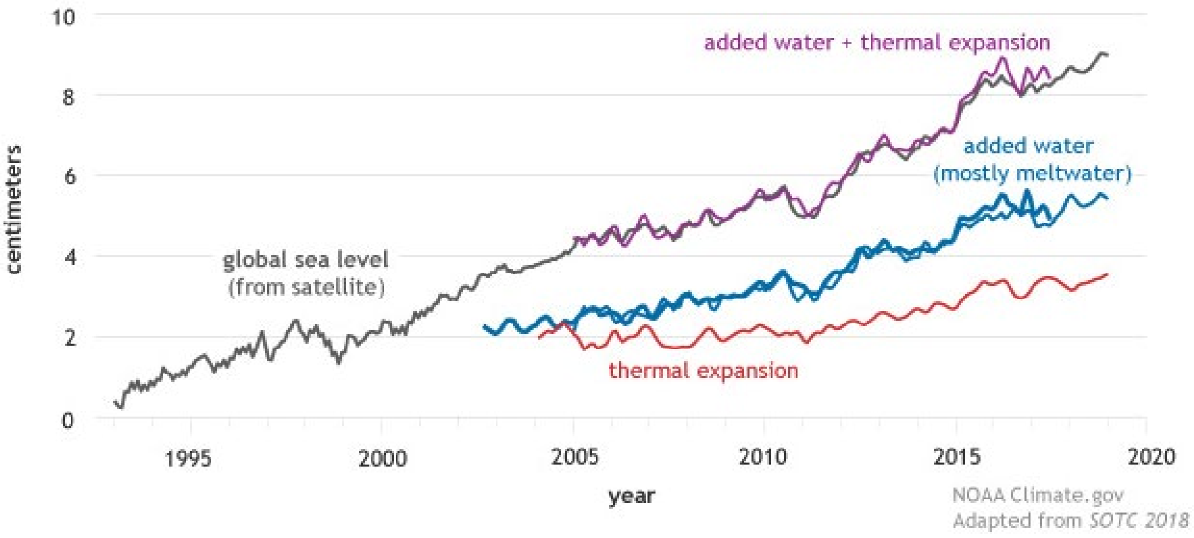


Figure 8: ***Primary Energy Consumption Levels (1949 – 2020)*** **U.S. Energy Information Administration. (2021A)**

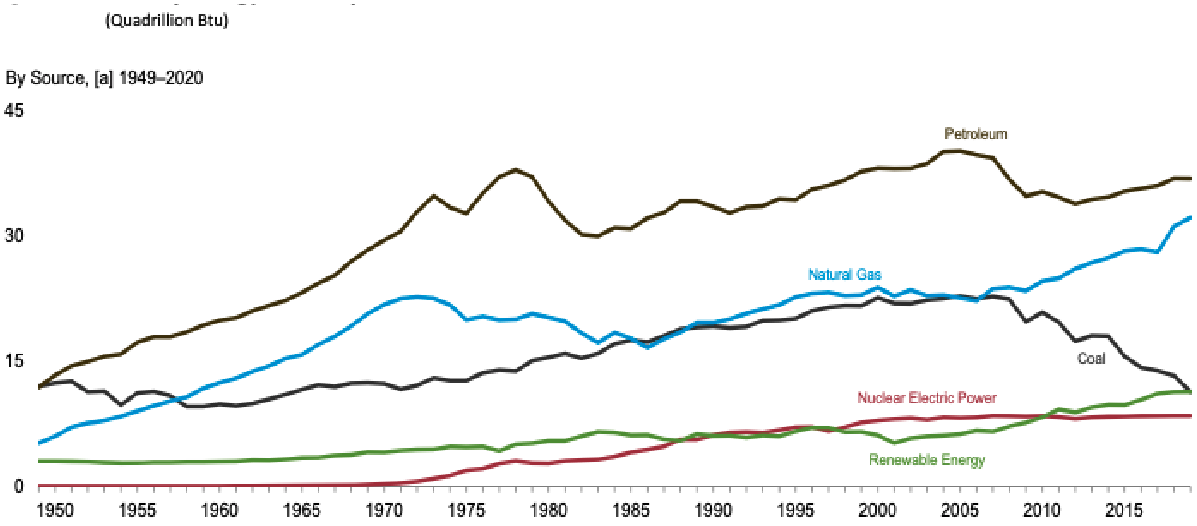


Figure 9: *Offshore Wind Turbine Structures.* (NYSERDA, 2018)

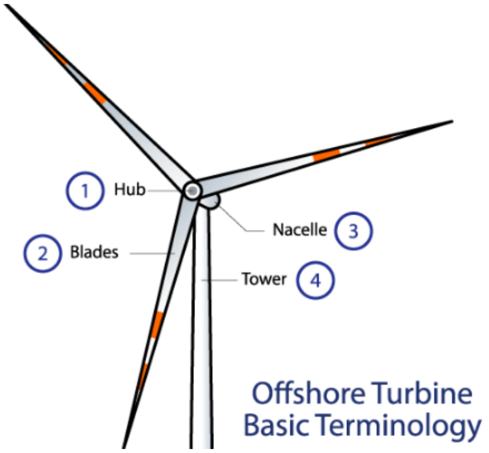


Figure 10: *Types of Offshore Wind Turbines.* (Bailey, Brookes, & Thompson, 2014)

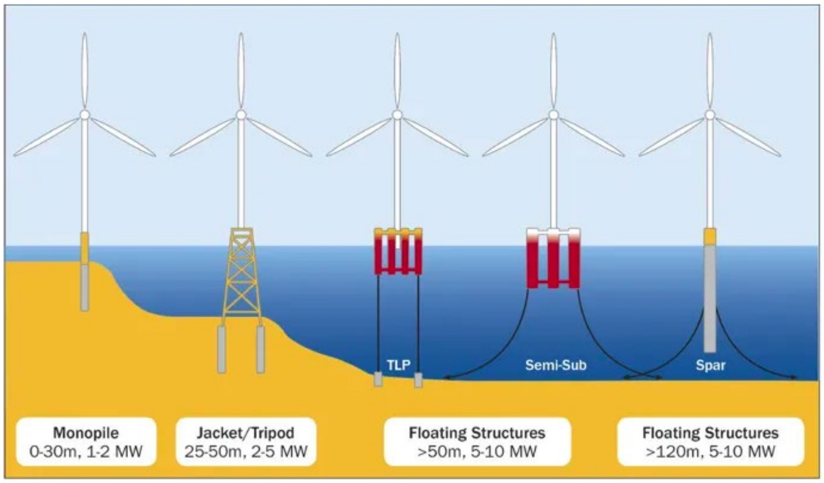


Figure 11: *Foundation, Array Cables, and Offshore Substation*. (Left*); Export Cable and Onshore Connection* (Right) (NYSERDA, 2018)

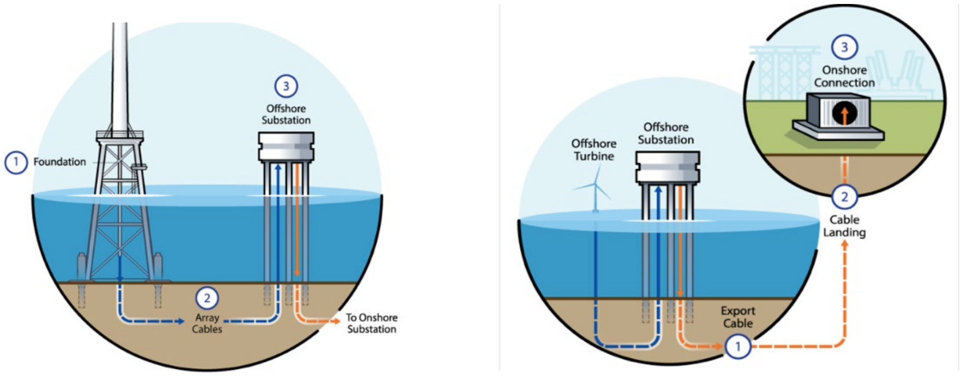


Figure 12 & 13: Wind Farm Implementation Exclusion & Evaluation Parameters (Diaz et al., 2018)

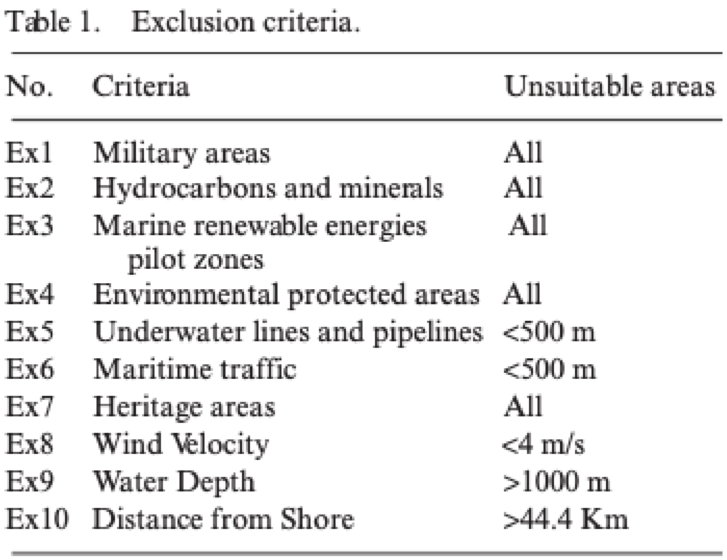


Table 1. Exclusion criteria.

No.	Criteria	Unsuitable areas
Ex1	Military areas	All
Ex2	Hydrocarbons and minerals	All
Ex3	Marine renewable energies pilot zones	All
Ex4	Environmental protected areas	All
Ex5	Underwater lines and pipelines	<500 m
Ex6	Maritime traffic	<500 m
Ex7	Heritage areas	All
Ex8	Wind Velocity	<4 m/s
Ex9	Water Depth	>1000 m
Ex10	Distance from Shore	>44.4 Km

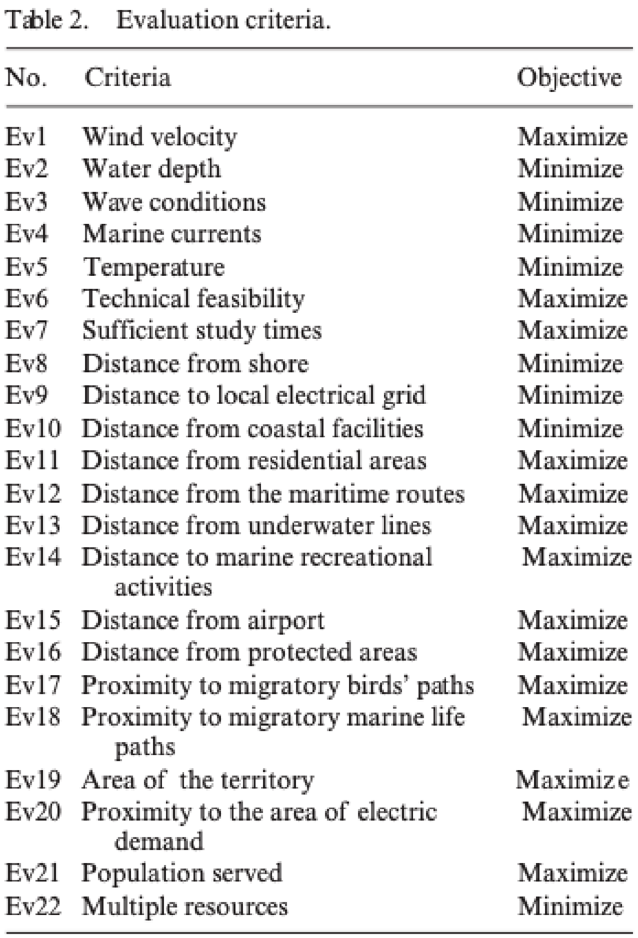


Table 2. Evaluation criteria.

No.	Criteria	Objective
Ev1	Wind velocity	Maximize
Ev2	Water depth	Minimize
Ev3	Wave conditions	Minimize
Ev4	Marine currents	Minimize
Ev5	Temperature	Minimize
Ev6	Technical feasibility	Maximize
Ev7	Sufficient study times	Maximize
Ev8	Distance from shore	Minimize
Ev9	Distance to local electrical grid	Minimize
Ev10	Distance from coastal facilities	Minimize
Ev11	Distance from residential areas	Maximize
Ev12	Distance from the maritime routes	Maximize
Ev13	Distance from underwater lines	Maximize
Ev14	Distance to marine recreational activities	Maximize
Ev15	Distance from airport	Maximize
Ev16	Distance from protected areas	Maximize
Ev17	Proximity to migratory birds' paths	Maximize
Ev18	Proximity to migratory marine life paths	Maximize
Ev19	Area of the territory	Maximize
Ev20	Proximity to the area of electric demand	Maximize
Ev21	Population served	Maximize
Ev22	Multiple resources	Minimize

Figure 14: ***Main pressures from OWF during the operational phase*****. (Bergström et al., 2014)**

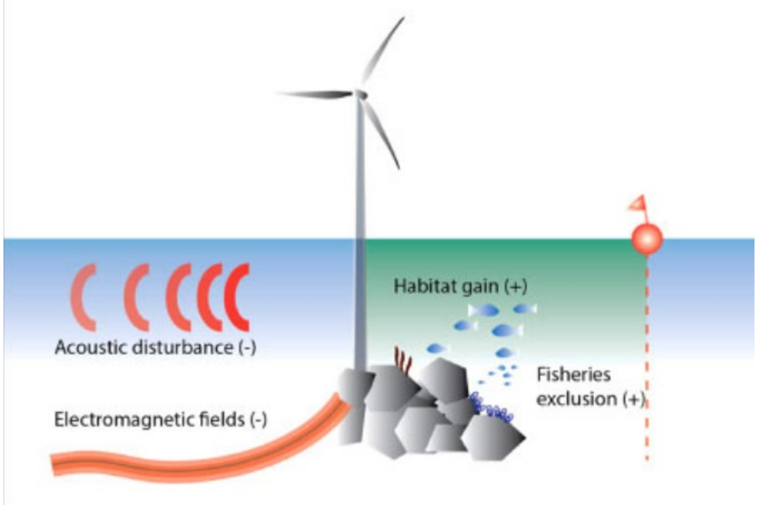


Figure 15: ***Summary of the generalized impact assessment*** **(Bergström et al., 2014)**

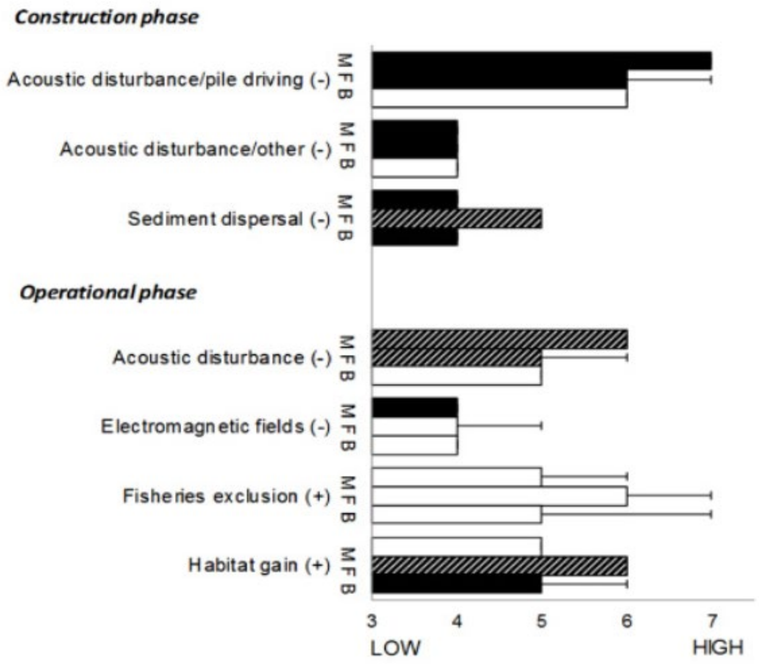
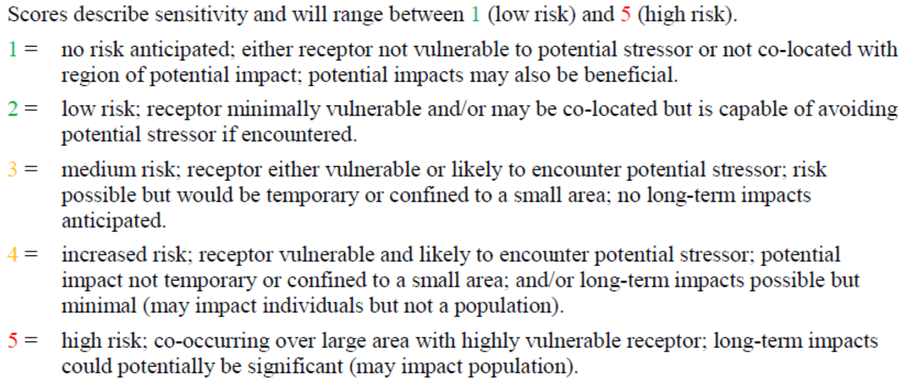


Figure 16: ***Descriptions for ratings of Risk Matrix.*** **(NYSERDA, 2017a)**



Scores describe sensitivity and will range between 1 (low risk) and 5 (high risk).

1 = no risk anticipated; either receptor not vulnerable to potential stressor or not co-located with region of potential impact; potential impacts may also be beneficial.

2 = low risk; receptor minimally vulnerable and/or may be co-located but is capable of avoiding potential stressor if encountered.

3 = medium risk; receptor either vulnerable or likely to encounter potential stressor; risk possible but would be temporary or confined to a small area; no long-term impacts anticipated.

4 = increased risk; receptor vulnerable and likely to encounter potential stressor; potential impact not temporary or confined to a small area; and/or long-term impacts possible but minimal (may impact individuals but not a population).

5 = high risk; co-occurring over large area with highly vulnerable receptor; long-term impacts could potentially be significant (may impact population).

Figure 17: ***Levels of potential risk associated with pre-construction activity.*** **(NYSERDA, 2017a)**

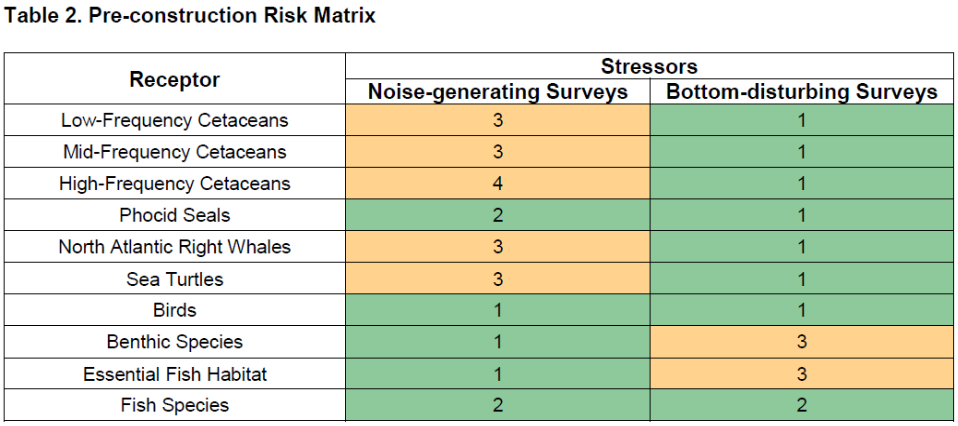


Table 2. Pre-construction Risk Matrix

Receptor	Stressors	
	Noise-generating Surveys	Bottom-disturbing Surveys
Low-Frequency Cetaceans	3	1
Mid-Frequency Cetaceans	3	1
High-Frequency Cetaceans	4	1
Phocid Seals	2	1
North Atlantic Right Whales	3	1
Sea Turtles	3	1
Birds	1	1
Benthic Species	1	3
Essential Fish Habitat	1	3
Fish Species	2	2

Figure 18: ***Levels of potential risk associated with construction activity.*** **(NYSERDA, 2017a)**

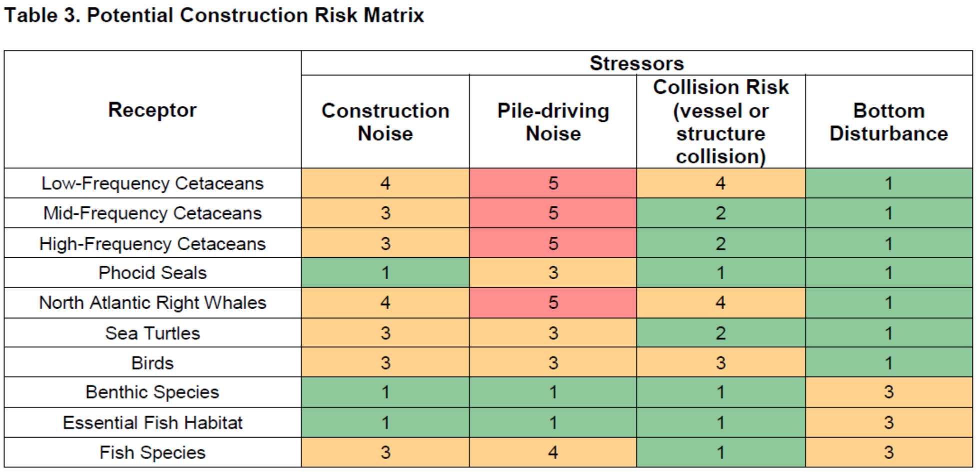


Table 3. Potential Construction Risk Matrix

Receptor	Stressors			
	Construction Noise	Pile-driving Noise	Collision Risk (vessel or structure collision)	Bottom Disturbance
Low-Frequency Cetaceans	4	5	4	1
Mid-Frequency Cetaceans	3	5	2	1
High-Frequency Cetaceans	3	5	2	1
Phocid Seals	1	3	1	1
North Atlantic Right Whales	4	5	4	1
Sea Turtles	3	3	2	1
Birds	3	3	3	1
Benthic Species	1	1	1	3
Essential Fish Habitat	1	1	1	3
Fish Species	3	4	1	3

Figure 19: ***Levels of potential risk associated with post-construction activity.*** **(NYSERDA, 2017a)**

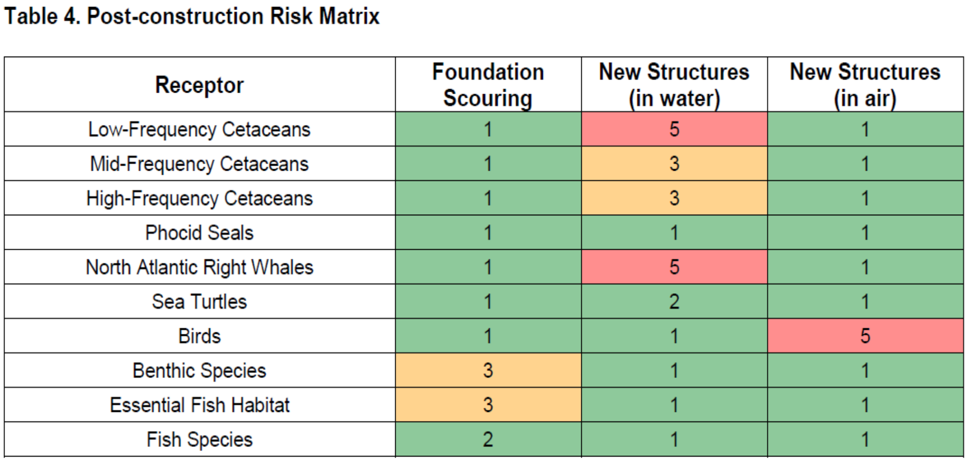


Table 4. Post-construction Risk Matrix

Receptor	Foundation Scouring	New Structures (in water)	New Structures (in air)
Low-Frequency Cetaceans	1	5	1
Mid-Frequency Cetaceans	1	3	1
High-Frequency Cetaceans	1	3	1
Phocid Seals	1	1	1
North Atlantic Right Whales	1	5	1
Sea Turtles	1	2	1
Birds	1	1	5
Benthic Species	3	1	1
Essential Fish Habitat	3	1	1
Fish Species	2	1	1

Figure 20: ***Levels of potential risk associated with all activity.*** **(NYSERDA, 2017a)**

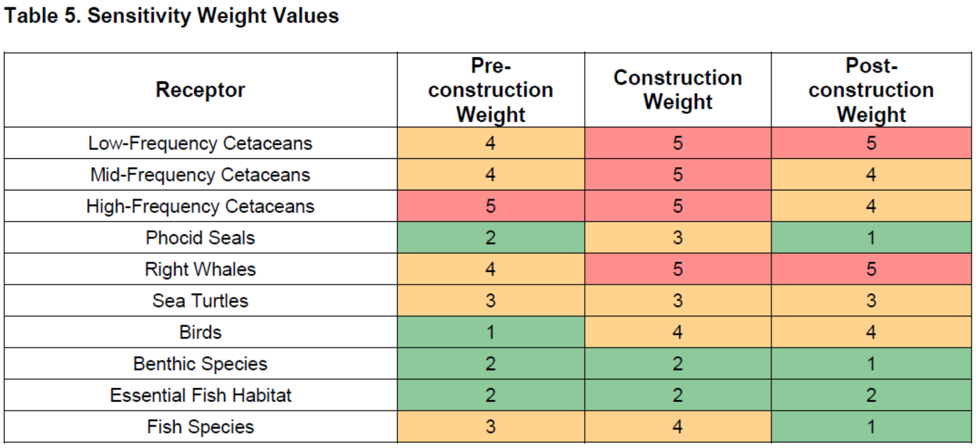


Table 5. Sensitivity Weight Values

Receptor	Pre-construction Weight	Construction Weight	Post-construction Weight
Low-Frequency Cetaceans	4	5	5
Mid-Frequency Cetaceans	4	5	4
High-Frequency Cetaceans	5	5	4
Phocid Seals	2	3	1
Right Whales	4	5	5
Sea Turtles	3	3	3
Birds	1	4	4
Benthic Species	2	2	1
Essential Fish Habitat	2	2	2
Fish Species	3	4	1

Figure 21: ***Alternative Burying Methods for EMF Reduction.*** **(BOEM, 2020)**

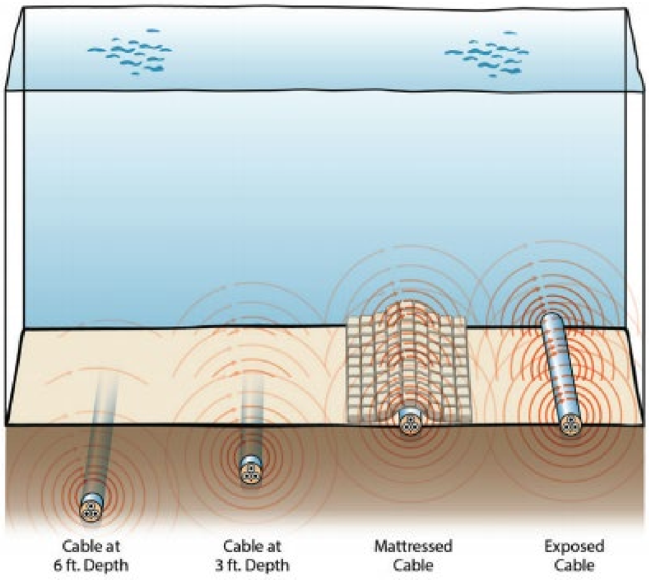


Figure 22: ***Predicted Mean Annual Wind Speeds at 90-m Height.*** **(NREL, 2021)**

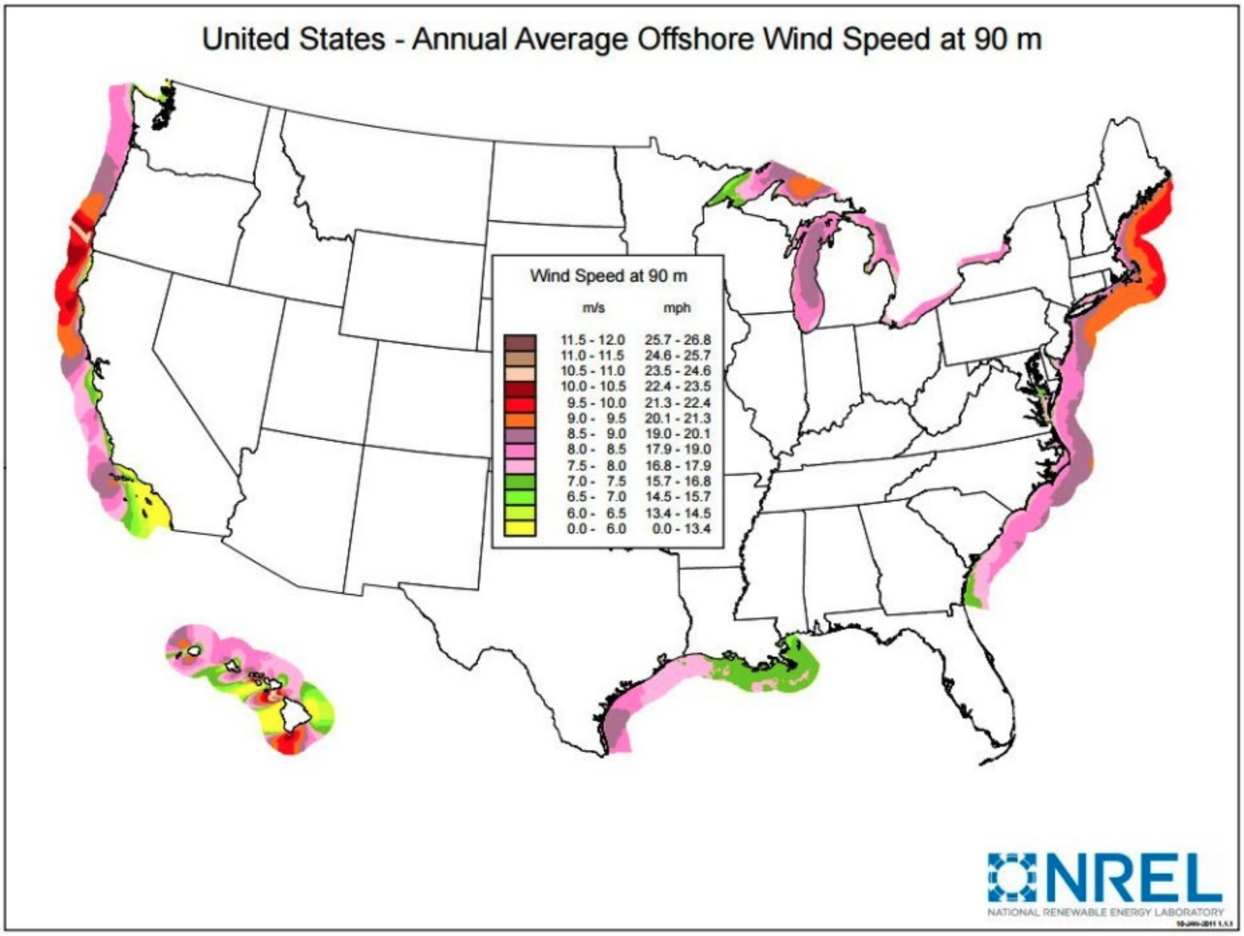
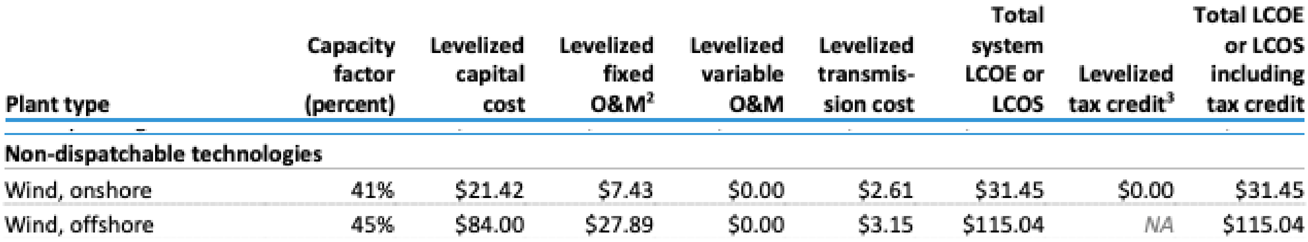
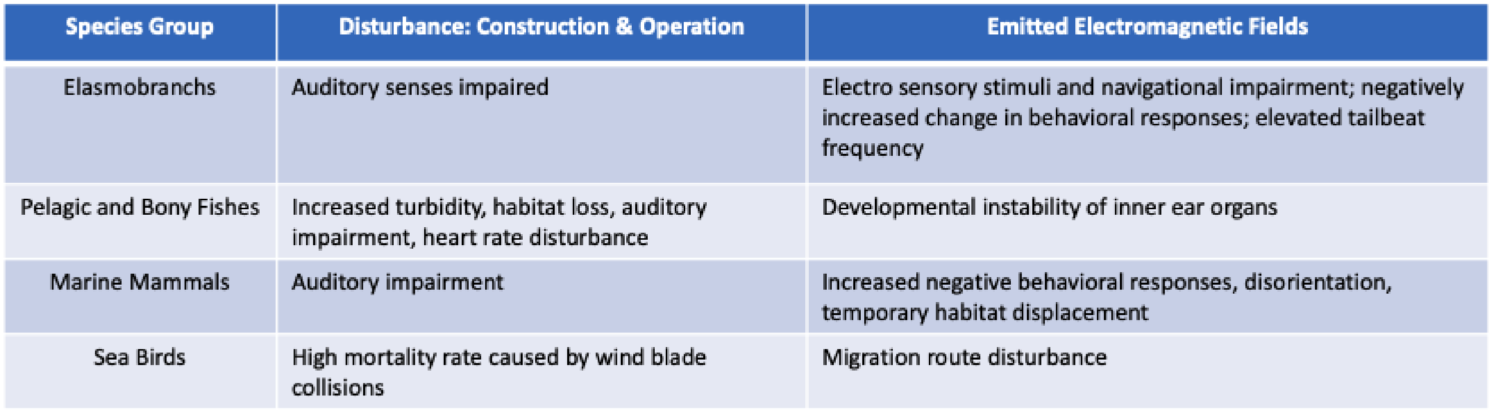


Figure 23: ***Estimated levelized cost of electricity for new resources entering service in 2026 (2020 dollars per MWh)*** **(U.S. Energy Information Admin., 2021)**



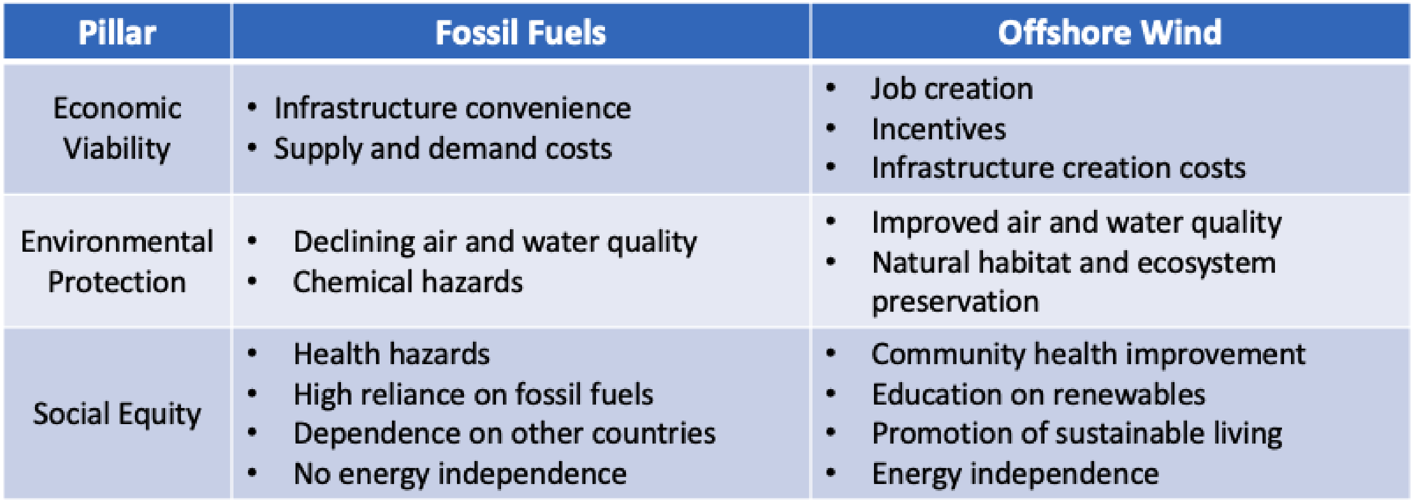
Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M²	Levelized variable O&M	Levelized transmission cost	Total system LCOE or LCOS	Levelized tax credit³	Total LCOE or LCOS including tax credit
Non-dispatchable technologies								
Wind, onshore	41%	$21.42	$7.43	$0.00	$2.61	$31.45	$0.00	$31.45
Wind, offshore	45%	$84.00	$27.89	$0.00	$3.15	$115.04	*NA*	$115.04

Table 1: ***Offshore Wind Farm Impacts on Sensitive Species.*** **(Erdesz, 2019)**



Species Group	Disturbance: Construction & Operation	Emitted Electromagnetic Fields
Elasmobranchs	Auditory senses impaired	Electro sensory stimuli and navigational impairment; negatively increased change in behavioral responses; elevated tailbeat frequency
Pelagic and Bony Fishes	Increased turbidity, habitat loss, auditory impairment, heart rate disturbance	Developmental instability of inner ear organs
Marine Mammals	Auditory impairment	Increased negative behavioral responses, disorientation, temporary habitat displacement
Sea Birds	High mortality rate caused by wind blade collisions	Migration route disturbance

Table 2: ***The Three Pillars of Sustainability: Fossil Fuels & Offshore Wind.*** **(Purvis et al., 2018)**



Pillar	Fossil Fuels	Offshore Wind
Economic Viability	• Infrastructure convenience • Supply and demand costs	• Job creation • Incentives • Infrastructure creation costs
Environmental Protection	• Declining air and water quality • Chemical hazards	• Improved air and water quality • Natural habitat and ecosystem preservation
Social Equity	• Health hazards • High reliance on fossil fuels • Dependence on other countries • No energy independence	• Community health improvement • Education on renewables • Promotion of sustainable living • Energy independence