Multi-criteria Analysis of Offshore Wind Energy Site Suitability in North Carolina

By

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There is growing social, political, and economic interest in developing renewable energy technologies in an effort to create a more sustainable and secure energy market. Wind energy has potential to satisfy energy needs with fewer negative impacts than conventional energy production. North Carolina has some of the greatest offshore wind potential in the US; however, a multitude of barriers prevent the construction of wind farms. Planners must consider a variety of exclusion variables when deciding where to allow development, including environmental, economic, and socio-political factors. The Bureau of Ocean Energy Management first released potential leasing blocks totaling approximately 474,016 hectares, based on applicable exclusion variables to gauge stakeholder interest and opinion. Based on responses, official Wind Energy Areas (WEAs) were defined. At 124,477 hectares, the WEAs are remarkably smaller than the original call areas, greatly limiting NC's potential in this new market. However, many of the variables limiting the WEAs have mitigation potential allowing for expansion of offshore wind.

This study utilizes public comment data and GIS layers for key exclusion variables used to define WEAs. By treating variables of interest as distinct layers, GIS was used to identify variations in the suitability in the ocean space off North Carolina's

coastline. By analyzing wind feasibility while taking into consideration site-specific mitigation techniques, four site suitability maps were developed: environmental, economic, social, and overall site suitability. Policy-makers and planners in NC can use these maps in the future to mitigate inherently local variables and to inform communication strategies that build public acceptance of offshore wind development, further improving chances of successful implementation.

Multi-criteria Analysis of Offshore Wind Energy Site Suitability in North Carolina

A Thesis

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By

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CHAPTER 1: INTRODUCTION

In recent years there has been growing social, political, and economic interest in developing renewable energy technologies in an effort to combat the growing risks associated with global climate change. The extraction and combustion of non-renewable fossil fuels destroys ecosystems, pollutes water resources and air, releases greenhouse gases causing climate change, and in many cases endangers the social capital and general quality of life within affected communities (Klass 2011). As world population grows and countries develop industrialized, fossil fuel dependent economies, the global need for energy resources rises as well. This ever-growing need for energy is accelerating exploitation and dependence of a finite resource. In order to address these issues, technology in renewable energy has become a major focus all around the world. Internationally, interventions by governments, private sector and environmental non-governmental organizations are being persuaded to develop more sustainable practices, including increasing renewable energy production. The European Union has set a renewable energy target to produce 20% of its energy from renewables by the year 2020 (Snyder and Kaiser 2009a). In the United States, the House and Senate have debated bills requiring 15% growth in renewable energy sources by 2020. To date, no significant initiatives have materialized; however, Renewable Portfolio Standards (RPSs) have been established in 27 states and the District of Columbia, which has stimulated the renewable energy industry (ibid).

Wind energy has impressive potential to satisfy growing energy needs with much fewer of the negative impacts that are associated with traditional methods of energy production. In the United States, the potential energy production for onshore and offshore wind energy combined is estimated to be 49,759,806 gigawatt hours (Lopez et al. 2012). It is projected that 16,975,802 of these gigawatt hours could be generated by offshore wind farms (Lopez et al. 2012). This is equivalent to a gross wind power resource of 4,223 gigawatts (GW) a year in American waters (ibid). To put that into perspective, one single GW of wind energy would supply between 225,000 and 300,000 average U.S. homes (ibid). Of particular importance to this research, the state of North Carolina has more potential for wind energy than any other coastal Atlantic state, however a multitude of barriers have prevented the construction of wind farms in North Carolina to date (Whichard 2011). Despite the documented cases of successful implementation in a number of countries including the United Kingdom and China, there seems to be hesitance in the United States as there are currently no operating wind farms in American coastal waters (American Wind Energy Association 2011).

This project seeks to analyze the spatial variation of suitability for offshore wind energy development in North Carolina's coastal waters by evaluating environmental, economic and socio-political factors that impact wind turbine development and planning. This project uses public comment data, publically available data, and existing research to create potential alternate suitability scenarios to create Wind Energy Areas (WEAs) in a future political climate that is more favorable towards renewable energy development and more willing to consider mitigation measures when identifying potential leasing blocks.

Research Questions

The goal of this project is to gain an increased understanding of the spatial suitability or acceptability of wind energy resource development off the North Carolina coast based on existing environmental, economic, and socio-political data. It is the intent of this research to compare the results to the blocks currently being considered in North Carolina to evaluate what factors most heavily influenced North Carolina's current Wind Energy Areas, and to inform which areas may be worth further consideration for future offshore wind energy development. The following questions guide the research and inform the literature reviewed, the data analysis, and the final recommendations:

1. What is the spatial variation of environmental, economic, social, and overall site suitability for offshore wind in North Carolina?
2. What factors are stakeholders most supportive of, or concerned about, regarding offshore wind development in North Carolina?
    a. What criterion do stakeholders recommend to planners?
    b. What factors can be mitigated to increase suitability?

This thesis is composed of 5 chapters. Chapter 2 includes a literature review of existing research on the environmental, economic and socio-political factors that impact offshore wind site suitability in addition to how GIS can be used to model suitability based on these factors. Chapter 3 includes the conceptual framework of the research, including the two-part research design and the methods for analysis used to complete this thesis. Chapter 4 outlines includes a discussion of the results of the study. Lastly, Chapter 5 includes a more detailed discussion of the findings and research questions, as well as the planning and policy implications of the research.

CHAPTER 2: LITERATURE REVIEW

History of Offshore Wind

While the idea of harnessing offshore wind power was discussed as early as the 1930s, it wasn't until 1990 that the first modern offshore wind turbine was constructed 250m offshore of Northern Sweden. This was followed in 1991 by the first offshore commercial wind farm constructed 2.5km offshore of Denmark (Bilgili, Yasar and Simsek 2011). Since then, offshore wind has grown exponentially, particularly in Northern European countries where a total of 2,488 wind turbines in 74 wind farms off the shores of eleven European countries fuel the electricity grid, for a total installed capacity of 8,045.3 megawatts (MW) of power. This is enough to cover approximately one percent of Europe's electricity demand (Corbetta et al. 2015).

Offshore wind has various advantages and disadvantages over its onshore counterpart. Advantages for offshore production include more reliable wind resources due to stronger, and steadier wind speeds and fewer aesthetic impacts than onshore (Esteban et al. 2011). The primary disadvantages of offshore wind production is that it is more costly than most energy production methods, including onshore wind (Esteban et al. 2011). This is a potential contributor to reluctance in countries such as the United States where offshore wind does not yet exist despite the number of cases of successful implementation in several countries around the world (Whichard 2011).

As with developments on land, offshore wind farms must go through a planning process in order to evaluate existing ocean uses and make educated decisions about how to most sustainably harness the resource with minimal impacts to existing habitats, industries, and societies. The ocean is a vast open space where the possibility for offshore wind energy development is promising.

North Carolina has some of the greatest potential for wind energy production of any coastal Atlantic state. This is primarily because the wind blows strongly and consistently miles off the state's coastline due to mid-latitude cyclones and storm tracks, pressure gradient between the Gulf Stream and the Labrador Current, and seasonal landmass-ocean baroclinic gradient (Whichard 2011). Despite North Carolina's promising offshore wind potential, the state lags behind other states in the development process. This could be due to the complicated, multi-variable nature of the planning process. There is a wide body of literature that analyzes environmental, economic, socio-political variables that impact the success of wind energy planning and development using a variety of methodologies. For purposes of planning for wind development in North Carolina, a large offshore feasibility study was conducted by several faculty from the University of North Carolina Chapel Hill (UNC-CH) in 2009. This study considered many variables that impact offshore wind suitability in an effort to assist the planning process. It identifies a wide body of literature applicable to this project and analyzes variables limiting offshore wind energy progress in North Carolina in addition to what needs to be done to mitigate these impacts and boost advancement. The following literature review will evaluate the many environmental, economic, and socio-political variables that should be taken into consideration when spatially evaluating the suitability of offshore wind energy developments.

Environmental Considerations

Developers of offshore wind energy projects must consider a range of environmental constraints. Any time development occurs on a large-scale, there will be some level of impact on the existing environmental functions. Unlike traditional fossil fuel energy production, offshore wind energy has fewer environmental impacts because it produces energy without burning fuel and emitting pollution. It is also less physically invasive than coal, natural gas, and oil extraction, which all have a history of large-scale ecosystem destruction. Regardless, the impact of construction and operation of wind farms on the surrounding environment must be carefully evaluated. The key variables commonly considered include marine mammal habitats, avian migration, habitat areas of particular concern (HAPC), and endangered species habitats (UNC-CH 2009). Ecological conditions can be extremely delicate in coastal environments. Because wind turbines are anchored below the ocean surface and stand hundreds of feet tall, developers must be careful not to locate farms where they could disrupt or deteriorate protected marine habitats underwater and bird and bat migratory paths in the skies above.

Offshore wind turbines stand up to 400 feet tall, and wind farms can cover large areas of ocean space. They pose a potential risk to migrating sea birds, bats, and butterflies. According to the UNC-CH (2009) wind feasibility study, risks for winged species include loss of foraging habitat, loss of life from blade impact, and energy loss for birds and bats that are forced to take longer routes in order to avoid wind turbines. However, the risks to sea birds drastically reduce as turbines and farms move further offshore. Golder (2004) notes that the highest concentrations of birds exist 2-3 miles offshore for shore birds (e.g. sanderlings or sandpipers) and at the western edge of the Gulf Stream for pelagic seabirds such as pelicans and sea gulls. Because of distance, avian use drastically declines at 6-12 miles distance offshore out to the 30 meter depth zone (Lee 2009). Risks to bats and butterflies decline with distance as well; however, a Swedish study conducted by Ahlen et al. (2007) showed that insects were attracted to the white color of wind turbines up to 14km offshore and that bats, who eat insects, followed the food source. Risk to monarch butterflies – whose sustainability is threatened because of habitat loss - was determined to be insignificant due to their tendency to fly extremely low and close to shore during migration (UNC-CH 2009).

Below the ocean's surface is an abundance of marine species that must also be carefully considered during the offshore wind planning process, some of which are already listed as threatened or endangered. The North Atlantic right whale, a critically endangered species once hunted for whale oil, can be found near shore during fall and spring migrations with some individuals calving in NC waters rather than their usual locations off of the coast of Florida and Georgia (Patteson 2008). While hunting is no longer a threat to the right whale, shipping collisions and habitat depletion remain a major concern. Other types of whales, as well as bottlenose dolphins and spotted dolphins are common to areas further offshore and must also be considered (Read et al. 2003). All species of sea turtles found in US waters are listed as threatened or endangered due to fishing/trawling (by-catch), pollution, vessel strikes, and loss of nesting and feeding habitat from erosion and oceanfront development – all persistent problems along the NC coast (UNC-CH 2009). With over 300 miles of oceanfront beaches, NC provides large areas of nesting habitat for sea turtle species to lay eggs.

Hatchlings migrate across ocean waters to the Gulf Stream in late summer and early fall, so there is a level of risk of them being distracted and set off course from noise during construction and the lights on operating turbines (UNC-CH 2009). However, wind farms may also provide positive benefits, as loggerheads have been known to be attracted to the mussel and crab habitats that favor oil platforms in the Gulf of Mexico. Because turbine platforms are likely to produce a similar artificial reef effect, it is likely that the turtle species that feed on similar food sources will also be attracted to wind turbine platforms (Lohoefener et al. 1990). The installation of wind farms is also expected to produce some amount of change for benthic invertebrates and fish habitats due to the hard-bottom habitat that turbine platforms will create, however this is predicted to be an ecologically beneficial impact due to the commercially and recreationally beneficial habitat that hard-bottom types provide (UNC-CH 2009).

There are multiple mitigation options that can be utilized to protect certain marine habitats. A study conducted in the United Kingdom by Wilson and Elliott (2009) found that careful design of turbine platforms can cause a net gain in habitat as loss during construction can be minimized and the end result can improve the ecology of the area. Turbine platforms can serve as fish aggregating devices (FAD), or man-made objects that attract ocean going pelagic fish (e.g., marlin and tuna). Oil rig platforms have also been known to serve as FADs (Wilson and Elliott 2009).

Minimal marine impacts have also been found in other European studies such as those carried out by Petersen and Malm (2006) and Copping et al. (2014). One of the major concerns is impact to habitat during the construction of the turbines. Copping et al. monitored the effect of offshore wind construction in Northern Ireland over six years of baseline monitoring and five years of post-construction observation including aerial and shoreline surveys and underwater noise surveys. While the turbines they studied are underwater tidal energy turbines rather than wind energy turbines, the study still offers valuable information on offshore renewable energy's impact on marine ecosystems. The data collected by this project shows no significant impact on existing marine, avian, or benthic habitat from tidal turbine function or noise (Copping et al. 2014). Careful attention to siting and construction operations must be considered during the planning process in order to reduce the risk of severe environmental impact. Petersen and Malm (2006) noted that mitigation measures such as noise reduction and turbine design have received little attention in existing environmental assessments or from key stakeholders in Europe. Given the emerging nature of offshore wind in the US, more studies of this nature are needed in the Atlantic, and these options and possibilities must be considered in order to more accurately assess offshore wind site suitability.

Beyond mitigation strategies related to wind farms themselves, there are also mitigation measures related to offshore wind that address the larger issues of climate change. Offshore wind is a renewable energy resource that can help reduce overall CO^2 emissions when compared to other energy generation options in any given region. CO^2 is one of several greenhouse gasses contributing to climate change. Erosion from sea level rise, rising water temperatures, and stronger coastal storms are all associated with a warming climate and pose a major risk to the same species that offshore wind could potentially impact. Whether or not the immediate risk of wind farms is greater than the overall impact of climate change requires further study, offshore wind's potential to greatly reduce carbon emissions must be taken into consideration when considering environmental risk. An offshore wind farm with 450 3.6MW turbines would offset between 3 and 5 million metric tons of CO^2 equivalents (MTCDE) at inception, and more than 50 million MTCDE over the lifetime of the project (UNC-CH 2009). This is equivalent to removing 9 million cars from the streets or the emissions produced from 11 coal-fired power plants (ibid).

Economic Considerations

There are a variety of technical and ocean use considerations that impact the economic feasibility of offshore wind energy development. The physical environmental factors that influence biodiversity also determine the type of technology that must be used in certain areas and therefore the price tag on the development an offshore wind project. These include wind resources, geological conditions (e.g. bottom type), distance from shore, and bathymetry (UNC-CH 2009). Existing industrial ocean use (e.g. sand minding locations for beach nourishment, military areas, fisheries, shipping lanes, etc.) must also be considered when siting wind farms (ibid). The impact of wind farms on existing ocean uses should be minimized as much as possible, and environmental conditions must be cost effective to support and maintain commercial scale wind developments. Taking the necessary steps to ensure farms are located in resourceful areas with minimal effect on existing uses will allow for offshore wind to successfully find its place in North Carolina's coastal economy.

Spatial attributes that impact economic feasibility include wind speed, bathymetry, and distance from the coast. Wind speed directly correlates with how much energy can be harvested in any given location because the stronger and more consistent winds blow, the more energy that can be produced by a wind farm (UNC-CH 2009). Samoteskul et al. (2014) describe the monetary impacts of bathymetry and distance from energy facilities. Depths below 60m require a jacket foundation, costing approximately $6250 per metric ton an increase costs by 1.3 million dollars per meter of depth. Greater than 60m of depth requires a floating foundation, which cost approximately 9.6 million dollars for a generic 5MW turbine. Distances less than 80km from shore require HVAC cables, costing around $1,128,000 per km while distances greater than 80km require HVDC cables with the increased cost of $2,150,000 per km (Samoteskul et al. 2014). Off the shores of North Carolina, wind speeds are exceptionally strong and the continental shelf drops off slowly, allowing for areas further from the coast to be developed using jacket foundations, giving North Carolina more potential for cost effective offshore wind than any other Atlantic state

However, there are still more variables to consider as new wind developments must also measure and mitigate their potential impact on existing ocean uses. As outlined in the UNC-CH wind feasibility study (2009), a multitude of ocean uses occur off of North Carolina's shores. A variety of military uses exist such as training areas and unexploded ordnance (UXO) dumping grounds that are off limits to any development, including offshore wind. While small vessels may be capable of navigating through wind farms, shipping corridors for large vessels will compete for ocean use and must be carefully considered. Offshore wind development could also impact existing commercial and recreational fishing uses. Some commercial and recreational practices will be able to continue in and around wind farms, however areas common to practices that require large vessels and activities such as bottom dredging should be avoided in the vicinity of a wind farm in order to prevent collisions (Voss, Peterson and Fegley 2013). In addition to these uses, cultural resources such as shipwrecks, mining resources for beach nourishment, and ocean dumping grounds must all be included in wind farm plans (UNC-CH 2009).

There are mitigation possibilities that could reduce use conflict in North Carolina. The potential for fish aggregation around wind turbine platforms has been given little consideration as a possible benefit to recreational fishing (Wilson and Elliott 2009). Wind farms could also be labeled Marine Protected Areas (MPAs) for safety and environmental conservation purposes. MPAs are areas where use is legally managed in order to conserve marine resources. Wind farms would serve well as MPAs due to their potential to aggregate fish species and restricted use could increase ecological and recreational productivity (Inger et al. 2009). Because environmental and economic impacts are a result of all energy production, assessing impacts as trade-offs through marine spatial planning (MSP), a process that considers multiple ocean uses (energy government, industry, recreation, conservation, etc.) to make coordinated decisions on ocean resources usage and sustainability, can also improve accuracy of site suitability assessment for offshore renewable energy (White, Halpern and Kappel 2012). Samoteskul et al. (2014) utilized cost-effectiveness analysis (CEA), a type of economic analysis that compares the costs and effects of a number of courses of action, to assess economic site suitability for Mid-Atlantic wind energy areas (New Jersey, Delaware, and Maryland) and found that altering commercial shipping routes to avoid prime offshore wind energy areas (adding about 18.5km per trip) would cost approximately $193 million dollars over the course of 29 years, while the combined savings for the offshore wind industry could amount to roughly $13.6 billion dollars, a significant trade-off value that has been given little consideration during the planning process for offshore wind in the US.

Socio-Political Considerations

The socio-political nature of offshore wind planning is quite complicated, however levels of social pressure and political will, or lack there of, has certainly had an influence on the development of offshore wind in the United States. Availability of political financial incentives, regulatory structure, and public perception are all examples of socio-political factors that influence offshore wind planning and site suitability, however the degree of influence that each of these factors has is widely debated.

While the United States is lagging behind in offshore wind energy, the industry is growing quickly in other places around the world, particularly in Europe where the social and political will to expand renewable resources has gained much more momentum. Political incentives are an example of overlap between economic and socio-political categorization, however the decision to initiate them is ultimately a political one and is beyond the power of the developers themselves. Looking at the framework in other countries where offshore wind developments have been successful offers further exploration into what it takes to drive a fruitful market offshore wind energy market.

On an international scale, one major policy driver behind the development of offshore energy has been the Kyoto Protocol, to which all United Nation member states except Andorra, Canada, South Sudan, and the United States are signatories.

According to Snyder and Kaiser (2009a), the Protocol calls for its signatories to reduce their carbon dioxide emissions using methods such as expanding renewable energy markets. Unlike most developed nations across the world, the United States chose not to sign the Kyoto Protocol due to the economic cost of lowering emissions in one of the world's top greenhouse gas producing nations. This ultimately placed the US behind other developed nations in the development of incentives vital to growth in the renewable energy sector. Kyoto Protocol signatories use a number of financial incentives to boost renewable energy. Common forms are feed-in tariffs, renewable energy tax credits, carbon taxes, grants and tenders (UNC-CH 2009). Feed-in tariffs ensure profit by setting a price on the energy production of developments before they are developed. Renewable energy tax credits, such as the renewable electricity production tax credit (PTC) in the United States, credit a certain amount of money per kWh of electricity produced by wind power. Carbon taxes are when developers of renewable energy projects are exempt from certain taxes based on reduced greenhouse gas emissions. Grants to fund development can also be offered. In the United Kingdom, the government offers grants for offshore energy developers. As of 2009, they had paid $194 million dollars in grants divided between 10 different projects, an effort that has helped the United Kingdom become one of the largest producers of offshore wind energy (Snyder and Kaiser 2009a). Methods to build competition and drive the renewable energy market have also been developed in many other Western European nations. For example, Denmark issues tenders for wind farms, which encourages competition between developers to offer the government the lowest feed-in price (Snyder and Kaiser 2009a).

In the same study, Snyder and Kaiser (2009a) explain that in the United States, renewable industry drivers are much less developed. The primary mechanism offered at the federal level in the United States is called the Production Tax Credit (PTC), which is a two-cent per kilowatt (kWh) federal tax credit for companies that produce renewable electricity. Unfortunately for developers in the United States where the planning process has been particularly time consuming, the PTC is written to expire if developments under it have not reached the stage of construction before a set date (Snyder and Kaiser 2009a). Frequent expiration deters companies that would otherwise invest in the market. Each time the PTC terminated, there was a decrease in the growth of the wind market, suggesting that the PTC has offered some stimulation in the American wind industry (Black et al. 2014, Snyder and Kaiser 2009a). As explained by Black et al. (2014), due to the lack of federal level incentives in the United States, the PTC must be accompanied by state level economic incentives in order to successfully drive renewable energy markets. Unlike offshore wind, onshore wind in the United States has grown rapidly due to state level political efforts such as tax exemptions, deductions, and credits, along with subsidies (grants, production incentives, and low-interest loans) and Renewable Portfolio Standards (RPS), which are regulations that require electricity supply companies to produce a specified amount of electricity from renewable sources (Black et al. 2014).

These initiatives are a start, however there is a substantial lack of state level subsidies and tax credits for states with offshore energy potential, such as North Carolina, making it difficult for the market to get a foothold. According to a second study by Snyder and Kaiser (2009b), without more effort at the state and even local levels to incentivize offshore wind markets, the cost-benefit of developing offshore wind farms will not be profitable enough for developers to invest. This unfortunate situation is apparent when offshore energy is compared to onshore energy and conventional fossil fuel sources. Due to cheap fossil fuel prices, lack of financial drivers, local opposition, and technological development, offshore wind is not yet economically competitive with onshore wind or conventional sources in the United States; however, this can change over time with advancements in technology, growth in the industry, additional incentives, and spikes in fossil fuel energy prices (Snyder and Kaiser 2009b).

Another socio-political factor to be considered when studying offshore wind development is the complicated nature of the regulatory process that governs projects in the United States (Figure 1). As explained by Martin and Smith (2004), the Submerged Lands Act (SLA) and the Outer Continental Shelf Lands Act (OCSLA) empower states with the right to govern waters within three nautical miles of their coasts. Beyond three nautical miles, where offshore wind developments are being considered, the federal government is given regulatory and permitting authority. Specifically under the OCSLA, the Secretary of the U.S. Department of the Interior is given authority to issue leases and permits for offshore energy and is delegated to the Bureau of Ocean Energy Management (BOEM). In order to gauge public and stakeholder opinion, BOEM is required to create potential wind development zones, known as "call areas" within offshore public trust waters, that may be suitable for leasing by utilities. Call areas generally have a range of positive attributes for wind energy production, and are potentially suitable for Environmental Assessment (EA) (Martin and Smith 2004). In North Carolina, the call areas were developed based on the 2009

UNC-CH wind feasibility study. These call areas are then presented to stakeholders and the public to gauge interest and concern. A public comment period is announced for stakeholders to respond with interest, support, and/or concerns. Upon evaluating respondents, BOEM then refines the call areas based on stakeholder input and releases new areas called wind energy areas (WEAs), which are followed by another comment period. They will either further alter WEAs or release them for EA. Once EA is recommended for lease issuance and site assessment activities, the next step in the process is leasing (BOEM 2015). A lease does not give the unconditional right to develop, rather gives the lessee the right to conduct site characterization studies and submit a Site Assessment Plan (SAP) and a Construction and Operations Plan (COP) for approval (Schaumberg, Auslander and Cossa 2014). If approved, the lease conducts the site assessment and submits SAP and a Site Characterization Study Report that includes mitigation strategies for any concerns identified by BOEM. BOEM then evaluates the submission and upon approval, a company may plan for construction (BOEM 2015).

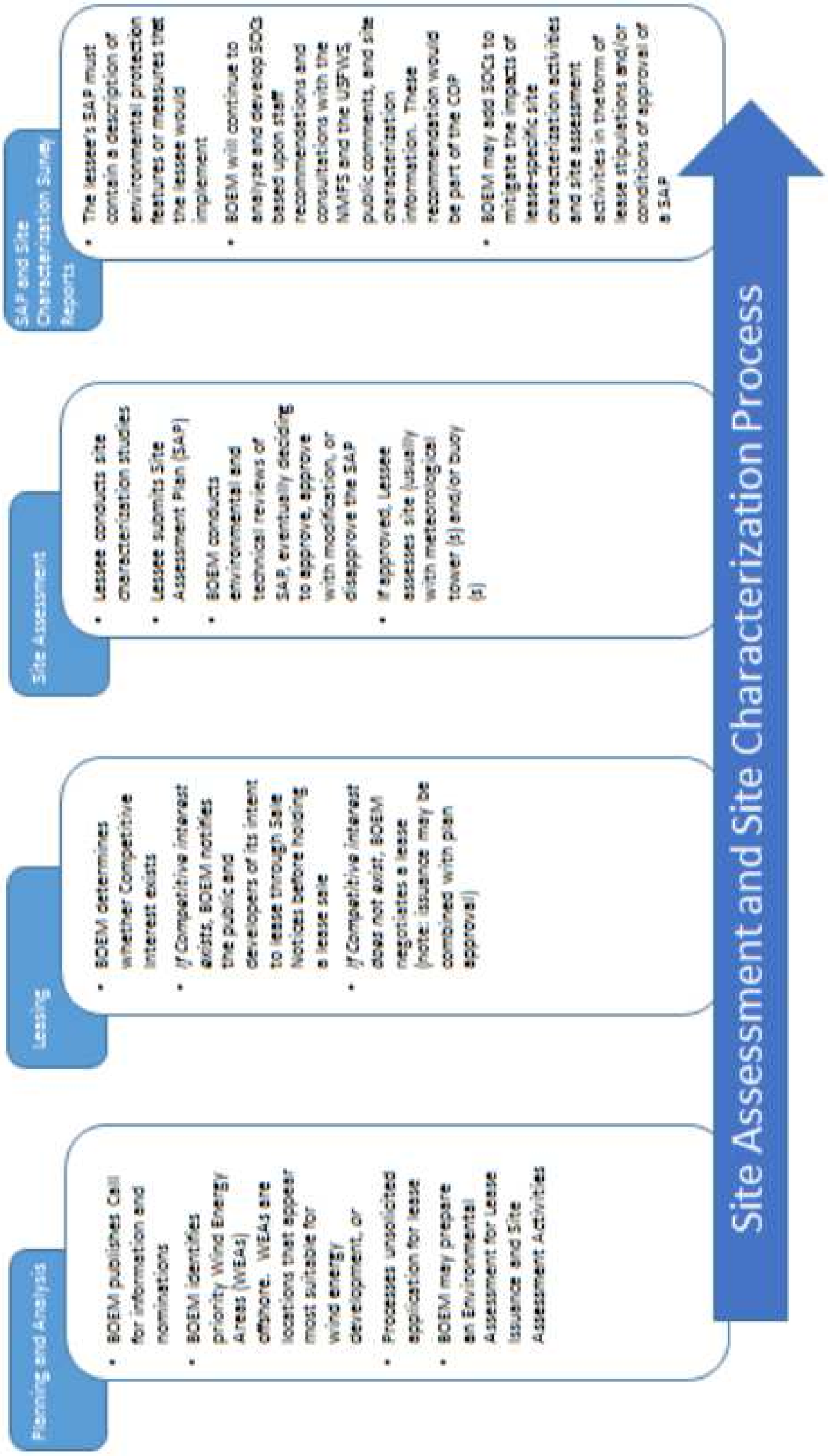


Figure 1: BOEM assessment and site characterization process

There are a number of offshore wind projects currently in the leasing stage in the northeast United States. After years of anticipation, the first competitive commercial wind energy lease sale was held by BOEM for leases on the OCS (Schaumberg et al. 2014). The successful bidders were Deepwater Wind, LLC and Dominion Resources, Inc. who signed agreements in 2009 to construct commercial wind farms off the coasts of Rhode Island, Massachusetts, and Virginia. In 2015, the Block Island Wind Farm, America's first offshore wind farm, began construction off the coast of Block Island, Rhode Island. Additional lease sales are expected in the near future off the coasts of New Jersey and Maryland. The Deepwater/Dominion wind project is predicted to generate two GW of electricity, which is enough to power approximately 700,000 homes (Schaumberg et al. 2014).

One of the first projects taken on in the U.S. was the *Cape Wind* project, located in the Nantucket Sound off the coast of Cape Cod, Massachusetts. Cape Wind's developers adequately addressed the factors outlined above, however major socio-political hurdles have significantly slowed the project's progress. According to Martin and Smith (2004), Cape Wind was first proposed in November of 2001. The proposed site is roughly five miles off the coast and will consist of 130 wind turbines, each around 400 feet tall. This location was chosen because Massachusetts has both adequate wind resources and relatively large subsidies for wind energy development within state-controlled waters. In addition, the state has promising renewable portfolio standards (RPS), and a 0.0005-dollar per kilowatt-hour tax on renewable power, which both are intended to make development of offshore wind energy more attractive (Martin and Smith 2004). Despite these state-level financial incentives, Cape Wind has encountered a 10+ year battle to acquire the proper approval and permits, a battle largely fueled by local public opposition (Powell 2012).

As explained by Powell (2012), among the groups contesting the placement was the Aquinnah Wampanoag Tribe, which filed a lawsuit in 2011 alleging that the turbines would ruin the view used for their sunrise ceremonies on Horseshoe Shoal, which is listed in the National Register of Historic Places. The lawsuit ultimately failed and approval was subsequently given for the project to proceed. This decision resulted in further resistance from other local interest groups (Powell 2012). The Alliance to Protect Nantucket Sound and the Town of Barnstable, Massachusetts filed a claim that BOEM did not "follow a coherent, objective, lawful decision-making process" which effectively contravened the public's right to participate in the review process for the project proposal (Powell 2012: 2042). The plaintiffs also pursued a case against the Federal Aviation Administration (FAA) on grounds that the FAA's approval that the project would not result in adverse effects on air space needed further study (Powell 2012).

The plaintiffs were able to do this with funding provided by businessman, William Koch who owns a home on the Nantucket Sound and started the Alliance to Protect Nantucket Sound (Rogers 2014). Koch is the son of the founders of Koch Industries, a business empire built on oil refining. Koch also owns a multi-million dollar family compound that sits on Nantucket Sound's waterfront within the viewshed of the proposed project (Seelya 2013). Over a decade after he started the Alliance to Protect Nantucket Sound, in March 2014 the Supreme Court ruled in favor of Cape Wind (Rogers 2014). Powell (2012) concludes that these types of issues may arise because of the federal government's inability to effectively govern the inherently local nature of offshore wind energy impacts and recommends more local control so that public opposition can be better handled.

Due to the array of localized issues that plague projects such as Cape Wind there has been an emergence of literature examining the public concerns and oppositions to wind farms. Opinion polls have tended to be the most common method of gauging public concern. Landry et al. (2012) used telephone and web survey data to analyze the potential impact of offshore wind farms on tourist's behavior and site choices in coastal North Carolina. Their survey revealed that offshore wind turbines would have little impact on beach visitation habits. Despite acknowledging some opposition to near-shore turbine placement, they note that overall, the overwhelming majority showed positive opinions of wind farm development (Landry et al. 2012). This study and others using survey and questionnaire methods document positivity and acceptance of wind farms, which seems contradictory since the failure of some projects has been attributed to public opposition (Baban and Parry 2001; Carlman 1986; Lee, Wren and Hickman 1989).

This raises several questions. The contestation between projects and public opposition has been publicized by the media, consequently giving fuel to the "NIMBY" theory, an acronym for "Not In My Back Yard." This is the notion that people overall support the idea of wind power development, but just do not want it where they live or where they have to see it on a regular basis. Toke's (2003) work supports the NIMBY theory by arguing that public perception is a major factor in offshore wind energy's success in America. He found an 80-84% correlation between the views of councils in locations where wind farms were being developed and council decisions about whether or not to approve planning permissions, suggesting that the closer people are to a wind farm, the more likely they are to be active against wind farm development (Toke 2003). Taking a different perspective, Devine-Wright (2009) argues that local opposition is a form of place-protective action due to place attachment and identity rather than a mere positivist spatial approach that claims proximity of a proposed development is the most dominant impact on opposition. This idea coincides well with circumstances such as William Koch's battle against Cape Wind. However, other geographers such as Wolsink (2000) argue that NIMBY is a myth entirely and that poor institutional arrangements (ie. unadapt regulatory systems) are the cause of offshore wind failure, not public opinion alone. For Devine-Wright (2009, 432), explanations like Wolsink's are only "partial explanations of opposition" and cannot be reconciled with empirical evidence from questionnaires that show that residents who were more attached to an area with a proposed project showed more negative outlooks about the proposal. Bell, Gray and Haggett (2005, 460) have a different approach to NIMBY; for them there is a gap between the "high public support for wind energy expressed in opinion surveys and the low success rate achieved in planning applications for wind power developments," or what they call the 'social gap.' This social gap is accompanied by an 'individual gap,' which they explain exists when an individual person has a positive attitude to wind power in general but actively opposes a particular wind power development (Bell et al. 2005).

The arguments supporting the NIMBY theory's considerable influence are puzzling considering the multitude of examples of environmental injustices where public opinion has been severely marginalized by powerful corporations seeking profit such as that seen with coal mining in poverty-ridden Appalachian communities. This begs the question, do local objectors really have as much power as it seems, or is there more to the equation? Scholars seeking to answer this question have argued that local objectors may not have as much of a role as originally thought. A study conducted by Aitken, McDonald and Strachan (2008) analyzed 700 rejection letters regarding a failed wind farm plan in Scotland. They assessed the most influential factors of opposition and concluded that local objectors ultimately had little influence on the outcome of wind development and rather than halting it, they merely delayed it.

Some researchers argue that the reason for contradictory conclusions in the literature is an issue of methodology. For example, it has been argued that the opinion poll alone is an ineffective method leading to a planning process that fails to communicate between the developer and the public (Ellis et al. 2009) and has also been described as a positivist approach that does not achieve a deep enough understanding of all sides of the issue (Ellis, Barry and Robinson 2007). Humans are complex, and people oppose or support wind energy for different reasons in different locations. This puts geography in the perfect position to assess offshore wind site suitability due to its interdisciplinary nature and use of mixed-methodologies. As evidenced in the foregoing literature, Geography has well developed methodologies for analyzing qualitative and quantitative information and applying it spatially, such as analyzing the offshore wind planning process and the environmental, economic, and socio-political site suitability of offshore wind energy.

CHAPTER 3: METHODOLOGY

As evidenced in the foregoing literature, offshore wind site suitability must consider multiple variables that are both qualitative and quantitative in nature. In order to adequately address the research questions, this project was devised as a two-part case study using a mixed-method research design that analyzes public comments and uses publicly available GIS data to create a set of site suitability maps for offshore wind energy in North Carolina.

Part 1 of this study addresses the research question, “what factors are stakeholders most supportive of and concerned with regarding offshore wind development in North Carolina?” This portion of the research is a qualitative content analysis of public comments using NVivo qualitative data analysis software in order to determine positive and negative trends in public and stakeholder opinion and to document specific wind farm siting recommendations. Content analysis interprets text from documents with the goal of retrieving meaningful information and inferences. By analyzing societal experiences, this design adds to findings by including qualitative data such as socio-political influence, an important aspect of case study research (Yin 1994). This study conducted a content analysis of public comments collected by BOEM to gauge variation in opinion of acceptability, and to assess stakeholder recommendations for offshore wind development. This information informs an analytic hierarchy of the variables. Saaty's (2008) analytic hierarchy process (AHP) uses pairwise comparison matrices to develop priority scales or weights based on the perceived importance of each variable. It works well to inform and develop an alternative site suitability map displaying most to least suitable areas based on information found in the public comments and academic literature. In order to get a comprehensive idea of site suitability variation, this study considered all of North Carolina’s coastal waters.

Part 2 of the study addresses the research question, “what is the spatial variation of environmental, economic, social, and overall site suitability for offshore wind in North Carolina?” This part uses Geographic Information System (GIS) layers in ArcMap 10.2 that are either publicly available or created using publicly available data. The layers represent spatially variant environmental, economic, and social exclusion variables. Weights developed using AHP were applied to the variables to take into consideration mitigation potential found in the literature and key recommendations identified in Part 1 of the study. This was used to create alternative site suitability maps that could be used in a future energy market that has a higher demand for renewable energy technologies.

Due to the high degree of geographic variability in siting wind farms, there is great potential for the use of geographic resources such as GIS for assessing feasible turbine placement (Christidis and Law 2012). These methods can be complimented by traditional qualitative methods, such as content analysis, that are effective for gathering data regarding socio-political variables such as policy and variation in public perception. Bishop and Miller (2007) assessed socio-political variables using survey data and GIS in order to assess the impact of visibility of turbines on public opinion. They issued an online survey that captured perception of visibility at various distances, lighting and weather conditions. They found that negative responses at the 4km distance were at 70.4% and dropped with distance to 46.6% at 8km and 36.2% at 12km suggesting that developers should consider developing further away from the coast to reduce opposition due to turbine visibility (Bishop and Miller 2007).

The Multi-Criteria Decision Making (MCDM) approach has been utilized in a multitude of site suitability studies including but not limited to Abudeif, Abdel Moneim and Farrag (2015), Al-Yahyai et al. (2012), Mekonnen and Gorsevski (2015), and Rodman and Meentemeyer (2006). This method groups variables into classes and assigns scores to each based on defined site suitability criteria. These values can be used in GIS by applying them to raster data for each variable to create a weighted overlay that displays the spatial distribution of each suitability class. This was used to weight the economic variables in this study.

The mixed methods research design utilized in this study allowed for identifying themes in the data and justifying them. This methodology assimilated a variety of information collected from multiple data sources, which allows for more well-rounded and unbiased findings (Creswell 2003). Using existing public response data and GIS data accounts for a variety of variables. Comparing distribution of opinion from a diverse dataset of public responses with the WEAs defined by BOEM allows discrepant information and varying perspectives to be identified and taken into consideration, increasing the credibility of the findings of this of this project (Creswell 2003).

Data and Study Area

As mentioned previously, in order to gather the information needed to assess offshore suitability in North Carolina, a wind feasibility study was conducted by the University of North Carolina at Chapel Hill (UNC-CH 2009) which provided data used to define call areas (Figure 2). The following exclusions were outlined by the UNC-CH study (2009): areas of high avian densities, areas with unsuitable wind resources, areas with unsuitable geological conditions and bottom types, areas within six miles from the shoreline, fish/fisheries/marine habitats, and military areas. Based on these exclusions, BOEM established three call areas off the coast of Kitty Hawk and Wilmington, know simply as Wilmington West, Wilmington East, and Kitty Hawk. Wilmington West begins seven miles from shore and stretches around 11 miles seaward, measures approximately 15 miles from east to west and has a total area of 78 square miles. Wilmington East begins 13 miles from the shoreline and extends approximately 28 miles seaward, stretches 21 miles from east to west, and covers a total of 327 square miles. Kitty Hawk begins six miles from the shore and extends 34 miles seaward, stretches approximately 45 miles north to south, and covers a total area of 1,036 square miles (Figure 2) (BOEM 2012c).

Upon releasing the call areas, BOEM opened 45-day public comment periods on December 13, 2012 and again on February 5, 2013. There were two dockets that the public could respond to, namely: BOEM's 'Notice of Intent (NOI) to Prepare an Environmental Assessment (EA)' and BOEM's 'Call for Information and Nominations.' The purpose of these comment periods was to allow the public and any applicable stakeholders to voice their opinions, support, concerns, interest and recommendations. BOEM uses submitted comments in addition to feedback from three public meetings to gauge stakeholder interest and to address concerns by further refining the call areas into updated WEAs (Figure 2).

At 124,477 hectares, the final WEAs are remarkably smaller than the original call areas (BOEM 2015). Wilmington West was slimmed to approximately nine OCS blocks (51,595 acres), begins 10nm from shore, and extends about 12.3nm at its widest point.

Wilmington East is now approximately 25 OCS blocks (133,590 acres), begins 15 nm from shore and extends 18 nm southeast at its widest point. The Kitty Hawk WEA consists of approximately 21.5 OCS blocks (122,405 acres), begins 24 nm from shore, extends east 13.5nm in the north and 0.6nm in the south, and spans about 25.7nm at its widest point (Figure 2) (BOEM 2015).

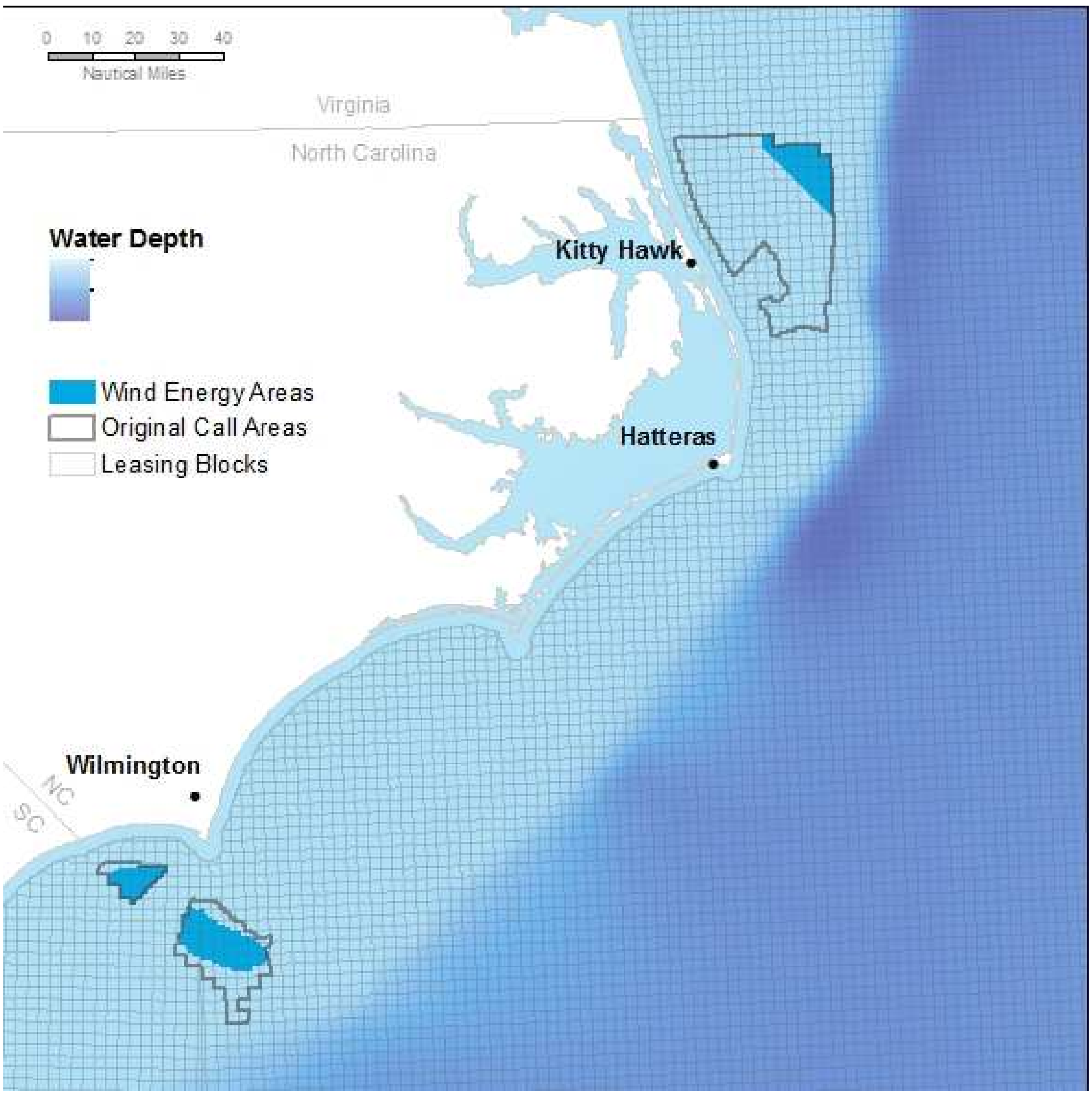


Figure 2: NC Call areas and WEAs

In BOEM's Announcement of Area Identification (2014), they outlined their reasons for the changes made when developing the WEAs. The Kitty Hawk WEA was reduced due to overlap with traditional shipping routes according the United States Coast Guard (USCG) and the maritime community. Additionally, there were aesthetic concerns. The National Park Service (NPS) requested that areas within the viewshed of the Bodie Island Lighthouse be excluded to reduce aesthetic impact on scenic views from the lighthouse, and the Town of Kitty Hawk passed a resolution that requested the elimination of all blocks within 20nm of the coast. BOEM responded to the concerns of NPS, USCG, and the Town of Kitty Hawk by eliminating all blocks within 33.7nm of Bodie Island Lighthouse and 24nm from the coastline of Kitty Hawk. Concerns regarding the Wilmington West WEA were also largely aesthetic. Due to apprehensions about visual impact during the day and at night, areas within 10nm of the coastline were eliminated. The Wilmington East Call Area included areas that overlapped with traditional shipping routes that utilize the Port of Wilmington. Based on recommendations from USCG and the maritime community, BOEM identified blocks to eliminate in an effort to minimize risk of vessel impact. Areas of high topographic relief and patches of consolidated hard bottom (correlated with high fish densities) were also eliminated (BOEM 2014).

This study will re-evaluate site suitability in all of North Carolina's coastal waters based on information found in the public comments and existing research in an effort to identify the spatial variation of environmental, economic, social, and overall site suitability for offshore wind in North Carolina. The current North Carolina WEAs are have been greatly reduced in size and in some locations, placed at distances so far from the coast that, given the infancy of the industry, make them a risky investment for potential developers. This was done in spite of initial review of public comment data and current research that indicate general public support for offshore wind development. This study involves new data sources and methods to determine acceptability of offshore wind development in NC for various sectors, and through examination of the research questions seeks to identify opportunities for future development. To this end, this study seeks to identify potential alternate suitability scenarios that could be used in a U.S. political and/or economic climate more tolerant of renewable energy development. The scenarios were developed after evaluating the public comment data that was collected with the purpose of assisting in the selection of the current NC WEAs to better understand the variation in support and opposition amongst various stakeholders. This information, in combination with mitigation strategies outlined in the literature, are used to develop a site suitability map that displays alternative areas that may be worth considering by offshore wind energy planners in the future.

Part 1: Public Comment Analysis

Part 1 of this study is modeled on the Socio-Political Evaluation of Energy Deployment (SPEED) framework presented by Stephens, Wilson and Peterson (2008). The SPEED framework is designed to better understand socio-political factors influencing the development of new energy technologies. It integrates analysis of regulatory framework, laws, industries, and policy writers; and considers spatially varied perceptions about the risks and benefits of renewable energy technologies. This facilitates an improved understanding of the complex nature of state energy systems.

Current research frequently overlooks the convoluted socio-political influences on the development and deployment of new technologies such as varying institutions, a complicated regulatory framework, existing industries, economic factors, and widely varying perceptions and awareness levels regarding risks, benefits, and costs. By taking these elements into consideration, the SPEED framework allows for empirical research to assist policy-makers, energy professionals, planners, and other stakeholders to better understand, develop, and implement effective strategies for more efficient development of emerging energy technologies (Stephens, Wilson and Peterson 2008). This framework has been used effectively in similar studies, such as one written by Fischlein et al. (2010), to evaluate the perceptions of key stakeholders in wind energy development.

Part 1 of this study utilizes a SPEED framework with a content analysis context to evaluate public comment data provided by BOEM to gauge stakeholder perceptions of offshore wind deployment in the NC Call Areas. Content analysis is helpful for identifying patterns in qualitative data, particularly when analyzing large amounts of text as is done here (Fischlein et al. 2010). The comment data used for this study is publically available online[1]. There are two dockets of data. One is public comment in response to the NC Call for Information and Nominations (BOEM 2012a) and the second set is comments responding to BOEM's Notice of Intent (NOI) to Prepare an EA (BOEM 2013). The first docket is made up of 38 submissions and the second 47, each of which vary greatly in the number of responses they contain. The responders fit into four distinct categories: Citizens, Industrial NGOs, Environmental NGOs, and

[1] http://www.regulations.gov/#!searchResults;rpp=25;po=0;s=BOEM-2012-0088;dct=PS

Government (Table 1). Some responses include only a single comment while others are compilations of hundreds or even thousands of individual responses such as the 2,282 individual responses submitted by Environment North Carolina. This data was chosen for its diversity of contributing stakeholders, depth, and influence on offshore wind development in North Carolina.

The comments were analyzed using QSR International's NVivo 10 qualitative analysis software. NVivo assists in analyzing patterns in large amounts of text. The coding categories were developed by Fischlein et al. (2010, 4,431) using a theoretical foundation where codes were "pre-structured from theory and refined during coding to ensure a high degree of exhaustiveness and mutually exclusive coding categories." The proxy unit of analysis is number of 'References.' References range from single sentences to paragraphs as long as they are addressing a single point. The comments were analyzed quantitatively by evaluating the number of references coded in each frame and qualitatively by careful analysis of the content of the coded text.

The references were coded into two types of nodes, nodes addressing the type of concern and a node identifying the reference as either positive, negative, or a recommendation. The following nodes were created to address the type of concern: environmental, economic, political, technical, aesthetic, and health & safety. Descriptions of the criteria for each node are outlined in Table 2. Any sentences that did not fit within these criteria were not included in the analysis. This was done in order to weed out text that was irrelevant to the study.

Recommendations were not used for the perception analysis, rather were used to get an idea of what actions individuals and/or groups suggest BOEM take to address or mitigate the issues that they present in their comment. Comments coded in these nodes, however, are included in the numbers listed in Table 1. This is important to consider because these numbers should not be compared to the numbers shown in the results, rather should be used to get an idea of the depth of coverage in each classification.

There were a large number of responses that included petitions or were made up of hundreds or thousands of pre-written form letters. This included a letter that was duplicated by 20 individuals that was not connected to a particular agency, a petition pulled together by the public titled “Bring Clean Offshore Wind Energy to North Carolina” with 1,544 American signees and 663 international signees, a petition submitted by the National Wildlife Federation with 532 signees, and a petition from North Carolina Conservation Network with 1,640 signees. In addition to these petitions, Sierra Club and Environment North Carolina enclosed thousands of letters from individuals that support their organizations. Both supplied a form letter for individuals to send, however many individuals added personal comments as well. References coded from form letters were only counted once in the analysis in order to avoid the skewing of data that would be caused by coding the same information thousands of times, but the weight of form letters and petitions are considered in the discussion. The 2,832 individual letters submitted by Environment North Carolina and the 1,467 individual letters submitted by Sierra Club were carefully combed through for additional statements that were unique from the form letter. Although these comments were enclosed in submissions from environmental NGOs, they were categorized under “Citizens” in Table 1 because all references coded in these submissions were unique statements from individuals rather than statements written by the environmental NGOs that compiled and submitted them. The references coded from form letters and petitions, however, were counted under “Environmental NGOs” since statements were written by an affiliate representing the NGO as a whole.

Submission Classification	**Contributors**	**Number of References**
Citizens/Public	Submitted by an individual citizen or member of the public	4,028
Environmental NGOs	Marine Mammal Commission, Sierra Club, NC Conservation Network, The Nature Conservancy, Audubon North Carolina, Natural Resources Defense Council, National Wildlife Federation, Southern Alliance for Clean Energy, Southern Environmental Law Center, The Humane Society of the US	642
Government	NOAA’s National Marine Fisheries Service, Town of Kitty Hawk, The NC Energy Office, Pat McCroy (NC Governor), Susi Hamilton (NC State Legislature), US Coast Guard, Fish and Wildlife Service, National Park Service	246
Industry NGO	Southeastern Coastal Wind Coalition, Virginia Maritime Association, Virginia Port Authority, Offshore Wind Development Coalition, Maryland Port Administration, World Shipping Council	176
Total		5,092

Table 1: Submission classification, contributors, and number of codes

Frames	Positive	Negative
Environmental	Reduces climate change/greenhouse gas emissions, reduces pollution, creates habitat, facilitates healthier environment	Negatively impacts avian migration, endangered species, marine mammal migration, fish populations, bats; facilitates less healthy environment
Economic	Market is available, financial incentives in place, positively impacts existing industries, creates jobs, positive cost-benefit, facilitates economic growth	Market unavailable, not developed for commercial scale, negatively impacts existing industries, negative cost-benefit, stifles economic growth
Political	Appropriate legislation is present, socially acceptable, politically supported, positive reputation	Controversial, politically sensitive, lack of appropriate legislation, inadequate planning process, socially unacceptable, negative reputation
Technical	Previously successful, available resources, feasible, technologies exist, infrastructure exists	Uncertain or unproven technology, infrastructure does not exist, limited technical capacity, research needed
Aesthetic	Aesthetically pleasing	Aesthetically unpleasing, deteriorates natural beauty, noisy

Table 2: Positive and negative coding criteria

Once every submission was read and coded, five matrix queries were created in NVivo, one for each submission classification: Citizens, Environmental NGO, Government, and Industry NGO; and one for all references regardless of classification. This allowed for a better idea of distribution of positive and negative perspective from different types of stakeholders and prevented the much higher number of citizen references from skewing the analysis results. The matrix queries were visualized using bar graphs displaying the distribution of positive and negative references under each category. The sentences coded under “recommendation” nodes were also analyzed in order to get a better idea of the reasoning behind the specific parameters that were used by BOEM when developing the WEAs. Information found in this section of the analysis helps to assist in defining parameters for the GIS analysis in Part 2 of the study.

Part 2: GIS Site-Suitability Analysis

Part 2 is a multi-criteria site suitability analysis that utilizes ArcGIS 10.2. The key objective is to identify environmental, economic, social, and overall site suitability/acceptability based on findings in part one and mitigation strategies found in the literature. By using these unique findings and literature that outlines potential mitigation measures, an alternative scenario is created that is more nuanced than the approach taken by BOEM that considers local concerns and desires and expands potential leasing blocks in NC. This highlights areas that could be considered when defining future WEAs, which would promote EA in more locations and expand the research necessary to determine true site suitability. Policy-makers and planners in North Carolina can use this project’s findings to mitigate inherently local impacts and to help develop communication strategies that build public acceptance of offshore wind development, further improving chances of successful implementation.

In order to include the wide variety of variables that impact offshore wind farm suitability/acceptability, three initial site maps were created: environmental, economic, and social based on spatially variant impacts and concerns found in the literature and the content analysis. GIS data was collected for each variable and converted into the appropriate formats for the analysis to be run. The environmental factors taken into consideration for this analysis were avian migration, marine mammal migration, and marine fish and hard bottom Habitat Areas of Particular Concern (HAPC). The economic factors were shipping, shipwrecks, military areas, unexploded ordnance (UXO) areas, bathymetry, distance from energy facilities, wind speed, and recreational fishing hot spots. The only social acceptability variable that was inherently spatial was aesthetics, so two visibility layers were created: distance from coastline and distance from NPS boundaries. Sources and descriptions for each layer are outlined in Table 3, Table 4, and Table 5.

Layer	**Description**	**Source**
Bird Flyways	This layer of Atlantic bird flyways represents a general pattern of bird movement along the eastern seaboard. It does not necessarily depict distribution.	Geo-Marine Inc. (2011)
Marine Mammal Migration	This layer was created based on coastline distances where marine mammals commonly migrate.	Created anew based on in literature and comments.
Habitat Areas of Particular Concern (HAPC)	This is a polygon layer of HAPC, which are selected subsets of Essential Fish Habitat (EFH) that are particularly ecologically important or vulnerable to degradation.	NOAA National Marine Fisheries Service (MarineCadastre.gov 2015)

Table 3: Environmental GIS layers, descriptions and sources

Layer	Description	Source
Shipping Fairways, Lanes, and Zones	Polygon layer for shipping zones delineated for activities and regulations for marine vessel traffic.	NOAA Office of Coast Survey (MarineCadastre.gov 2015)
Shipwrecks	Point layer of Atlantic coast shipwrecks	Geo-Marine Inc. (2011)
Recreational Fishing Hot Spots	Point layer of common spots for recreational fishing.	Geo-Marine Inc. (2011)
Military Training and unexploded ordnance (UXO) Dumping Areas	Polygon layer for military training areas and known disposal locations of munitions	Geo-Marine Inc. (2011)
Seafloor Bathymetry	Atlantic bathymetric contours in meters	Geo-Marine Inc. (2011)
Coastal Energy Facilities	Point layer for locations of coastal facilities that generate electricity	U.S. Environmental Protection Agency (MarineCadastre.gov 2015)
Wind Speed	Estimates of annual average wind speed at 90 meters	DOE National Renewable Energy Laboratory (MarineCadastre.gov 2015)

Table 4: Economic layers, descriptions, and sources

Layer	Description	Source
Aesthetics: Distance from coastline	Viewsheds based on distance from the east coast	Created from scratch based on recommendations in the literature and comments
National Park Service (NPS) Areas	Polygon for NPS areas	Geo-Marine Inc. (2011)

Table 5: Social layers, descriptions, and sources

Four to five suitability classes and scores for each variable were developed based on information identified in part one of the study: Most (4), Moderately (3), Marginally (2), Minimally (1), and Not (0). The criteria for each of these classes is based on the results of the content analysis and are defined in chapter 4. Each layer had to be converted into raster format in order to run the analyses. The Weighted Overlay tool was used in GIS to create each suitability map. The weighted overlay tool uses overlay analysis to solve multi-criteria problems such as site suitability (ESRI 2011). The tool reclassifies the suitability values in the input rasters, multiplies the cell values by weight of importance, and adds the resulting cell values together to produce the output (ESRI 2011).

The layers for the environmental suitability and social acceptability maps were given equal weights because it was difficult to justify the importance of one layer over another within these two categories. The environmental data utilizes general information on bird flight paths and marine migration in addition to polygons representing Habitat Areas of Particular Concern. All three layers consider endangered species that are protected by law. A future study that uses more specific data that is broken down by species or quantitatively identifies species occurrence would likely need to be weighted, however because the generalized nature of the data used for this study, it was difficult to justify weighing one variable over another. The same goes for the aesthetic layers used for social site suitability. The importance of the NPS boundary was represented in the suitability criteria by making the distances for each suitability factor greater than the criteria used for coastline distance layer. Weighting the NPS distance layer over the coastline distance layer gave the NPS boundary too much sway because the distance criteria already accounts for this difference in influence. In order to prevent skewing the data, these layers were also equally weighted.

On the other hand, the economic variables impacted cost in drastically different ways, so weights were developed using the Analytic Hierarchy Process (AHP). AHP, developed by Saaty (2008), is a theory of measurement that utilizes pairwise comparisons and relies on educated judgments to derive priority scales that indicates how many times more important or dominant one variable is versus another. It utilizes Saaty's fundamental scale of absolute numbers (Table 6). The scales used for economic site suitability are based on the results of part one of the study. Each economic later was given an intensity of importance compared to each other layer, which was then used to calculate the weights used in the weighted overlay tool in GIS.

Intensity of Importance	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1-1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small umbers would not be too noticeable. Yet they can still indicate the relative importance of the activities.

Table 6: The fundamental scale of absolute numbers (Saaty 2008, 86)

Once the initial three site suitability/acceptability maps were created in GIS, they were then used to create the map for overall site suitability. Rather than using AHP, the weights for overall site suitability are based on the percentage of total comments for each and percentage of negative comments. Both of these percentages are considered in order to incorporate overall variability in topics and variability in concerns specifically, since negative comments were specifically regarding the impacts that site suitability attempts to avoid. Environmental includes comments categorized as environmental. Economic includes comments categorized as economic and technical combined because both of these include variables that impact cost. The category 'Social' includes comments categorized as aesthetics since it is the only inherently spatial socio-political variable analyzed. This category represents both social and cultural acceptability, which directly influences which areas are considered suitable or unsuitable for wind energy development. A weighted overlay for each, percentage of total and percentage of negative were created and equally overlayed resulting in a final overall site suitability map. The specific quantitative measures that are used directly depend on the results outlined in Part 1, creating an overlap in methodology and results. These measures will be outlined in greater detail in the following section.

CHAPTER 4: RESULTS

The mixed-method nature of this study was well suited to answer the research questions: “what factors are stakeholders most supportive of and concerned with regarding offshore wind development in North Carolina?” and “what is the spatial variation of environmental, economic, social, and overall site suitability for offshore wind in North Carolina?” The content analysis of the public comment data collected by the Bureau of Ocean Energy Management (BOEM) revealed multiple factors that various stakeholders had positive and negative perceptions of. Many recommendations were also identified that helped educate well-rounded GIS criteria. The factors that were spatial in nature were selected and mapped using criteria defined by the results in part one. Because the methodology for the GIS analysis is based on the results of the content analysis, we do see some overlap between the two chapters.

Content Analysis of Public Comment Data

The results for the first part of this study, the content analysis, had varying outcomes between the different classifications of commenters. Overall, the results were overwhelmingly positive perceptions for all six comment categories with 80.7% positive codes for aesthetics, 91.8% positive codes for economics, 81.6% positive codes for environmental, 95.6% positive codes for health and safety, 93.5% positive codes for political, and 91.3% positive codes for technical. Figure 3 is a bar graph of the overall results. The overall results depict a very positive view of offshore wind energy in North Carolina, however it is important to take into consideration the results of different types of commenters in order to get a better idea of the distribution of positive and negative perception. The variation between positive and negative comments varies wildly between the four classifications: citizens, environmental NGOs, government, and industry NGOs.

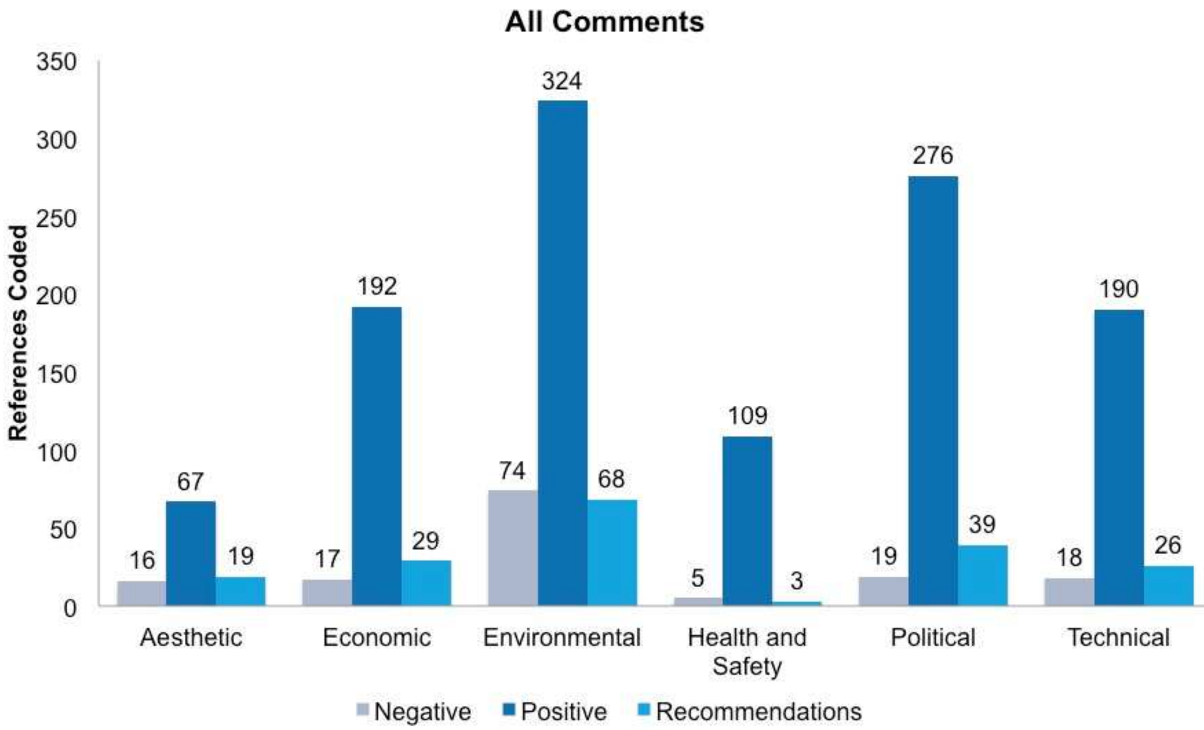


Figure 3: Bar graph of the results for all comments

Citizens

There were hundreds more references coded from comments submitted by citizens who showed positive views under all six categories. This is largely due to the individual citizens that took the time to attach their own notes and opinions to the form letters they submitted. To put into perspective how many people did not add their own notes, the form letters numbered into the thousands. These results (Figure 4) indicate that citizens may have a more positive view than the actions taken so far in the planning process would lead to believe. The most frequently repeated positive comments were the potential for jobs the wind industry could bring and the reduction in emissions and pollution.

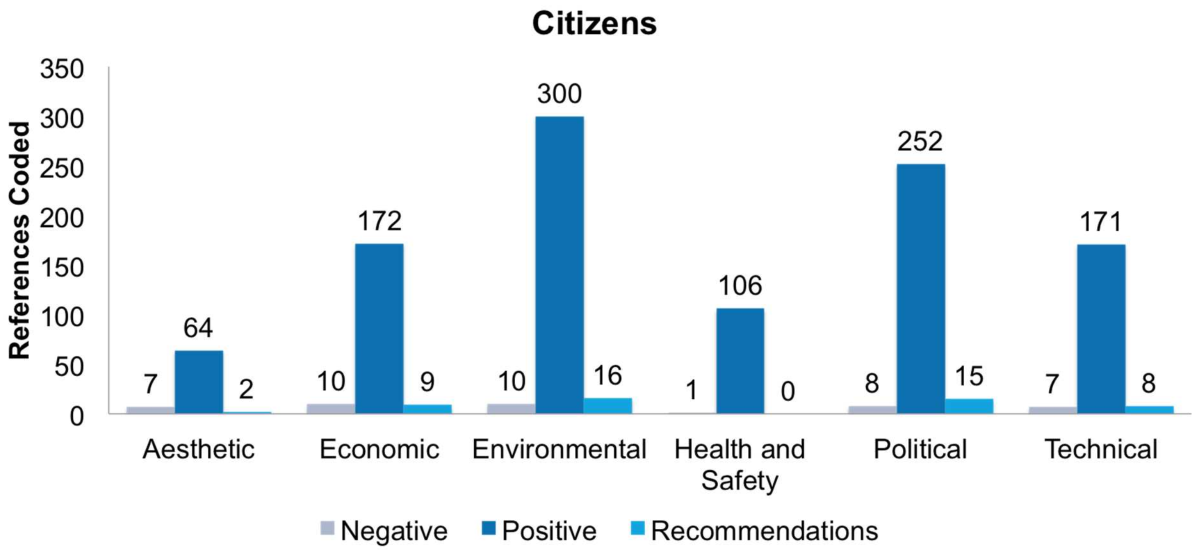


Figure 4: Bar graph of the results for comments submitted by citizens

Environmental NGOs

As expected, Environmental NGOs had more environmental comments than anything else. There were slightly more negative environmental comments due to the widely vocalized concerns with avian and marine species impact. As displayed in Figure 5, the positive comments were mostly in regard to the overall cleanliness of using renewable energy resources over conventional energy methods such as burning fossil fuels. Renewable energy does not burn fuel, so therefore it does not produce emissions or waste and does not contribute to climate change. It also does not require physical extraction from the earth, so is less risky for both the environment and workers than coal mining and oil drilling, both of which have lead to major accidents in the past and environmental degradation due to coal slurry and oil spills.

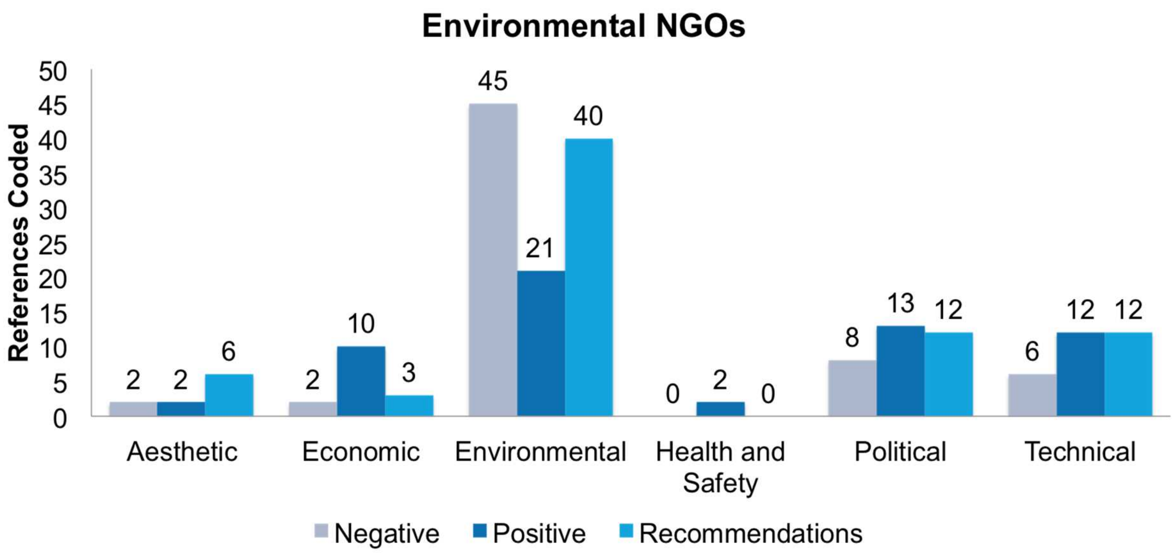


Figure 5: Bar graph of the results of comments submitted by environmental NGOs

Government

Governmental entities vocalized their negative perception of aesthetic and environmental impacts, while they had more positive views of the economics, politics, and technical aspects of offshore wind farms. It is unclear why governments are not promoting the same perception as the citizens that they lead. It is also somewhat contradictory that the government is particularly concerned with potential environmental impacts, yet by holding back wind development, they are promoting conventional energy production, all of which are known to be environmentally destructive and some, such as mountain top removal coal mining, are also aesthetically unpleasing. These contradictions may be caused by the heterogeneous nature of the entities that submitted comments under this category. For example, the NPS and the Town of Kitty

Hawk were most concerned with aesthetics, while the USCG was mostly concerned about impacts on shipping. The NPS and the Town of Kitty Hawk were both concerned with aesthetic impacts on the scenic beauty of the coast as it is one of North Carolina's most popular tourist attractions. NPS stated that it was their lawful obligation to preserve the scenery, history, and wildlife within the park under The NPS Organic Act of 1916.[2] The results of a visualization study that the NPS completed with BOEM revealed that the turbines were still visible on a clear day at the 20nm distance and were even more visible from atop Cape Hatteras and Cape Lookout Light Houses. They specifically requested that the distance of turbines be no closer than 26.3nm for a 400 foot tall turbine and that the "NPS would like to collaborate with BOEM on further analyses to determine the exact distance where the visibility falls off and to evaluate the efficacy of mitigation such that turbines cannot be seen during the day and at night." This distance must also consider viewshed from atop of the lighthouses because they are considered an important tourist attraction due to their proximity to Nag's Head. The Town of Kitty Hawk requested that all blocks within 20nm of their coastline be removed for the same aesthetic concerns. The US Coast Guard (USCG) (2012) submitted its Atlantic Coast Port Access Route Study (ACPARS) Interim Report, a risk-based assessment where outlining areas of high navigational safety risk, areas in need of further investigation and areas of low navigational safety risk. These were developed based on automated information system (AIS) vessel density data, traffic patterns, and existing literature (USCG 2012).

[2] 16 U.S.C. 1

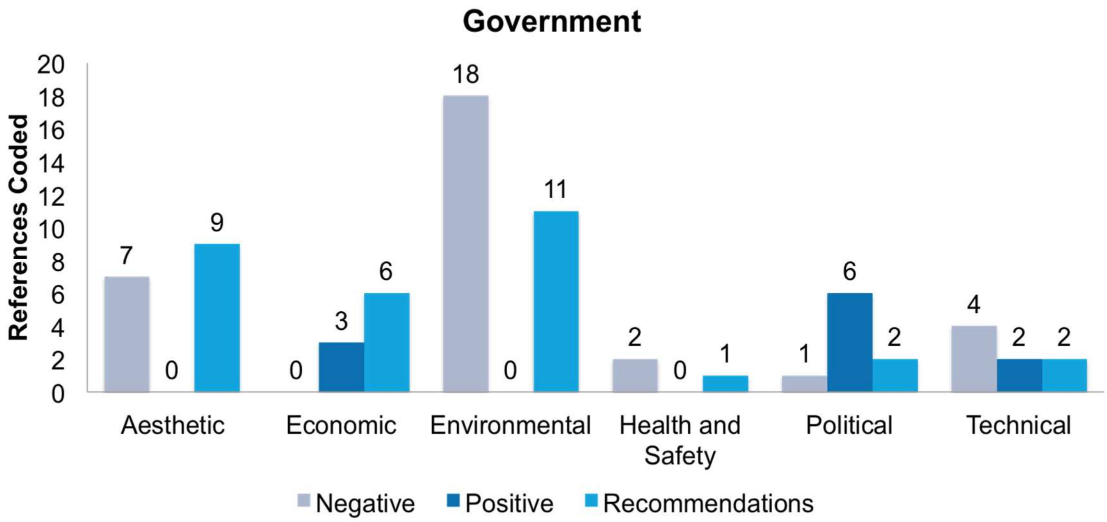


Figure 6: Bar graph for the results of comments submitted by governmental entities

Industrial NGOs

Industrial NGOs had an overall more positive perception and also gave a large number of recommendations for their concerns. Similarly to the 'Government' category, Industrial NGOs are also heterogeneous in nature and have a variety of interests. The results (Figure 7) indicate that industries that currently use the same ocean space that wind may someday inhabit showed the most concern, while wind industry NGOs were fully supportive in their comments and recommendations.

The World Shipping Council outlined potential use risks including vessel collisions in cases of GPS malfunction or loss of steering or propulsion USGS recommended that all red blocks be removed to reduce navigational safety risk associated with offshore wind turbines. They also noted their support for USCG's ACPARS Interim Report.

The Offshore Wind Development Coalition and the American Wind Energy Association outlined arguments in favor of keeping as many blocks as possible. Actions in other Atlantic WEAs such as those off the coasts of Virginia, Maryland, Delaware, New Jersey, Rhode Island, and Massachusetts were conducted under identical federal laws and found no foreseeable significant impact for many of the activities deemed significant in North Carolina's WEAs. This highlights an important consideration: that the variables deemed significant by BOEM vary with the different political and economic interests found in different locations along the Atlantic coast. The Mid-Atlantic Finding of No Significant Impact (FONSI), a document constructed by BOEM as part of the later stages of the planning process, states: "Visual impacts of meteorological facilities and project-associated vessel traffic to onshore cultural resources would be limited and temporary in nature, if noticeable, and consist predominantly of vessel traffic which most likely would not be distinguishable from existing vessel traffic" (BOEM 2012b, ix). In the same comment from the Offshore Wind Development Coalition, they point out that according to the Massachusetts EA (180-181):

> "[T]he widest portion of the meteorological tower (the deck) would be below the visual horizon and would not be visible from shore . . . [and] the mast of the tower would not be discernible by the naked eye in the best visibility conditions (a clear, low humidity day). Overall, visual impacts to onshore viewers of meteorological towers in daylight would be expected to be negligible to minor . . . Lighting markers at the top of the tower would likely be visible on clear nights from the shoreline. However, boats/ships frequently appear on the horizon, making it difficult to distinguish the tower from the other lights. Weather conditions such as fog, haze, clouds, or rough seas would also greatly limit the visibility of the towers and lighting from the shore. Therefore, the presence of a flashing light or lights on a meteorological tower at night would result in minor impacts when no other lights could be seen on the horizon and negligible impacts if other lights were present. Because meteorological buoys would be at the same approximate height of the meteorological towers' decks, the visual impacts from the buoys are anticipated to be negligible."

And in the Mid-Atlantic EA (x):

> “The increase in vessel traffic, and activities associated with the installation/operation of the meteorological towers and buoys would not significantly impact current or projected future shipping or navigation. It is unlikely that vessels would collide with meteorological towers or buoys due to USCG requirements related to marking and lighting meteorological towers or buoys, the fact that the WEAs were identified and refined to avoid the highest traffic areas, and the fact that the few anticipated structures are small and dispersed over such a wide area of ocean.”

As outlined further in the comments, in the Mid-Atlantic WEAs, BOEM made the decision to keep almost all of the OCS blocks in the original proposed areas despite vessel density per aliquot (portion of ocean space) in New Jersey (76-250 total vessels/aliquot/year) and Maryland (74-257 total vessels/aliquot/year), which are as high or higher than the densities found in the Kitty Hawk and Wilmington East areas that were coded red by USGS. Due to the strict parameters and substantial exclusion zones used for the North Carolina WEAs, BOEM is severely limiting the potential for the success of offshore wind in North Carolina. Offshore projects benefit from economics of scale, which has been drastically diminished under these stipulations.

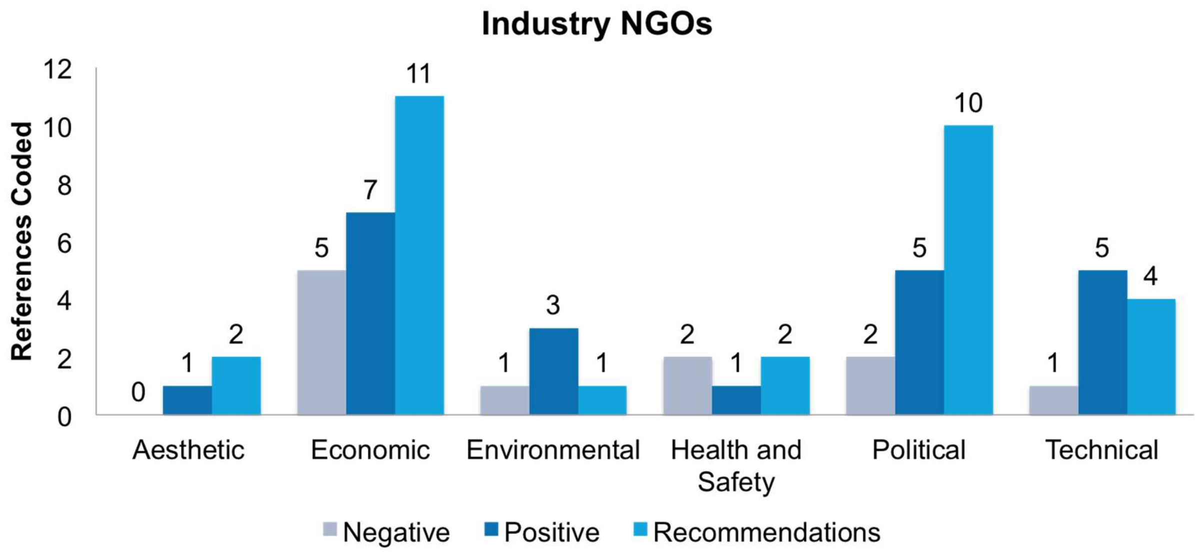


Figure 7: Bar graph of the results of comments submitted by industrial NGOs

Recommendations

Coding recommendations separately allowed for them to be carefully analyzed in order to better address concerns in this study. Ideally, BOEM should take each and every recommendation into consideration, however there were only a few specific concerns that were directly addressed when the WEAs were created. According to BOEM, the changes to the WEAs were made specifically because of comments submitted by the Town of Kitty Hawk (5 total codes), NPS (48 total codes), World Shipping Council (66 total codes), and the USCG (20 total codes) (BOEM 2014). The comments that they submitted outline their reasoning. Based on these comments alone, BOEM's final decision was to remove all bocks within 33.7nm of Bodie Island Lighthouse and within 24nm of the coastline (ibid). Additionally, BOEM responded to the concerns outlined by USCG and The World Shipping Council by removing several blocks in the Wilmington areas (ibid). The comments submitted by citizens, environmental NGOs, and certain industrial NGOs (American Wind Energy Association and The Offshore Wind Development Coalition) appear to have carried little weight on BOEM's changes to the WEAs.

The results from part one identified the factors that stakeholders were most supportive of and most concerned with. Although BOEM decided in favor of the few above concerns rather than the comments as a whole, a number of the concerns that resulted in the removal of leasing blocks have mitigation potential that, if taken into consideration, would make them feasible in an alternative suitability map. The results for the GIS analysis in part two of this study will take into consideration mitigation measures and suggestions found in both the literature and will also weight variables based on the overall variation of positive and negative perception rather than only the concerns of a selected few stakeholders.

Multi-Criteria Site Suitability Analysis

The results from the content analysis of BOEM's public comment data were used to inform the multi-criteria GIS site suitability analysis in the second part of this project. There are several stages of results for the GIS analysis. In order to create the three initial environmental, economic, and social suitability maps, site suitability criteria for each layer had to be determined based on the above content analysis results. The entire North Carolina coast was taken into consideration for the GIS analysis. The variables were chosen based on availability of data, the variables utilized by the UNC Wind Study, and commonly mentioned concerns in the comments.

In order to use the overlay tool within GIS, each dataset was converted to raster format and assigned a criteria category from among the five suitability classes as defined in the graphs below: most suitable (4), moderately suitable (3), marginally suitable (2), minimally suitable (1), and not suitable (0). Variables were taken into consideration using publically available data. During initial mapping, each suitability map was only given four suitability classes rather than including exclusions, however it was decided after some experimentation that exclusion zones (not suitable (0)) would need to be applied for military/UXO areas for safety reasons in addition to a six nautical mile buffer for animal habitat and visibility in order to achieve the most realistic results possible. Without adding these as exclusions, these important off-limits areas were lost in the overlay analysis due to the number of other layers.

Environmental

The most vocalized environmental concerns in the comment analysis and in the literature were avian impacts, marine habitats, marine mammal migration impacts, and endangered species such as various sea turtles. Because the entire study area is home to a number of species that could be impacted, the goal here is to find spaces with the least amount of impact possible.

In order to incorporate avian migration, a layer for major bird flyways, provided by Geo-Marine Inc. (2011) was used. Suitability was based on distance from common flyways assuming that the farther away from commonly traversed avian migration passageways, the least likely a farm will have negative impact.

Another commonly mentioned environmental factor is marine mammal and turtle migration. According to comments submitted to BOEM by the National Resource Defense Council, 20 to 30 nautical miles off the coast is a migratory corridor for the endangered Atlantic Right Whale. This corridor is part of the Atlantic Gulf Stream, which moves seasonally and is a common migration route for various species. Marine species are also commonly found within five nautical miles of the coast. Areas from zero to five nautical miles of the coast were deemed minimally suitable, 25-40nm (Gulf Stream) as marginally suitable, 5-25nm moderately suitable, and beyond 40nm most suitable in terms of impact on the marine ecosystem.

Habitat Areas of Particular Concern (HAPC) are areas deemed by National Oceanic and Atmospheric Administration (NOAA) as habitats with exceptionally important ecological functions or are particularly vulnerable to degradation. These areas were deemed marginally suitable. They were placed here rather than minimally suitable because there is some potential for mitigation regarding hard bottom habitats. In the literature, Petersen and Malm (2006) explain that turbine foundations can be engineered to mimic the original habitat. There would be temporary impact during construction phases, however artificial reefs have excellent potential for building hard bottom habitat once the construction phase is complete (Petersen and Malm 2006). This could not only maintain a healthy ecosystem, but also improve the recreational fishing economy.

After some initial mapping, it was decided that a coastal exclusion should be added due to the high prevalence of delicate ecosystems within five nautical miles of the coast (UNC-CH 2009). Although it overrides the minimally suitable label for the marine habitat layer, it was necessary to add in order to insure that this important consideration was not lost in the final overlay.

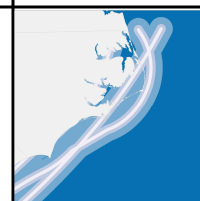
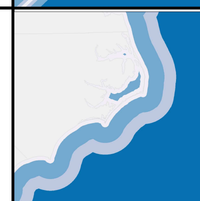
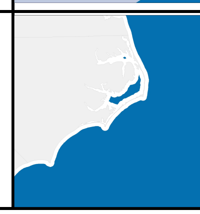
Variable	Suitability					Layer
	Most	Moderately	Marginally	Minimall y	Not	
Distance from Bird Flyways (nm)	15+	6-15	1-6	0-2		
Marine Mammal Migration (nm from coast)	> 40	5-25	25-40	0-5		
HAPC			HAPC			
Habitat Exclusion					0-5	

Table 7: GIS analysis criteria for environmental variables

These layers were analyzed using the weighted overlay tool with equal weights due to their relatively equal importance. The resulting map is shown in Figure 8, clearly highlighting the swaths of 'moderately suitable' created by the avian flight paths as well as the habitat areas of particular concern. Marginally suitable areas can be seen where HAPCs and bird flyways overlap. This includes the abrupt polygonal angle in the south caused by the HAPC layer. The most suitable areas are furthest from the coast where fewer vulnerable habitats exist. There are a few sections of most suitable areas along the OCS just off the coast of Cape Hatteras. These areas may be sufficient spaces to consider for offshore wind, however more accurate avian data could change these results.

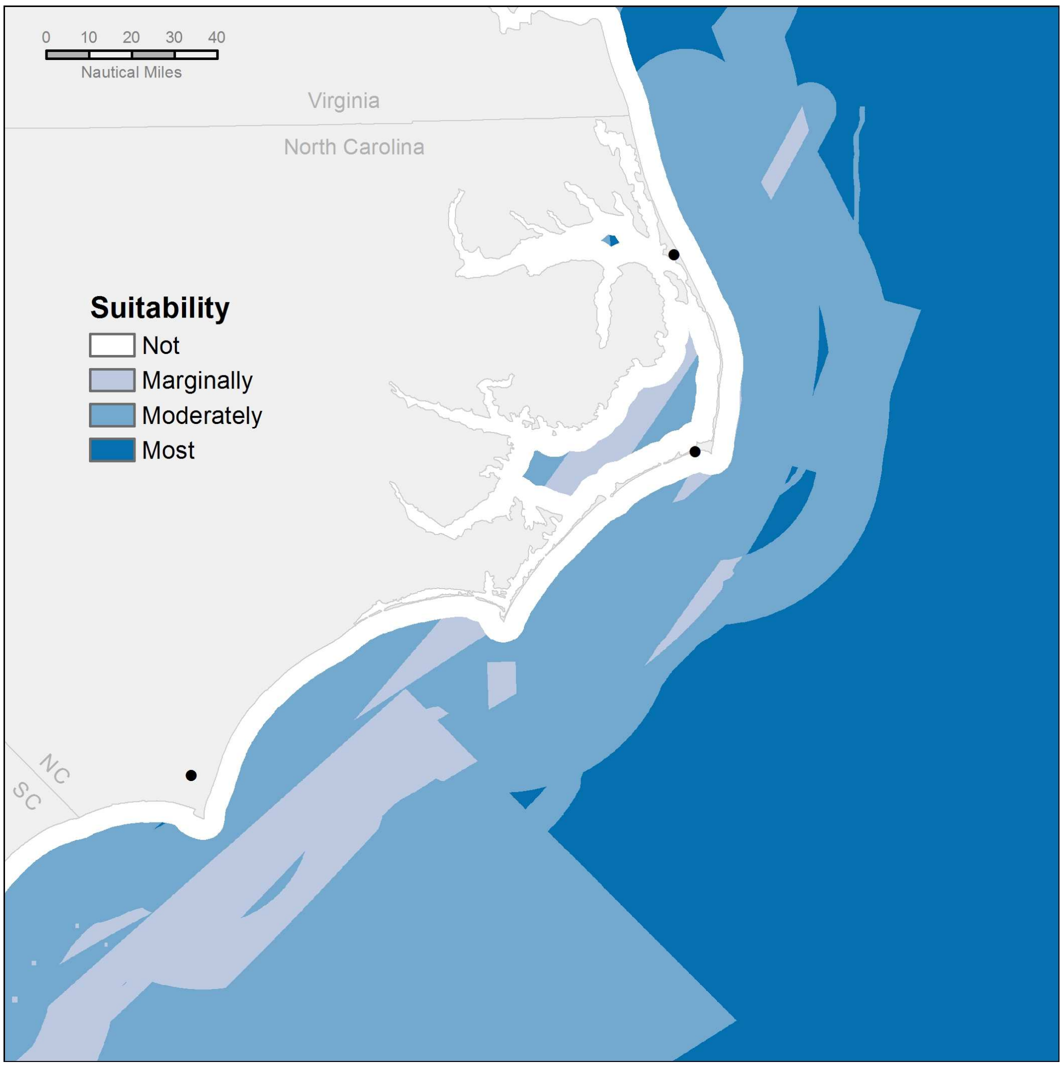


Figure 8: GIS suitability map for environmental variables

Economic

The economic site suitability map is the most complex of all three initial site suitability maps. Because this map has several more layers of varying importance, Analytic Hierarchy Process was used to developed weights for the weighted overlay. Wind speed, distance from energy facilities, and depth zones all have a direct correlation with the overall cost of an offshore wind project so were given more weight than variables with more mitigation potential such as recreational fishing hot spot density and shipwreck density.

Both shipwreck density and recreational hot spot density were created using natural breaks in point density for each variable. The exclusions for this map are military and unexploded ordnance (UXO) areas and shipping fairways/lanes/zones. Wind speed criteria were based on National Renewable Energy Laboratory's definition of suitable offshore wind resource, which is an annual average wind speed greater than or equal to 6.4 meters per second at 90m height (Lopez et al. 2012).

The criteria for depth zones and distance from energy facilities were based on estimated costs outlined by Samoteskul et al. (2014). At less than 60m of depth, jacket foundations are used at the cost of approximately $6250 per metric ton. Weight of the jacket goes up with every meter of depth by about $1.3 million. At depths above 60m, floating foundations must be used costing approximately $9.6 million each. Distance from energy facilities impacts cable costs. At distances greater than 80km, HVDC cables are used at the cost of $2,150,000 per kilometer. At distances less than 80km, HVAC cable is used at the cost of $1,128,000 per kilometer (Samoteskul et al. 2014).

Distance from the coast and depth hugely impact the cost and feasibility of an offshore wind farm.

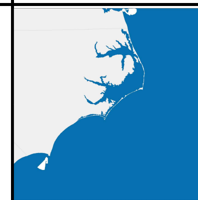
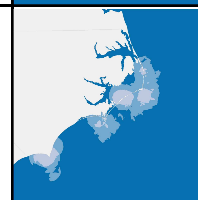
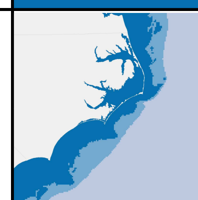
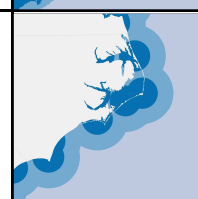
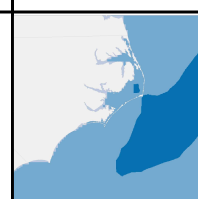
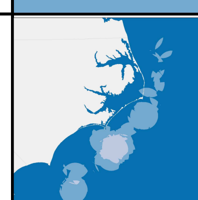
Variable	AHP	Suitability					Layer
		Most	Moderately	Marginal	Minimally	Not	
Shipping						Ship Areas	
Shipwreck Density (per m)	0.08	0-0.008	0.008-0.015	0.015-0.023	0.023-0.031		
Military & UXO						Mil & UXO Areas	
Depth Zones (-m)	0.28	0-30	30-60	60-200	>200		
Distance from Energy Facility (nm)	0.30	0-20	20-40	40-100	>100		
Wind Speed (m/s)	0.27	10-12	7-10	5-7	< 5		
Fishing Hot Spot Density (per m)	0.07	0-0.004	0.004-0.008	0.008-0.012	0.012-0.016		

Table 8: GIS suitability criteria for economic variables

The resulting map with the above criteria and AHP weights can be seen below in Figure 9. Each of the layers has its influence. Unlike the environmental map in Figure 8, many of the layers for the economic map decrease in suitability with distance from to the coast rather than increase distance. The strong winds off of Cape Hatteras are evident, which gives this area even more potential on top of the potential found in the environmental results. The circles of most suitable sites scattered along the coast clearly identify that close proximity to an energy facility strongly impacts economic suitability. The pixilation in some areas was due to the wind data used. This could be improved by using data that is designed for this type of GIS analysis, however the data used was the only data that was publically available. Fishing hotspots and shipwreck density had little effect other than the spots of moderately suitable found within the loops of most suitable created by the distance from energy facilities layer.

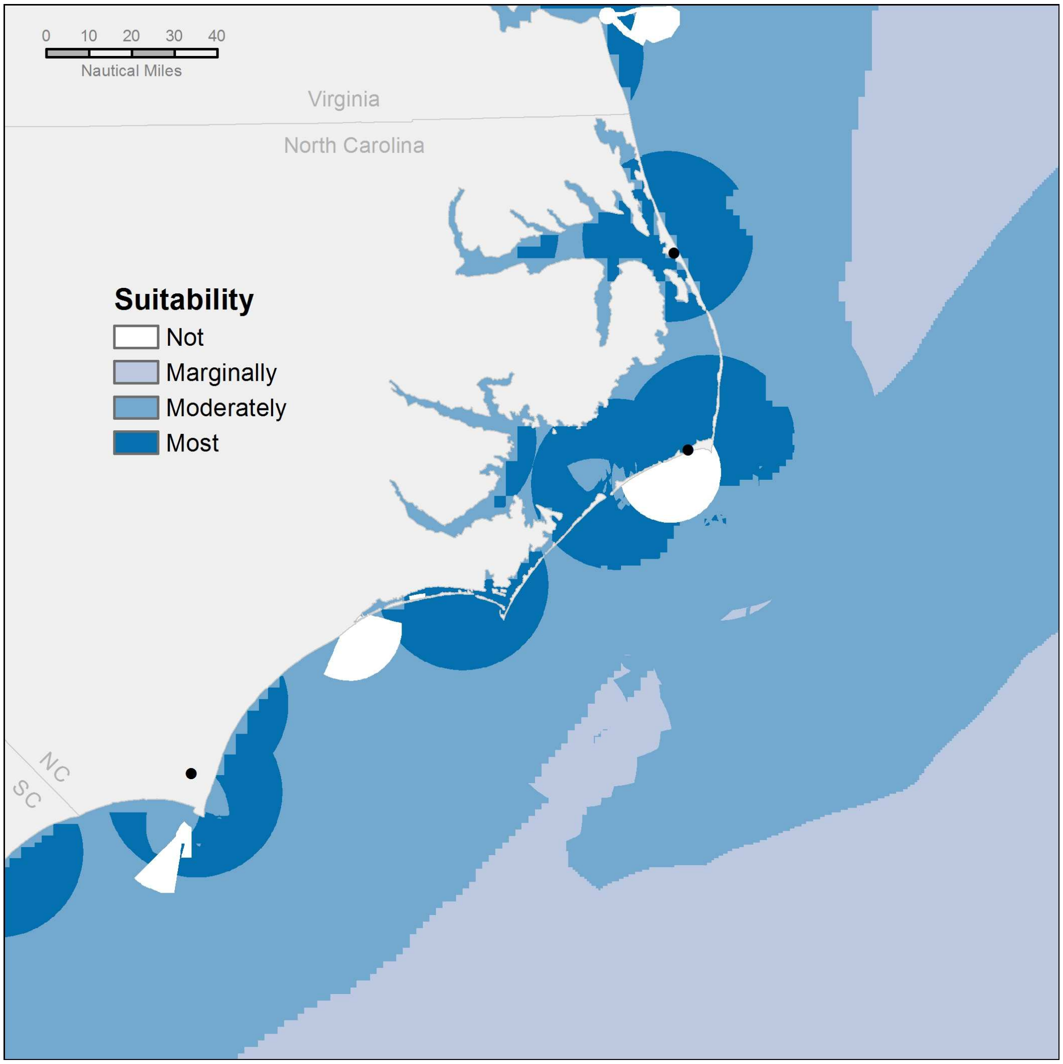


Figure 9: GIS suitability map for economic variables

Social

While the only inherently spatial social variable is related to aesthetics, it is a topic that comes up frequently when discussing wind energy development. For some, the aesthetic impact is a major priority, while for others, it caries very little weight. In Europe, it is frequently argued that offshore wind is a more favorable option aesthetically compared to onshore wind (Bilgili et al. 2011). Aesthetic concerns in America are perceived preferences because they are opinions generated without having seen an offshore wind farm. Based on the number of positive aesthetic comments, the results of Part 1 reveal that overall opinion on aesthetics is not always as negative as some stakeholders make it seem. Regardless, large amounts of space have been removed from the WEAs due to this concern, specifically from the Town of Kitty Hawk and NPS. Environmental Design & Research (2014), a landscape architecture, engineering, and environmental services company, conducted a visual assessment for BOEM that analyzed visual impact of meteorological towers at the nearest point of each WEA. It found that at distances of 12 miles, the shape of the tower and its various components can be discernable, but at distances greater than this the towers appear as faint lines on the horizon or do not appear at all. In their visual assessment of offshore wind turbines, Bishop and Miller (2007) found that at a distance of 4km, the rate of negative responses was 70.4%, however this fell to 46.4% at 8km and 36.2% at 12km. Perception of wind turbines can also change over time with the political climate as renewable energy becomes more favorable politically and economically due to its lack of pollution and invasively compared to extracting and burning fossil fuels for energy (Christidis and Law 2012).

Findings such as these and the suggestions outlined by the Town of Kitty Hawk and NPS were all taken into consideration when developing the following criteria. There were two layers for this map, one for distance from the coastline and one for distance from NPS boundaries. The distance from the NPS boundaries layer has slightly more strict suitability than the general distance from coastline layer due to the historical and environmental significance of the NPS.

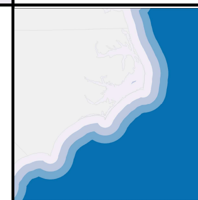
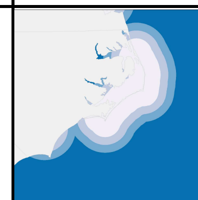
Variable	Acceptability				Layer
	Most	Moderately	Marginally	Minimally	
Distance from coastline (nm)	30+	20-30	10-20	0-10	
Distance from NPS Boundary (nm)	40+	30-40	20-30	0-20	

Table 9: GIS suitability criteria for social variables

These two layers were overlaid with equal weights and the outcome can be seen in Figure 10. Including two layers for visibility allowed for more sensitive areas in the national parks where tourists commonly flock to have a bit more distance from a potential wind farm. This did cause some inconsistencies in the sounds because one of the layers was distance from NPS, the overlay considered parts of the sounds that are still too close too close to shore to be considered minimally or marginally suitable. More site-specific data would help to take this inconsistency into consideration.

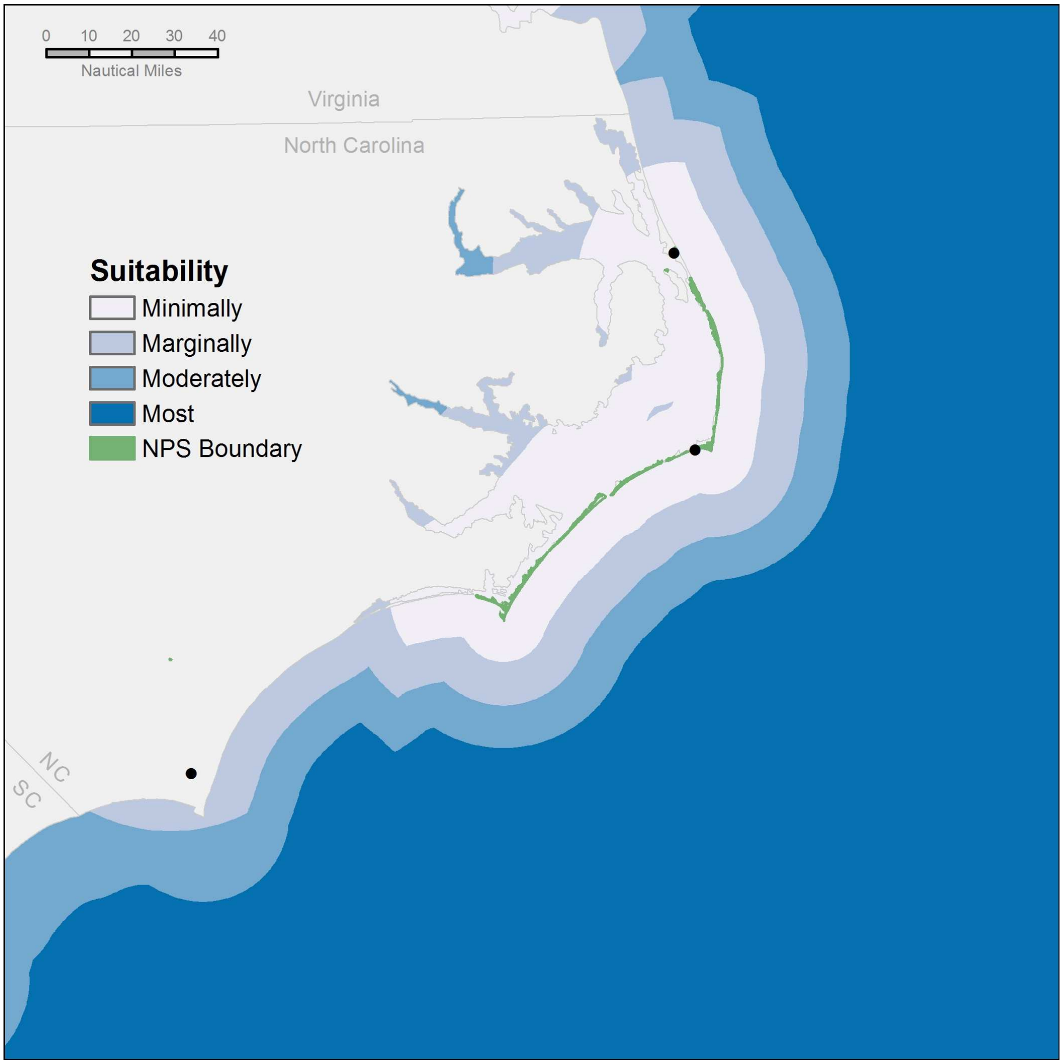


Figure 10: GIS suitability map for social variables

Overall

Overall suitability was determined by creating a composite suitability layer of above three outputs with the weighted overlay tool using weights calculated from the percentage of total comments and percentage of negative comments for each. ‘Environmental’ considered environmental comments. ‘Economic’ includes both economic and technical comments. ‘Social’ includes comments coded under aesthetics. The results for each percentage of total comments and percentage of negative comments were combined to created the final overall site suitability map shown in Figure 11.

You can see the layers that had a particularly heavy influence such as wind speed, made apparent by the large swath of “Most Suitable” dipping down from the North East. A potentially ideal location for wind that should be considered is the edge of the OCS directly east of Hatteras. This space is approximately 20nm from the coast and with the particularly high wind speeds, shallow waters, and proximity to energy facilities, this location is one of the more suitable according to this analysis given there be careful attention to mitigating environmental impacts. Although the wind blows strong beyond 20 nautical miles, the OCS drops to approximately 200km, which would require floating turbines, a cost that may not be feasible in initial stages of building the offshore wind economy. In a future with higher demand for wind energy and more advanced technologies, moving further away from the coast could be a fruitful option.

Another area that has long been eliminated from consideration is the inner area of Pamlico and Albemarle Sounds. The sounds are shallow, windy, and their vast size allows for minimal aesthetic impacts. Because the sounds have delicate ecosystems, they *may* not be particularly suitable for large-scale commercial wind development (more research would be needed to confirm this such as small-scale, experimental wind turbine developments), however they would be excellent locations for small-scale, experimental offshore wind farms to assist with the large amount of research that is needed to adequately plan for offshore wind. Scientists could get a much better handle on how and to what degree turbines impact the surrounding environment and how these impacts can be mitigated.

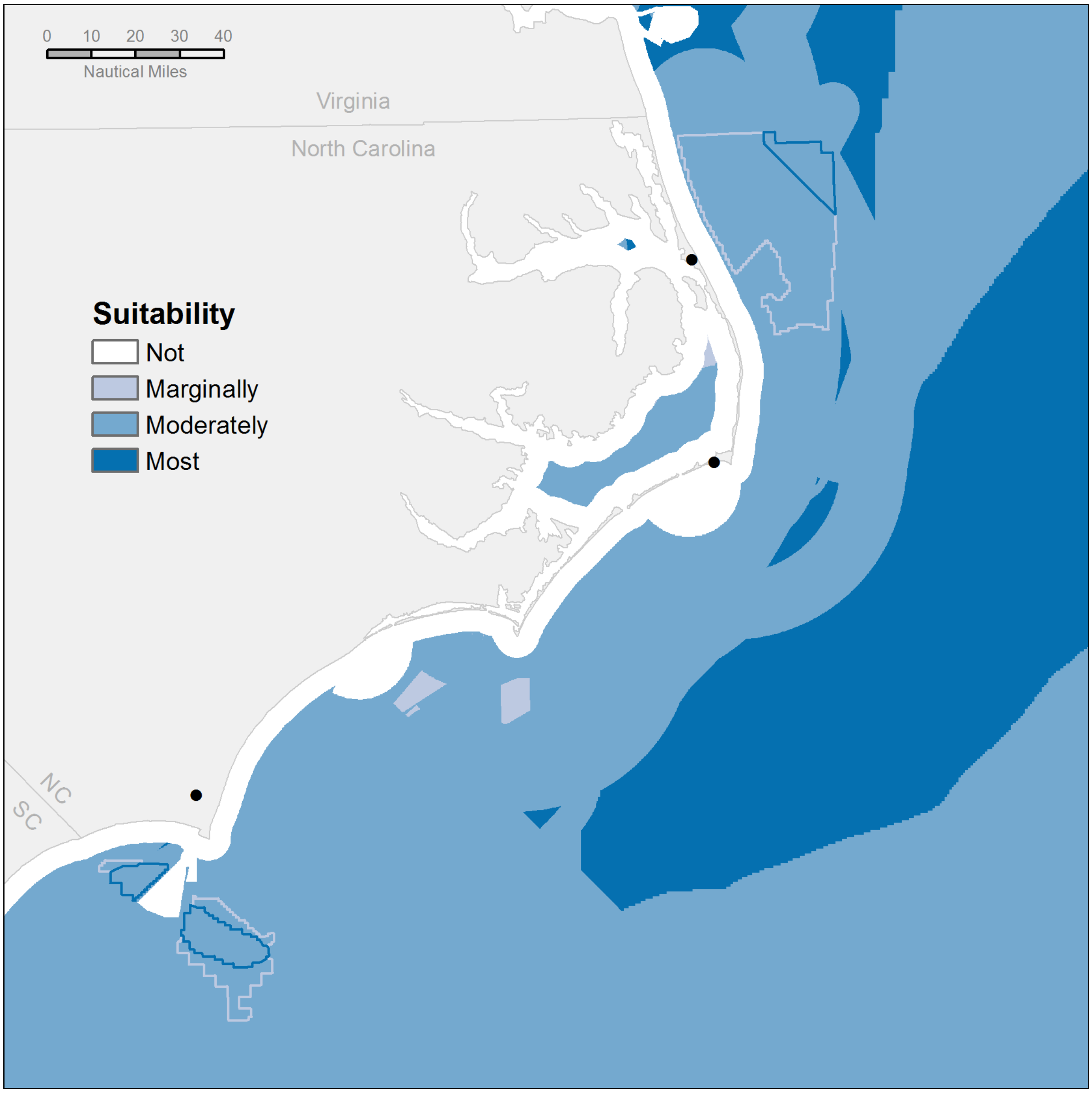


Figure 11: Overall GIS suitability map with outlines for current NC WEAs

While some impact is inevitable, with careful planning, offshore wind can have minimal impact, especially when compared to its conventional energy counterparts. It is only a matter of time before renewable energy gets the foothold that it needs to flourish, and when that happens, North Carolina should absolutely reconsider the sites where it plans to locate offshore wind. The potential is obvious, but the politics will need to change in a way that better considers the opinions of all stakeholders as well as better considers opportunities for mitigating negative impacts in a way that allows multiple ocean uses to coexist successfully.

CHAPTER 5: DISCUSSION AND CONCLUSION

The thousands of supportive petition signees in addition to the thousands of individual letters of support that were submitted during this comment period show a strong public support in favor of offshore wind energy. The recommendations of stakeholders in North Carolina were taken into consideration by BOEM as evidenced by the significant change in the size of wind areas from the call areas to the WEAs, however it can be argued that these decisions were not in response to the nature of the comments as a whole rather were in response to only a select few commenters.

The answer to the secondary research question, “what factors are stakeholders most supportive of and concerned with regarding offshore wind development in North Carolina?” was clearly evident in the results of part one of this study. There was a huge number of positive comments, however when you look at the distribution between the different classifications, you see that there is more to the story. It is also important to note that there is some possibility of bias in this data due to the nature of the call. Those who responded to the call were motivated to do so by their positive or negative outlook on offshore wind, so there is some inherent bias within these comments. A random study sample may yield different results, however this sample was used in this study due to its importance to the offshore wind planning process.

Citizens had significantly more responses coded than did any of the other three types of contributors. This is largely because so many of the citizen responses were encouraged and pulled together by a larger organization, while only a handful of citizen comments were entirely unaffiliated. Regardless, citizens were certainly more supportive than negative. Citizens commonly spoke of the jobs that the industry could bring to their communities, climate change reduction, and the overall cleanliness of offshore wind versus alternative offshore energy options such as offshore oil drilling.

Governmental associates were more negative on all but economics and politics. The comments recognized the potential economic benefits that renewable energy could bring to North Carolina. Government entities also commented saying that they believe that voters would favor politicians who set goals to advance renewable energy development such as offshore wind. On the contrary, they were more concerned with aesthetics than any other group and not once mentioned offshore wind's potential environmental benefits such as greenhouse gas emission reduction and the lack of risk of environmental disasters such as the BP oil spill in the Gulf of Mexico and the Duke Energy coal slurry spills in North Carolina. The governmental comments clearly had more weight in BOEM's decisions. This identifies a potential bias that may need to be addressed in future research on offshore wind site suitability.

Environmental NGOs were largely concerned with potential avian and marine habitat impacts and stated their recommendations for mitigating these impacts. Specifically, they called for planners to carefully consider avian migration and endangered species such as the Atlantic Right Whale and various sea turtles. They recognized offshore wind's potential environmental benefits and were supportive overall. They also noted that even with the inherent risk to native marine habitats, offshore wind still poses less risk than alternatives such as offshore oil drilling. Their comments were largely a call for more research on potential ecosystem disruption. Industrial NGOs also had several recommendations. Industries such as shipping were largely not in favor of offshore wind development while others such as offshore wind coalitions were adamantly supportive and offered a variety of mitigation recommendations. This variation in support between industries shows the need for a planning process that more adequately attempts to mitigate offshore wind's impact on existing industries without severely limiting advancement in offshore wind development.

In addition to the distribution of positivity and negativity, another important discovery that the comment analysis yielded were the comments coded under "recommendations." As a whole, one of the most common requests in all of the comments was the need for more research, something that was also commonly seen in the literature. It can also be noted that the recommendations as a whole did not entirely reflect the decisions made by BOEM for the WEAs. For the Kitty Hawk WEA, it was never explained as to why BOEM excluded blocks within 33.7nm rather than the requested 26.3nm and within 24nm of the coast rather than the 20nm requested by the Town of Kitty Hawk. The same viewsheds were not applied to the Wilmington WEAs, where the closest blocks are 10nm from beaches with substantial tourism revenue. As explained by the Offshore Wind Development Coalition, BOEM was not consistent with what it deemed significant impact on vessel traffic and visualization between WEAs in other areas of the Atlantic even though they were all developed under the same federal regulations.

Regardless of these considerations, the results of part one provided input to the GIS analysis. Not all of the information gathered in part one was spatial in nature (eg. Political and Health and Safety), so only geographically variant variables were identified and considered as evidenced in the GIS methodology. The final results of the GIS analysis were certainly revealing of environmental, economic, social, and overall site suitability, effectively answering the primary research question, “what is the spatial variation of environmental, economic, social, and overall site suitability for offshore wind in North Carolina?”

The environmental data used for this study were based on general patterns in marine animal activity and habitats. Because of this, it is difficult to pinpoint *exact* locations within 40nm from the coast that are, without a doubt, entirely environmentally suitable. The data used were only spatially specific enough to give generalized environmental suitability results, however it still gives us an idea of areas that may be worth reconsidering such as the ocean space adjacent to Cape Hatteras.

The ‘Economic Suitability’ map was the only map (aside from the final map) that utilized weighted layers. It was observed that wind speed had quite an influence on the final product as you can see by the large swath of “Most Suitable” dipping down from the northeast. Both distance and bathymetry were weighted similarly due to their substantial impact on overall cost the farther you move from the coast. Similarly to the environmental results, the economic results also highlight suitability off the coast of Cape Hatteras due to the strong consistent winds and shallow waters.

The overall results point out that those locations off the coast of Cape Hatteras may be worth reconsidering for offshore wind energy. Additional wind energy resources exist within the state estuarine waters of the Pamlico and Albemarle Sounds; however, as of today, several legal and economic limitations prevent feasible constructions in the sounds (UNC-CH 2009). In a future political climate that is perhaps more supportive of renewable energy advancement, these laws could be re-evaluated in an effort to include them in site suitability planning and research for offshore wind. The overall map also shows ‘Most Suitable’ waters at very long distances from the coast. These may one day be perfectly suitable waters, however with today’s wind technology, it is simply too expensive to consider these locations in the infancy of the industry. This expense with distance was considered in the variables for the economic site suitability map, however their influence in the overall results was somewhat lost in the multitude of other variables that were *more* suitable with distance such as vulnerable habitats and visibility. Issues such as this could be managed with more site and issue specific data.

These inconsistencies support the need for further research. The lack of available data and need for further research is one of the most important issues that needs to be addressed in future studies. The methods utilized for this study were well suited for a multi-criteria site suitability analysis, however the quality of the results directly correlates with data quality. There are a number of variables that would benefit from more site-specific data, and this need was widely recognized in both the comments and in the literature. Data on bird sightings and flight paths need to be quantified rather than estimated. Shipping lanes and vessel occurrence could also benefit from quantitative spatial data in order to determine which lanes can be adjusted to accommodate offshore wind. Studies showing which habitats have the potential to flourish with artificial reef generation and those that would be more sensitive to artificial reefs would also assist site selection and foundation design.

This study could be built upon in multiple ways that did not fit in the time frame for this project. Statistical analysis of the numeric findings would be beneficial to better refine and substantiate the data. Further exploration in NVivo by creating sub-nodes (e.g. avian migration, marine habitat, climate change, and pollution) would allow for more specific trends to be analyzed. A more specialized qualitative study could further educate the GIS analysis. For example, a future study could consider sending surveys designed for an analytic hierarchy analysis to key stakeholders and have the stakeholders develop weights for the weighted overlay in GIS. This would also help to eliminate bias by having a sample of opinions rather than having only the perception of the researcher.

Looking for lessons from nations who have already begun implementing renewable energy is a wonderful place to start, however, an article by Vaissière et al. (2014) recommends doing so with caution. After analyzing several European Environmental Impact Assessments (EIAs – the equivalent of an American EA), they noted that the data and knowledge we have gained from European nations is minimal and limited. European policies facilitate fast growth in the industry, while policy in the U.S. is severely limited. This political momentum has, in some cases, resulted in EIAs that lack rigor and a coherent mitigation hierarchy. Negative impacts are being overlooked by developers who, rather than actually addressing them, justify them by claiming that positive impacts such as artificial reef creation exceed the negative. Renewable energy technology is advancing in Europe, but research on its effects is lagging behind (Inger et al. 2009; Vaissière et al. 2014).

Conclusion

As evidenced in this study, planning for offshore wind presents inherent and unavoidable trade-offs: greenhouse gas reduction versus biodiversity protection, aesthetic risks to tourism industry versus new jobs and new industry, and many more.

In Europe, governments and NGOs have chosen to support greenhouse gas reduction in the hope that slowing climate change will eventually reduce biological destruction from ocean acidification and sea level rise. There is risk of damage in having lax environmental assessments, but there is also risk of slowing down the development of renewable energy technologies needed to decrease known detrimental environmental impacts associated with consumption of conventional energy (Vaissière et al. 2014).

This is where academia can work together internationally towards this common goal. If significant academic research points to similar conclusions as this study, there may be enough information to influence political will and improve offshore wind site suitability research. Research in all aspects of site suitability should be carefully designed. Environmental research should utilize site specific records of animal occurrence and endangered species vulnerability. Economic research should analyze cost-benefit that includes mitigation techniques. Socio-political social acceptability research should attempt to utilize data collected from a more random sample of opinions in order to supplement information collected from comment periods. Planning officials should also take careful measures to consider comment data as a whole. In addition to improving acceptability studies, education efforts could further improve the public's understanding of offshore wind energy development so that citizens and politicians can make educated decisions for their communities.

Utilizing the progress that has been made in other countries could further help build our research, political structure, and planning processes in a way that reduces impact as much as possible without severely limiting development. In order to refine and improve our offshore wind planning and development process, there needs to be intensification of research and a political paradigm shift regarding the environmental, economic, and socio-political impacts of offshore wind energy site suitability not only in North Carolina but also the United States as a whole.

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