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Author names and affiliations:
Kateryna Samoteskul[1] (ksam@udel.edu), Jeremy Firestone[1] (jf@udel.edu), James Corbett[1] (jcorbett@udel.edu), John Callahan[2] (john.callahan@udel.edu)

[1]University of Delaware, School of Marine Science and Policy, Robinson Hall, Newark, DE, 19716, USA

[2]Delaware Geological Survey, 257 Academy Street, Newark, DE 19716, USA

Corresponding author:

Kateryna Samoteskul
Email: ksam@udel.edu

Abstract

With the recent emphasis on offshore wind energy Coastal and Marine Spatial Planning (CMSP) has become one of the main frameworks used to plan and manage the increasingly complex web of ocean and coastal uses. As wind development becomes more prevalent, existing users of the ocean space, such as commercial shippers, will be compelled to share their historically open-access waters with these projects. Here, we demonstrate the utility of using cost-effectiveness analysis (CEA) to support siting decisions within a CMSP framework. In this study, we assume that large-scale offshore wind development will take place in the US Mid-Atlantic within the next decades. We then evaluate whether building projects nearshore or far from shore would be more cost-effective. Building projects nearshore is assumed to require rerouting of the commercial vessel traffic traveling between the US Mid-Atlantic ports by an average of 18.5 km per trip. We focus on less than 1,500 transits by large deep-draft vessels. We estimate that over 29 years of the study, commercial shippers would incur an additional $0.2 billion (in 2012$) in direct and indirect costs. Building wind projects closer to shore where vessels used to transit would generate approximately $13.4 billion (in 2012$) in savings. Considering the large cost savings, modifying areas where vessels transit needs to be included in the portfolio of policies used to support the growth of the offshore wind industry in the US.

Keywords: offshore wind energy, cost-effectiveness analysis, marine transportation, marine spatial planning, vessel rerouting

1.1 Introduction

Emerging ocean uses, such as offshore wind energy development, tend to increase the crowding of ocean areas and emphasize the need for integrative planning. Development of wind projects often requires repurposing ocean areas that were previously used for other activities. Such reorganization often can produce tensions. In Europe and the US, coastal and marine spatial planning (CMSP) has become one of the major resource management processes utilized to reduce conflicts between existing and new uses and to allocate space for specific activities (Douvere and Ehler, 2009; Douvere et al., 2007; Qiu and Jones, 2013). In the US, CMSP is being implemented through Executive Order 13547 (White et al., 2012). However, CMSP is rarely paired with economic valuation techniques, such as cost-effectiveness analysis (CEA), which could be used to estimate the economic effects of repurposing ocean areas for wind development.

In the recent years, offshore wind energy has been discussed as an important sector to the US economy (US Department of Energy (DOE), 2011). Development of wind energy is thought to diversify the energy mix, help improve air quality, increase energy security, mitigate climate change, and boost domestic manufacturing (US DOE, 2011; Musial and Ram, 2010). This vision is reflected nationally in the goal set by the DOE (2011) to develop 54 GW of offshore wind capacity by 2030. This would involve building thousands of wind turbines. The push to determine optimal locations for these wind projects has been the main catalyst for applying CMSP framework in the US (White et al., 2012; Douvere and Ehler, 2009).

Thus far, several leasing blocks – called Wind Energy Areas (WEAs) – have already been allocated to offshore wind development in the US Northeast and Mid-Atlantic. The US Department of the Interior's Bureau of Ocean Energy Management (BOEM) determines the locations for these leasing blocks. Assuming that the existing WEAs will be filled in the next several years, and assuming the push to meet the goal of 54 GW by 2030, additional WEAs will have to be designated. Also, as wind projects become more prevalent, commercial shippers will be compelled to share their historically open-access waters with these projects. In this study, we estimate which locations for future WEAs could be most cost-effective considering possible changes to the current vessel travel routes.

Our study demonstrates the utility of using cost-effectiveness analysis (CEA) to assess tradeoffs between offshore wind power and other uses, such as commercial shipping, within a CMSP framework. The analysis is timely as the US Coast Guard (USCG) is conducting the Atlantic Coast Port Access Route Study (PARS) to assess the potential impacts of offshore wind development on commercial navigation (US Coast Guard, 2011b).

1.1.1 *Connecting Offshore Wind Development, Coastal and Marine Spatial Planning and Cost-Effectiveness Analysis*

Development of ocean-based renewable energy projects has been one of the main catalysts for the debate on allocation of ocean space (White et al., 2012; Douvere and Ehler, 2009, Firestone and Kempton, 2007). In a very broad sense, CMSP analyzes and allocates marine spaces to specific uses or non-uses to achieve economic, social and environmental objectives that are determined through a political process (Douvere and Ehler, 2009; Ehler and Douvere, 2007). Thus, CMSP facilitates a more integrated resource management process (Lester et al., 2013; Douvere and Ehler, 2008; Jay, 2010), considers the requirements of different ocean sectors, and provides greater certainty for long-term investment decisions (Ehler, 2008). The CMSP framework also helps balance costs and benefits of particular management measures (Ehler, 2008).

However, established ocean users often resist attempts to conduct CMSP analysis as it may require changing the status quo to accommodate new uses (White et al., 2012). Thus far, CMSP has drawn little from resource economics or other economic valuation tools to inform the planning process (White et al., 2012). As a result, CMSP does not explicitly offer economic assessment tools to quantify, monetize and reduce spatial conflicts among different sectors (White et al., 2012; Douvere and Ehler, 2009; St. Martin and Hall-Arber, 2008).

A few studies integrate quantitative analysis within the CMSP framework. Spaulding et al. (2010) use depth, geology, distance, etc. and wind speed to optimize wind project siting off Rhode Island. This analysis was later extended to include social and ecological constraints (Grilli et al., 2013). An ecosystem services approach was used to determine optimal arrangements among wind projects, commercial fishing and the whale-watching sector off Massachusetts (White et al., 2012). But there are only a few studies evaluating the economic effects of vessel rerouting.

Thus far, the studies that consider the economic effects of rerouting vessels concentrate on the cost of avoiding piracy-ridden seas (Bowden et al., 2010) or the cost of reducing the probability of vessel strikes of whales (Kite-Powell and Hoagland, 2002; National Marine Fisheries Service (NMFS), 2008; Betz et al., 2011). Here, we conduct the first study to use CEA as a decision support tool for CMSP and to assess cost savings from altering vessel routes to open areas for wind development.

CEA is widely used as an alternative to cost-benefit analysis (CBA). It is useful when the analysis focuses on estimating which alternative policy achieves the greatest desirable outcome for the cost (Cellini and Kee, 2010). CEA often provides a cost-effectiveness ratio, which is the ratio of the costs of the alternatives and a single quantified (not monetized) effectiveness measure (Boardman et al., 2011). As here the considered alternatives are equally effective in terms of the amount of electricity produced, we calculate the actual cost differential between the alternatives rather than a cost-effectiveness ratio.

1.1.2 *Study Area and Scope*

We focus on the US Mid-Atlantic region as it has a shallow continental shelf, steadily growing power demand (Musial and Ram, 2010), tremendous wind resource potential (Kempton et al., 2007), and several designated WEAs. The area is also a home to the proposed offshore transmission system off New Jersey.

Our analysis does not incorporate all of the existing ocean activities and thus, is not a full-fledged CMSP. We limit the problem to two mutually exclusive ocean uses: commercial shipping and offshore wind energy development. Our analysis evaluates large deep-draft ships traveling between the port areas of New Jersey/New York, Delaware Bay and Chesapeake Bay (Fig. 1). Deep-draft vessels include container ships, bulk carriers, general cargo, tankers and vehicle carriers. Less than 1,500 annual vessel transits would be affected. An average increase in the voyage length would be 18.5 km.

We use the CEA framework for our analysis because we are not estimating whether there are benefits from building offshore wind projects instead of other electrical generation. Instead, we assume that offshore wind projects would be built and their locations will be largely determined by vessel traffic. Therefore, we use CEA to calculate which of two scenarios would be more cost-effective if the wind projects are built. The scenarios we consider would produce equivalent amounts of electricity. (The number of wind turbines employed would differ in the two scenarios, as fewer turbines are needed to produce the same amount of electricity farther from shore where winds are stronger). This allows us to make a comparison of total (private and social) costs.

We construct two scenarios where the location of future WEAs is influenced by the paths taken by vessels transiting between the US Mid-Atlantic ports. In the first scenario – "Status Quo" – vessels would continue to transit within a virtual corridor[1] 53 km from shore and wind projects are built beyond the vessel routes far from shore (Fig. 2 and 3). In the second scenario – "Alternative" – vessels would transit within a virtual corridor 74 km from shore and wind projects would be built where vessels used to transit (Fig. 2 and 3). We then apply cost-effectiveness analysis framework to quantify and monetize the effects of this hypothetical vessel rerouting.

As we are evaluating the effects of a hypothetical policy on an existing marine activity, we develop several assumptions. During the next decades, the currently designated WEAs and other nearshore areas with minimal spatial conflicts and water depths of less than 30 meters would come to house wind projects. In the Status Quo scenario, to prevent conflicts, developers would then have to build far from shore beyond the existing traffic routes (Fig. 3). For our analysis, we call these wind areas Status Quo WEAs (SQ-WEAs). Without changes in ship traffic patterns, these far-shore sites would need to be developed

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[1] The vessel corridor, referred to as habitual traffic pattern (HTP), represents movements of vessels transiting between the US Mid-Atlantic ports (Fig. 1 and 2). Following Vanderlann, et al. (2009), we define HTPs as areas between ports or traffic separation schemes (TSSs) (which guide vessels in and out of ports) with relatively more vessels than in adjacent areas of the ocean.

if the US is to meet its goal of deploying 54 GW of offshore wind capacity by 2030. The SQ-WEAs avoid major existing vessel routes and areas determined unsuitable for wind development by the US Department of Defense (DOD) (Fig. 3). We assume that the SQ-WEAs would be larger than 260 km^2 and located in transitional waters of more than 30 meters.

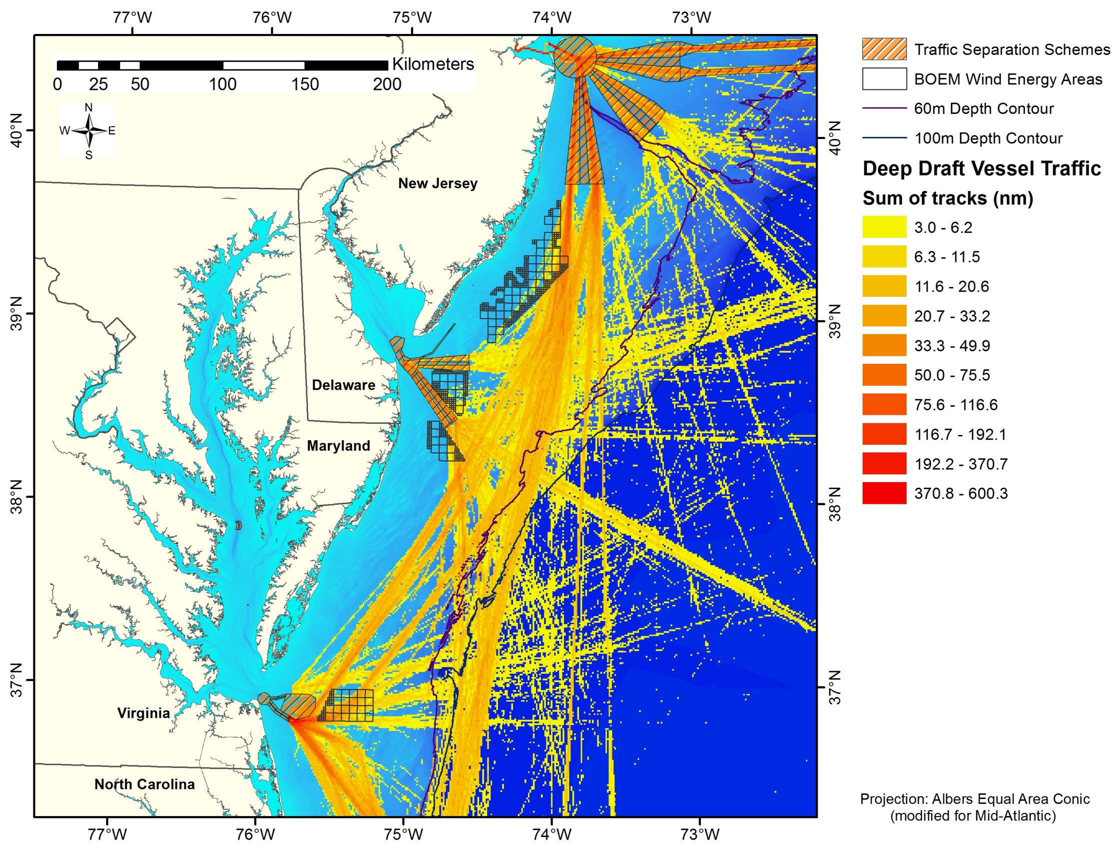

Fig. 1: Relative density of vessel traffic in the US Mid-Atlantic. The value of each 1 km x 1 km cell represents the added length of all voyages taken by vessels transiting through each cell. Existing BOEM Wind Energy Areas are marked as rectangular areas closest to shore. Depth contours are marked in 60 m and 100 m depths.

In the Alternative scenario, nearshore vessel traffic would transit farther from shore. The nearshore space where these ships used to travel would be used for wind energy development (Fig. 3). We call these wind areas Alternative WEAs (ALT-WEAs). Each WEA contains hundreds of 5 MW turbines: NJ (~800 turbines), DE (730), MD (680), and VA (560).

Our analysis proceeds as follows. We 1) estimate current vessel traffic density in the region; 2) estimate the cost savings of wind projects; 3) estimate the additional costs vessel operators would incur in the form of annual fuel, operating and capital costs; and

4) quantify the value of environmental and health damages of added emissions during longer ship transits and the value of reduced emissions from vessels transporting wind turbine components to construction sites now located closer to shore.

2.1 Methods

2.1.1 Vessel Traffic Densities and Selecting Affected Transits

We use ArcGIS and Quantum GIS software to determine commercial vessel traffic density and vessel corridors (habitual traffic patterns with higher densities of ships compared to the surrounding ocean). We also identify specific vessel trips that would be rerouted and draw hypothetical Status Quo and Alternative WEAs.

We model the relative density of vessel traffic in the US Mid-Atlantic using vessel tracks based on the Automatic Identification System (AIS) dataset. AIS is a maritime digital communication system that continuously receives and transmits vessel data (US Coast Guard, 2011b). We use an annual dataset for 2009 (with a partial month of June)[2].

We also use the US Army Corps of Engineers (USACE, 2009) Port Entrances and Clearances dataset that lists origins and destinations of all foreign vessels engaged in commerce in the US. It also classifies vessels by type. These data are used to select large deep-draft vessels from the AIS dataset. We specifically avoid rerouting tug and barge traffic, much of which travels approximately 10 km from the coast and is excluded from our analysis. Fishing vessels and passenger ships are excluded from the analysis, although, depending on size, they also may have to reroute.

Relative vessel densities are modeled for each ship type separately using grid cells of 1 km x 1 km and are displayed using a common range of density values (Fig. 1). Within each grid cell, we calculate the added length of all vessel tracks that appear in that cell. This method does not directly translate into the number of vessels per cell, but depicts the relative spatial coverage of vessels and allows for visual determination of the HTPs (Vanderlaan et al., 2009).

To determine the number of vessel transits affected by the proposed policy, we isolate large deep-draft vessels that transit between three port complexes: NJ/NY harbor, Delaware Bay and Chesapeake Bay. Based on 2009 data, 1,488 vessel transits would be affected[3]. To determine the extent of rerouting, we calculate the average length of transits for each port pair in the Status Quo and Alternative scenarios. The distances are

[2]The data was originally downloaded in a point format and converted to track lines (polylines) linking broadcast data from unique vessel identification numbers for each month. A beta tool (AIS Data Handler for ArcMap 10) developed by National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (NOAA, 2011) was used for this.
[3]This number of vessel trips is comparable to the 2010 and 2011 estimates of the total number of cargo and container ships transiting between the bays/harbors in the region provided by the US Coast Guard.

measured from the boundaries of respective traffic separation schemes (TSSs) that guide vessels in and out of ports. The average added length per trip is 18.5 km (Table 1).

Table 1. Added distance per trip in the Status Quo and Alternative scenario

Route	Distance (SQ)	Distance (Alt)	Added distance per trip	Added time per trip
NJ/NY – DE Bay	144.5 km	166.7 km	22.2 km	48 min
NJ/NY – CH Bay	355.6 km	370.4 km	15 km	28 min
DE Bay – CH Bay	203.7 km	222.2 km	18.5 km	42 min

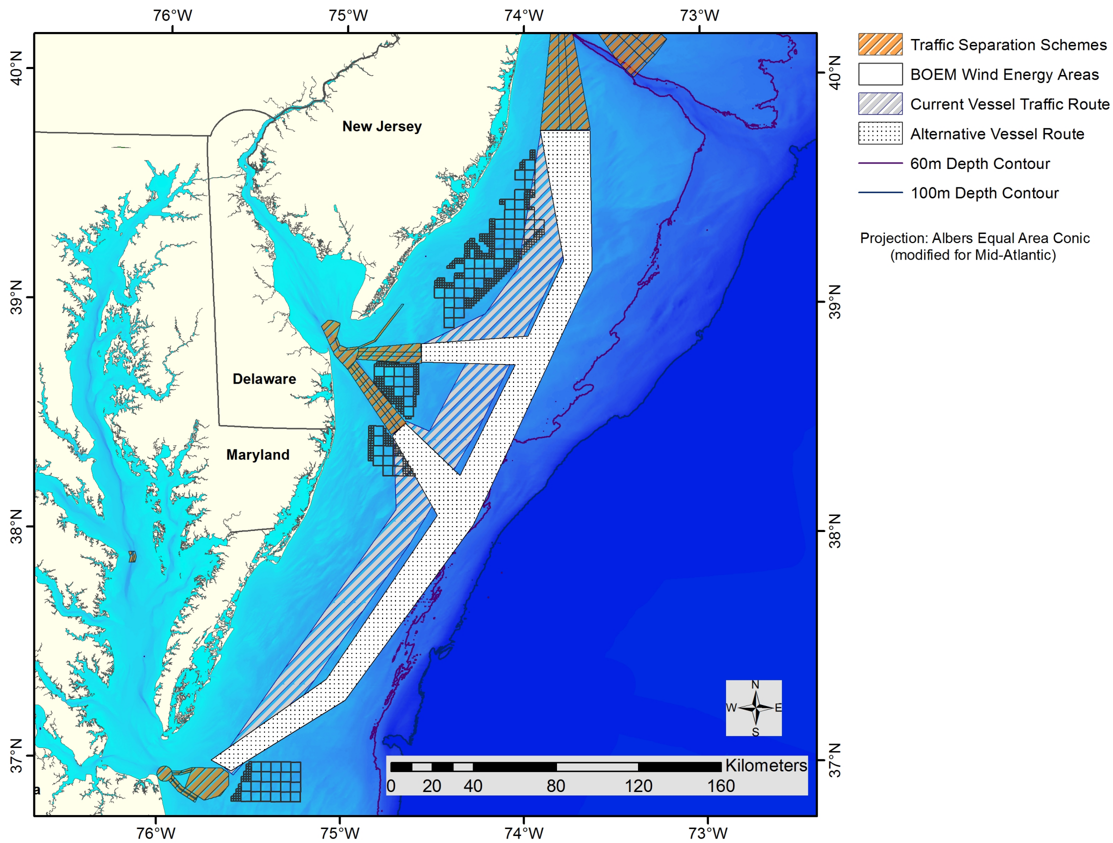

Fig. 2: The affected vessel route, used by ships transiting between the US Mid-Atlantic ports, is located nearshore. We are proposing to move this route farther from the coast.

2.1.2 Determining Water Depths within the Wind Energy Areas

Water depth determines the type of foundations used to build wind projects. With jacket foundations, the depth also affects foundation weight. We assume that jackets would be used for water depths of up to 60 m, with floating Tension Leg Platform (TLP) foundations (vertically moored floating structures) deployed in waters deeper than 60 m[4]. We estimate the average depths within the SQ and ALT-WEAs based on the bathymetry contours from the NOAA Coastal Relief Model (NOAA, 2009). Based on the depth within each WEA, we determine which foundation technology would be employed in the Status Quo and Alternative scenarios.

As a result, in the SQ scenario, off NJ and VA, turbines would be housed almost entirely on jacket foundations. Off Delaware and MD, only floating foundations would be used. In the ALT scenario, jackets would be used on all turbines in all of the WEAs.

2.1.3 Economic Analysis

2.1.3.1 Direct Costs

During the proposed rerouting, vessel operators would incur additional direct costs - fuel, operating and capital costs. To calculate these, we use the 2004 Lloyd's Register of Shipping database. The database contains data on vessel size, number of engines and their power. We link the Lloyd's Register dataset with the USACE dataset. As many data fields in both datasets are missing or incomplete, the added cost is calculated based on a sample of 290 vessel trips. We later scale these added costs to represent the added costs for all 1,448 affected vessels.

Fuel costs are calculated using an estimate of fuel used by each vessel in the sample on its voyage between the US Mid-Atlantic ports. The usage estimate consists of fuel used by main and auxiliary engines (based on Corbett et al., 2009). The fuel estimate does not include fuel used during maneuvering in and out of ports, as this would not change between the original and alternative trips. We assume that vessels would be using Marine Diesel Oil (MDO) or Marine Gas Oil (MGO). Based on global prices for 2012, we assume that MDO/MGO costs approximately $1,000/metric ton.

The added operating costs are modeled following Wilkinson et al. (2011). Costs include: crew wages and medical expenses, provisions, lubricating oils and stores, spares, maintenance and repair, insurance, registration costs, management fees, sundries and administration total.[5] For example, the daily operating cost is $7,500 for a 6,000 TEU container ship and $2,000 for a 5,000 dead weight ton (DWT) general cargo ship.

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[4] Monopile foundations are not used because of the water depth and the large size of the turbines.

[5] These are financial or accounting costs and are not economic resource cost used by the Army Corps in their analyses of navigation operation. Financial costs are more of a snapshot in time. They reflect the rates shippers charge for moving cargo, but are often based on market conditions and can be very volatile or skewed by the level of competition or by other external factors (Knight and Mathis, 2010).

The added capital costs in the form of debt payments are modeled using available average capital costs (Table 2) (UNCTAD, 2011). We assume that the ships in the sample are all new builds and would be financed over 15 years. The debt payments are calculated using a 6% interest rate.

Table 2. Example of capital costs of new vessels

Vessel Type	Capital Cost, 2012$
Dry bulker (75,000 DWT)	$37 million
Oil tanker (160,000 DWT)	$69 million
Container (6,500 TEU)	$26 million

Source: (UNCTAD, 2011)

2.1.3.2 Direct Cost Savings

Capital costs and operating and maintenance (O&M) costs of offshore wind projects increase dramatically with water depth and distance from shore (Bilgili et al, 2011; Green and Vasilakos, 2011; Prassler and Schaechtele, 2012: Jacquemin et al, 2011; Snyder and Kaiser, 2009; European Environment Agency (EEA), 2009; Renewable UK, 2012; Elkinton et al., 2012; KPMG, 2010). We calculate the direct cost savings that could be attained if offshore wind projects were built in shallower waters closer to shore instead of at deeper far-shore sites.

Capital costs include: foundation costs, transmission cable costs, transmission cable installation costs, and wind turbine and foundation transportation costs. Other expenditures, such as development fees, cost of geological and geotechnical surveys, turbine installation costs and others are beyond the scope of this analysis. However, development and construction far from shore raises the overall cost of wind projects.

The cost savings for wind projects are calculated assuming that the WEAs would be populated with 5 MW REpower turbines with a 128-m rotor diameter. We calculate the number of turbines within each WEA, assuming they are spaced 8 x 8 rotor diameters apart, resulting in an array spacing of 1.1016 km^2 (Sheridan et al., 2012). It is important to note that the drawback of moving wind projects closer to shore means reducing the power output per wind turbine due to lower wind speeds closer to the coast.

Distance from shore determines the length and the type of transmission cables used and the associated transmission losses. The cost of transmission cable procurement depends on the type of cable used (HVDC or HVAC), with a tradeoff between the cost of cable per km and the transmission loss. HVDC, which costs $2,1500,000/km, is used for longer transmission (>80 km), because it has lower transmission loses. HVAC, which has higher transmission losses is employed for shorter cable runs (<80 km), because it is cheaper at $1,128,000/km (Table 3) (Elkinton et al., 2012). We assume that irrespective of the type of the cable type, the installation cost is $675,000/km. This cost includes mobilization, route survey, engineering and testing, and other major services related to cable installation (Elkinton et al., 2012).

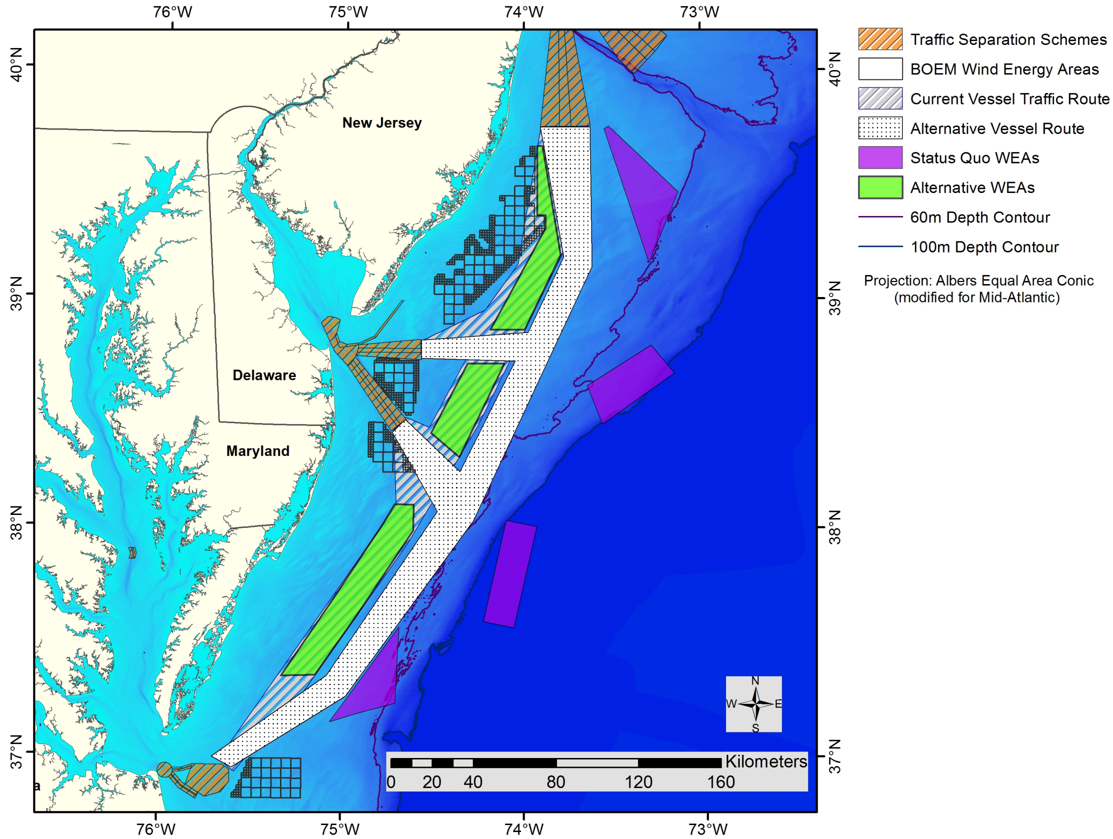

Fig. 3: The current vessel route and the proposed alternative route. The hypothetical Status Quo WEAs are located far offshore and Alternative WEAs are nearshore within the boundaries of the proposed alternative vessel route.

Cable losses are calculated based on losses per km (Table 3) using the average distance from the projects to shore points near electrical substations in the respective states. In the case of New Jersey, the distance is measured to the proposed offshore transmission line. Using these estimates, we calculate the power output for 25 years of project operation. Based on transmission losses and wind speed within different WEAs, we adjust the number of turbines in the SQ and ALT-WEAs so power output is equal.

Table 3. Transmission cable losses, optimized for a 320 kV 1,000 MW cable

Cable type	Losses per km
320 kV HVDC, 500 MW capacity	0.0094 MW/km
230 kV HVAC, 250 MW capacity	0.0718 MW/km

Source: Atlantic Wind Connection (2011)

Water depth directly impacts the amount of steel needed to manufacture foundations for wind turbines. We calculate the weight of each jacket foundation using a weight function for a jacket supporting a generic 5 MW turbine (Jacquemin et al., 2011). We estimate the cost of each jacket by multiplying its weight by the average cost of fabricating one metric ton of steel - $6,250/metric ton (in 2012$). For example, a jacket at an average depth of 35 meters would weigh 495 metric tons and cost $3.1 million while one at 55 meters would weigh 790 metric tons, and cost $4.9 million.

Where water depth is greater than 60 m and is thus too deep to deploy jackets, a floating tension leg platform (TLP) is used. The components used for each TLP foundation include the platform, three mooring lines and three anchors. The cost of steel amounts to $6.1 million, mooring lines - $2.2 million and anchors - $1.2 million. The total cost for each floating foundation is $9.6 million (Jacquemin et al., 2011).

The further the installation site is from shore, the higher the cost of transporting wind turbine components to the construction site. The cost per trip to the project site is calculated based on hourly operating and fuel cost (Table 4) and doubled to account for round trip travel. We assume that turbines installed on floating foundations would be transported to a site by two tugs. Thus, we double the cost per trip for these foundations.

Table 4. Components of transportation cost

Tug day rate	$8,100
Jack-up day rate	$60,000
Tug monthly fuel rate ($3.25/gallon)	$475,800
Tug average operating speed	4 knots

Source: Weeks Marine (2011)

As wind projects are extremely capital intensive, they are financed with debt, which becomes a component of total capital cost estimated here. Lower capital costs mean lower debt for developers. To estimate the total debt payments that would be paid by project developers, we assume that the wind projects would be financed over 15 years (Levitt et al., 2011) with the debt rate of 7.5% (Massachusetts Department of Public Utilities, 2012).

O&M costs include both scheduled and unscheduled maintenance costs incurred during the 25-year lifetime of the project. The difference in O&M costs between projects located in the SQ-WEAs and the Alt-WEAs depends primarily on the distance service personnel have to travel to perform maintenance. The annual O&M costs range from $73,947/MW for projects that can be serviced from an onshore O&M base to $91,766/MW for projects that are serviced from an offshore base (Jacquemin et al., 2011). The cost is modeled for each WEA using the distance to a hypothetical O&M base on the coast.

2.1.2.3 Indirect Costs and Benefits

Indirect (external) costs and benefits of the proposed policy focus on the external cost of air pollutants: SO_2, NOx, PM, and CO_2. The added external costs are calculated by monetizing the health and environmental damages from emissions generated during the extra distance vessels would have to travel to facilitate development in the Alt-WEAs. External benefits represent the value of reduced damages from emissions generated by tugboats transporting components to wind project sites, if they were located closer to shore.
The amount of air emissions generated by commercial vessels is calculated using the estimates of fuel used on trips between the US Mid-Atlantic ports, as discussed above. Emissions generated by tugboats during transportation of turbine components are calculated using the average daily fuel consumption of 6,000 gallons (22.28 metric tons). To estimate the number of tons of each pollutant generated in both scenarios, the fuel usage for each trip is multiplied by emission factors for each pollutant (Table 5). The estimated number of tons of each pollutant created in both scenarios is then multiplied by the average social cost per metric ton[6] (Table 6).

Table 5. Emission factors in kg/metric ton equivalent

Pollutant	Emission factor
NOx	61
SOx	9.2
PM	1.7
CO_2	3,190

Source: International Maritime Organization (IMO) (2009)

Table 6. Social cost of pollutants

Pollutant	Social cost per metric ton (2012$)
NOx	$6,583
SO_2	$14,368
PM_{10}	$13,991
CO_2	$40

Sources: (Gallagher, 2005; US EPA, 2005; Wang and Corbett, 2007; Boardman et al., 2011; US DOE, 2012)

[6] Though the value of health damages from these pollutants (except for CO_2), would likely increase with the proximity to shore, we assume that the social cost per ton remains the same in both scenarios.

2.1.2.4 Estimating the Effects over 29 years

The effects of the proposed policy are estimated over a 29-year period (2 years of construction, 25 years of operation, and 2 years of decommissioning). We select 2020 as the start date as the earliest time period these areas would be ready for development. Cost to vessel operators would start accruing in 2020 and continue through 2048. Cost savings in the form of reduced capital costs and reduced emissions from tugboats would begin accruing in 2020, as project construction would begin then, and spread over 2 years. Benefits in the form of reduced operating costs and debt payments would start accruing in 2022 after the projects are installed. These would spread over 25 years. Due to limited O&M cost data, these costs are assumed to stay flat throughout the project life, though it is feasible that they would increase with time. All values are brought into the common metric of $2012. Present values are calculated with a social discount rate of 3.5% used to evaluate projects spanning less than 30 years (Boardman et al., 2011).

4.1 Results

4.1.1 Costs

In 2009, large deep-draft ships engaged in foreign trade traveling between US Mid-Atlantic ports completed 1,488 trips. Nine percent of the trips were completed by tankers; 72% by container ships; 12% by vehicle carriers; 4% by bulk carriers; and 3% by general cargo. These transits would be affected annually if the wind projects were moved closer to shore and were located within the Alt-WEAs. On average, 18.5 km per trip would be added to the distance of each voyage.

We first calculate the additional costs that would accrue to vessel operators annually if the policy were introduced in 2012, the most recent year in which cost and vessel data are available. This added cost is assumed to increase annually given the projection that the number of vessels in the East Coast container fleet would increase by 35% by 2035 (increase of 2.2% per year) (USACE, 2012). It is difficult to project whether a similar increase can be expected for the rest of the fleet or whether the increase in the number of vessels would mean a proportionate increase in the number of trips taken. Unfortunately, we do not have access to such estimates. In addition, while our study period does not conclude until 2048, the fleet projection estimate runs until only 2035. In light of these limitations, we assume that the 1,488 trips between the US Mid-Atlantic ports in 2012 would increase by 2.2% annually.

The added costs listed below represent the approximate annual added costs for ships traveling between the US Mid-Atlantic ports in 2012, prior to the assumed 2.2% increase in the number of vessels (Table 7). Fuel (54%) and social costs of emissions (36%) are the largest components of costs incurred during rerouting. Operating and capital cost payments constitute just 7% and 3% of the total costs respectively. Importantly, 36% of the additional costs associated with the proposed rerouting would come in the form of the increased air pollution and would be borne by the public at large rather than by the shippers.

Table 7. Summary of added annual cost during rerouting, in million 2012$ before discounting

Route	Added Fuel Cost	Added Operating Cost	Added Capital Cost	Added Social Cost	Total Added Cost
NY/NJ – DE Bay	$1.5	$0.1	$0.2	$1.0	$2.9
NY/NJ - CH Bay	$3.7	$0.16	$0.3	$2.5	$6.7
DE Bay – CH Bay	$0.09	$0.01	$0.01	$0.06	$0.16
Total	$5.29	$0.27	$0.51	$3.56	$9.76

As discussed above, we assume that policy would be implemented in 2020 and would continue for 29 years (25 years of wind project operation, plus 2 years each for installation and decommissioning). We also assume that the number of trips between the US Mid-Atlantic ports would increase by 2.2% annually starting with 1,488 trips in 2012. The additional cost incurred by vessels annually is assumed to grow proportionate to the number of trips taken. As a result, if the rerouting starts in 2020 rather than in 2012, the annual added cost of rerouting would be $12 million (in 2012$, before discounting), compared to $9.8 million (Table 7). In 2048, the total additional cost for all vessels traveling between the US Mid-Atlantic ports would reach $24 million per year (in 2012$, before discounting).

Over 29 years, the added direct and external cost of vessel rerouting would amount to almost $523 million (in 2012$, before discounting). To bring the estimate in present terms, we use the 3.5% social discount rate. The present value of the total added rerouting cost is approximately $193 million (in 2012$).

4.1.2 Benefits

The cost savings calculated from moving wind projects closer to shore as proposed in the Alternative scenario are summarized here in the form of reduced capital and O&M costs over 29 years (Table 8). All values are in 2012$, before discounting. We note that in the case of Maryland and Virginia, in the alternative, the two areas SQ WEAs become a single ALT-WEA adjacent to both States (see Fig. 3). Additionally, O&M and transmission cable installation costs increase in some cases because we assume that more turbines would be built in nearshore wind energy areas compared to far-shore sites where wind speeds are higher.

Table 8. Cost savings in the New Jersey Wind Energy Area (in 2012$ before discounting)

Cost Savings	New Jersey	Delaware	Maryland/Virginia
Capital cost debt payments	$2.3 billion	$8.2 billion	$13 billion
Foundations	$0.4 billion	$3.8 billion	$6.5 billion
Transmission cables	$0.6 billion	$10 million	$1.3 billion
O&M	$0.6 billion	-$0.6 billion	-$0.7 billion
Installation of cables	$0.4 billion	$10 million	-$0.41 million
Transportation	$12 million	$38 million	$90 million
External cost of emissions	$4 million	$30 million	$60 million
Total savings	**$4.3 billion**	**$12.5 billion**	**$20.5 billion**

The combined savings for all WEAs amount to $37.4 billion (in 2012$ before discounting), with benefits from reduced emissions from construction vessels accounting for $94 million. The breakdown of estimated benefits by the WEA is shown in Table 9.

Table 9. The estimated direct and indirect benefits for WEAs. All values are in billion 2012$ before discounting

	Capital	O&M	Capital Cost Payments	Social	Total
NJ	$1.37	$0.6	$2.32	$0.004	$4.3
DE	$4.84	-$0.6	$8.19	$0.03	$12.5
MD/VA	$7.89	-$0.7	$13.3	$0.06	$20.6
Total	$14.1	-$1.2	$24.5	$0.094	$37.4

Using a 3.5% social discount rate, we estimate that the present value of costs generated by the proposed policy is $0.2 billion and present value of savings - $13.6 billion (in 2012$). This means that the alternative scenario that would bring offshore wind development closer to shore would be more cost-effective than building the same amount of generation in the Status Quo areas by more than $13 billion. To put the results into a different form, the benefit to cost ratio is 71:1.

To test the robustness of the findings, we perform a sensitivity analysis. We run the model again based on assumptions that would increase the cost of rerouting ships and decrease the cost of building wind projects in deeper waters farther from shore. We 1) double the cost of fuel; 2) cut in half the cost of foundations and transmission cables; 3) use the higher end values of the social cost of emissions; and 4) use a high 10% social discount rate.

With the above parameters, the combined cost for 29 years of the policy being in effect would amount to $934 million, compared to $523 million previously (in 2012$ before discounting). The benefits decrease to $18 billion, compared to $37.4 billion previously (in 2012$ before discounting). Even when a high 10% social discount rate is applied, locating wind projects closer to shore would still be more cost effective by approximately $1.7 billion (discounted to 2012$). Benefits would outweigh the cost 20:1.

Finally, even if we extended the sensitivity analysis further and increase the number of vessel trips four-fold, rerouting ships would remain cost effective, with the net benefits of $1.4 billion (2012$, with the high 10% SDR), and a benefit:cost ratio of 5:1.

5. 1 Discussion

As federal and state governments and industry are taking steps to promote offshore wind development, concerns are growing about the effects of these projects on the existing users of the ocean. We focus on rerouting a small portion of total vessel trips to estimate cost-effectiveness of placing wind projects nearshore instead of far from the coast. The shipping industry is likely to initially raise concerns regarding the proposed rerouting. But given what appears to be a relatively small expense to the shipping industry, we expect that if safety aspects to such a rerouting can be addressed, the shipping industry will come to support this accommodation as it has with, for example, north Atlantic right whales.

Although we made several assumptions about the future all of which have a certain degree of uncertainty, it is worthwhile to consider how such a policy would impact the shippers and consumers. First, the proposed rerouting would increase the fuel, operating, capital and external cost per vessel trip by about $7,400 from approximately $86,000[7]. Of the $7,400 in added vessel costs, the external cost of emissions would amount to about $2,700. Therefore, the private added cost of transporting a metric ton of goods would increase by 25¢,[8] a cost that would either be absorbed by shippers or passed on to consumers, adding less than a ½ penny to the cost of transporting a large flat screen television. The remainder (14¢/metric ton) would be absorbed by society in the form of increased pollution.

Furthermore, implementing the proposed rerouting scenario could bring significant savings to consumers as compared to deploying wind power far offshore. If the wind projects that we consider were built, they would supply approximately 3.8 million households with electricity annually (based on 2011 demand). And if the more cost-efficient scenario is chosen, the savings could be used to build an additional 2,240 MW of wind capacity (based on the cost of building shallow-water projects - approximately $6 million/MW) (Levitt et al., 2011). This additional 2,240 MW of offshore wind capacity would power an additional 593,000 households. The electricity from these wind turbines

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[7] An average across all routes and vessel types; the cost of distance traveled between the TSSs only.
[8] We divided the total annual added cost of rerouting by the total tons transported by the affected vessels annually.

would displace approximately an additional 133 million tons of CO_2 over 25 years by displacing fossil fuel generation from the grid (based on data in PJM, 2009).

Alternatively, the cost savings could be used to reduce the cost of delivering clean, domestically produced offshore wind power to consumers. Assuming that the wind projects are built nearshore rather than farshore, the cost of electricity generated from the nearshore projects could be reduced by 3¢/kWh. This would reduce the monthly cost of consuming electricity from these nearshore wind projects by approximately $30 for an average household. Furthermore, vessels transiting farther from shore would discharge air pollutants farther in the ocean. Though we do not monetize these effects, emitting pollutants farther from the coast, could potentially reduce health effects (Winebrake et al., 2009; Camping et al., 2013).

It is important to emphasize that in our model, we use average distances, depths, vessel operating and design speeds, engine sizes, cable costs, foundation weights, and the average external cost of emissions. Therefore, it is likely that our results illustrate the average effects expected from the proposed policy. However, the sensitivity analysis shows that the findings are robust. Moreover, even though we do not estimate the cost of delays and the effects of the proposed measures on passenger ships, smaller domestic vessels, fishing boats etc., the proposed policy would still be more cost-effective even if the number of vessels affected by rerouting increased 50-fold.

Lastly, although the CEA of the proposed rerouting suggests a specific policy change, other site-specific considerations (e.g., commercial fishing and wildlife habitats) would have to be assessed prior to the permitting of wind projects in any specific area within the alternative nearshore WEAs[9]. A full CMSP analysis would include these and other marine uses, highlighting the utility of applying economic valuation methods to resolve disputes regarding management of ocean resources.

6.1 Conclusions

During the recent years, policy planners and developers have been expected to limit the impacts of offshore wind projects on the existing marine uses while facing pressures to reduce costs. Our study shows that using CEA as a decision support tool for CMSP can help create an effective resource management framework in the US Mid-Atlantic and beyond. Our study analyzes a hypothetical scenario regarding placement of wind projects in the US Mid-Atlantic and does not capture all of the details involved in estimating the full costs and benefits associated with the proposed rerouting. However, the analysis is robust enough to show that here relocating commercial ships is a viable way to lower the cost of offshore wind energy development.

If the US is to advance toward meeting its goal to build 54 GW of offshore wind capacity by 2030, finding cost-effective locations for these wind projects is critical. By modifying vessel routes, shallow, nearshore sites in the US Mid-Atlantic could be opened for wind

[9] The effects of building wind projects closer to shore on property values are not assessed because the projects would not be visible from the coast.

development, allowing consumers to have the benefit of clean, domestic, carbon-free wind energy at a cheaper price per kWh. Particularly since the cost of offshore wind power is presently above market rates, such modifications need to be included in the portfolio of policies used to support the growth of the offshore wind industry. Similar benefits could potentially be realized in the North Sea, off the Chinese coast and in other waters around the world. Careful planning, stakeholder engagement, and consideration of economic effects can help build a robust offshore wind sector in the US, and further it in the North Sea, while ensuring the uninterrupted and safe operation of the maritime industry.

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