Socioeconomic Assessment of Shipping and Navigation for Potential New York State Offshore Wind Development

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Serve as a catalyst – advancing energy innovation, technology, and investment; transforming New York's economy; and empowering people to choose clean and efficient energy as part of their everyday lives.

Socioeconomic Assessment of Shipping and Navigation for Potential New York State Offshore Wind Development

Final Report

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Notice

Abstract

This study supplements a collection of studies prepared on behalf of the New York State Energy Research and Development Authority (NYSERDA) to provide information related to a variety of environmental, social, economic, regulatory, and infrastructure-related issues implicated in planning for future offshore wind energy development off the coast of New York State. This study assesses the potential socioeconomic impacts of rerouting commercial vessels around potential offshore wind farms within the Area for Consideration identified by New York State in the New York State Area for Consideration for the Potential Locating of Offshore Wind Energy Areas report State. Economic costs could potentially impact vessel operators, but the societal benefits associated with reduced carbon dioxide emissions can more than offset incremental costs. Given the high variability in economic and operational costs, as well the social cost of carbon dioxide, a range is presented for the calculated socioeconomic costs. NYSERDA's intent is to facilitate the principled planning of future offshore development, to provide a resource for the various stakeholders, and to support the achievement of the State’s offshore wind energy goals.

Keywords

offshore wind, shipping, navigation, socioeconomic, vessel

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Acronyms and Abbreviations

AIS	Automatic Identification System
COLREGS	International Regulations for Preventing Collisions at Sea
CO_2	Carbon dioxide
EPA	Environmental Protection Agency
ES	Environmental statement
GDP	Gross domestic product
GIS	Geographical Information System
GHG	Greenhouse gas
HFO	Heavy fuel oil
IMO	International Maritime Organization
MGO	Marine gasoil
NO_x	Nitrogen Oxides
NSRA	Navigation Safety Risk Assessment (USA)
NYSERDA	New York State Energy Research and Development Authority
PM10	Particulate matter having a particle size less than or equal to 10 microns diameter
RCG	The Renewables Consulting Group LLC
SFOC	Specific Fuel Oil Consumption
SO_2	Sulfur dioxide
TSS	Traffic Separation Schemes

Executive Summary

The New York State Energy Research and Development Authority (NYSERDA) has commissioned this study to assess the potential socioeconomic impacts of rerouting commercial vessels around potential offshore wind farms within the Area for Consideration proposed by New York State. This study supplements the shipping and navigation study published as part of NYSERDA's offshore wind Master Plan.

A methodology was developed to determine the economic costs that ships would incur if they needed to reroute around potential offshore wind farms developed within Area for Consideration. Economic costs are challenging to determine because they can vary depending on vessel transit distances and durations, engine size, and fuel consumption rates by fuel type and variability of market price at the time of purchase. This is further compounded by vessel size and type (e.g., cargos, tankers, passengers, tugs and towing), sea state, weather conditions, and vessel speed. Operational costs were also calculated as part of this economic assessment—and like fuel costs—can be influenced by a range of factors, for example, crew size, insurance coverage, maintenance costs, repair needs, and other overhead items that increase with longer journey times and greater vessel use.

Assumptions underpinning estimates for economic costs (fuel and operational) were obtained from a literature review. Economic costs could potentially impact vessel operators, but the societal benefits associated with carbon dioxide (CO_2) emissions can significantly offset the overall impact. The economic costs associated with vessels rerouting around the Area for Consideration are considered the base case. Given the high variability in the economic and operational costs, and social cost of CO_2, a range for the total socioeconomic cost was calculated with a minimum, a maximum, and a "typical" cost. The latter being the cost associated with the most prevalent engine size (kW) for each vessel type, which were based on findings from the literature.

The extra transit distances and durations for vessels rerouting were calculated using a Geographical Information System (GIS) model, Automatic Identification System (AIS) data records for U.S. coastal waters from the Marine Cadastre portal (2013), and proprietary vessel traffic analysis software. The vessel types evaluated included cargo, tanker, passenger (cruise liner) and tugs and towing, whereas smaller vessels such as commercial fishing and recreational vessels were not as they are more likely to transit through the wind farm, avoiding the need for significant rerouting.

The socioeconomic costs of vessel rerouting were evaluated under four different scenarios:

- Scenario 1: Rerouting around the entire Area for Consideration (East and West)
- Scenario 2: Rerouting around the Area for Consideration (West) only
- Scenario 3: Rerouting around the Area for Consideration (East) only
- Scenario 4: Rerouting around four sites in the Area for Consideration (West)

Scenario 4 was chosen as an example layout capable of fitting the 2.4 GW required by New York State to show how much socioeconomic costs can be reduced by simply reducing the area of development and carefully siting offshore wind farms.

Among other factors, the Area for Consideration (West and East) was sited to avoid impacting Traffic Separation Schemes (TSS) lanes entering and exiting the port of New York and New Jersey and to avoid disrupting other unofficial traffic routes (where practical).

Seven major vessel routes (defined as having >10 vessels a day) were identified in the shipping and navigation study as potentially being affected by offshore wind farm development within the Area for Consideration. The maximum socioeconomic costs associated with the four scenarios were ordered from worst to least as follows:

- Scenario 1 (where rerouting was modeled around both portions of the Area for Consideration) had the largest potential effect on commercial vessels ~$5.7 million/yr
- Scenario 2 had the next largest costs ~$3.9 million/yr
- Scenario 4 has a much lower cost of ~$2.1 million/yr
- Scenario 3 has the least cost impact of ~$1.7 million/yr

Careful siting of offshore wind farms around popular traffic routes, especially those used by tug and towing vessels (considered the most sensitive to cost impacts due to their slow transit times), could further mitigate the potential economic costs to these stakeholders. The costs listed in the bullet points are maximum costs and are considered to be in the high range. The more typical socioeconomic costs associated with the four scenarios are significantly lower.

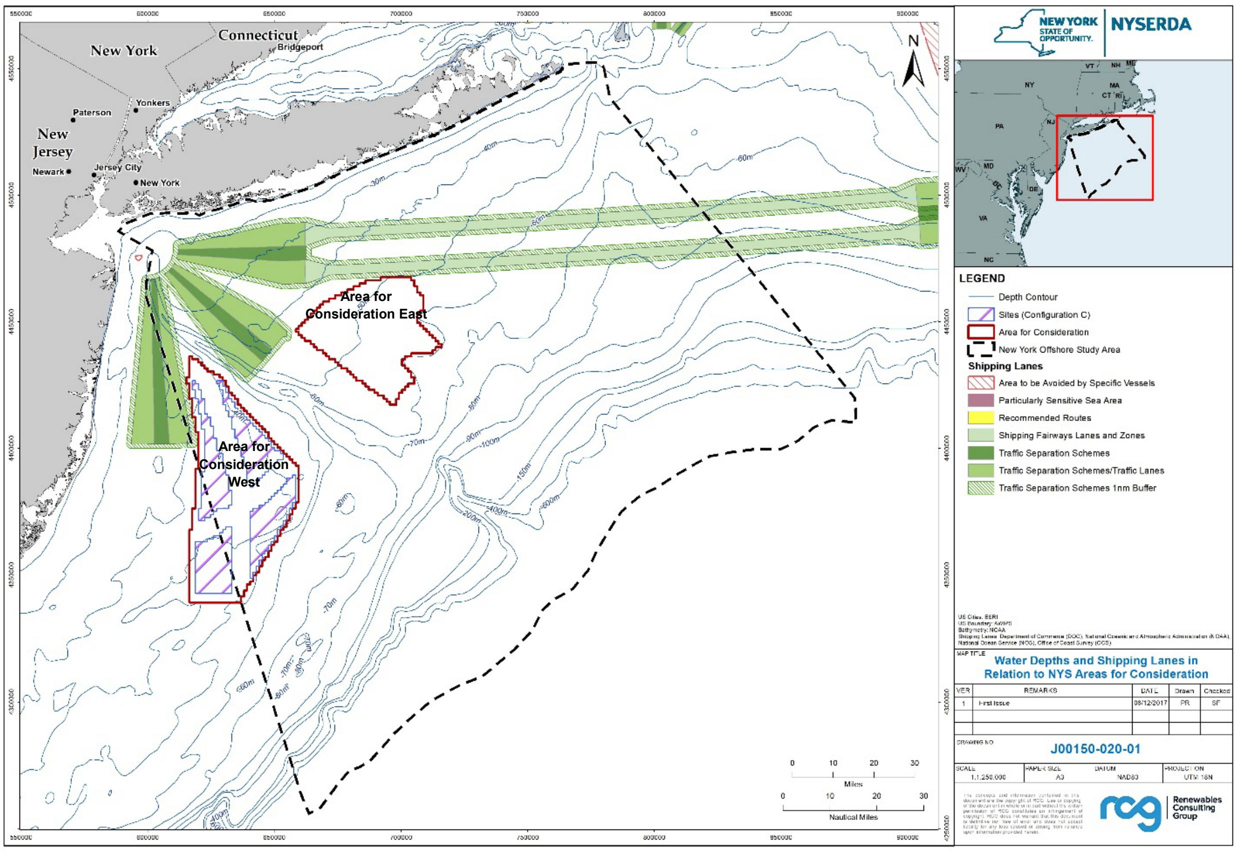
There were some common patterns across all scenarios and vessel traffic routes. Cargo vessels were found to have the highest fuel costs compared to the other vessel types analyzed because overall their consumption and engine size are much larger than other vessel types. By comparison, passenger vessels had the highest overall economic costs (fuel and operational) across all scenarios and routes.

This study presents several worst-case scenarios for socioeconomic costs caused by potential wind farm development, but these costs would be offset by the societal benefit of the wind farm (i.e., CO_2 offsets). Offshore wind farms would also offset emissions of other greenhouse gases (GHG) and pollutants (e.g., PM_{10}, NO_x, SO_2), further reinforcing overall net positive impacts.

1 Introduction

The New York State Energy Research and Development Authority (NYSERDA) contracted the Renewables Consulting Group LLC (RCG) to assess the potential socioeconomic costs of rerouting commercial vessels around the Area for Consideration (West and East) seen in Figure 1. This study supplements the shipping and navigation study published as part of the New York State Offshore Wind Master Plan (Master Plan).

Figure 1. Area for Consideration (East and West) and Example Wind Farm Sites in the West



2 Methodology

The following tasks were undertaken for this study:

Task 1. Desktop review: Desktop review of references on economic costs (fuel and operational) relating to vessel rerouting, factors influencing the distance and duration of route deviations, and European offshore wind farm shipping impacts.

Task 2. Modelling of vessel rerouting: High-level categorization of the potential socioeconomic costs of vessel rerouting was determined using a Geographical Information System (GIS) analysis and vessel route modeling software described in Section 2.2 below. [1]

Task 3. Downstream impacts: Identification of any shipping-related industries potentially impacted.

Task 4. Recommendations: Development of recommendations for how the findings of this study could further characterize and mitigate potential socioeconomic impacts of siting offshore wind farms within the Area for Consideration.

The assessment does not include potential economic cost impacts to ports and harbors, commercial fishers, or recreational users.

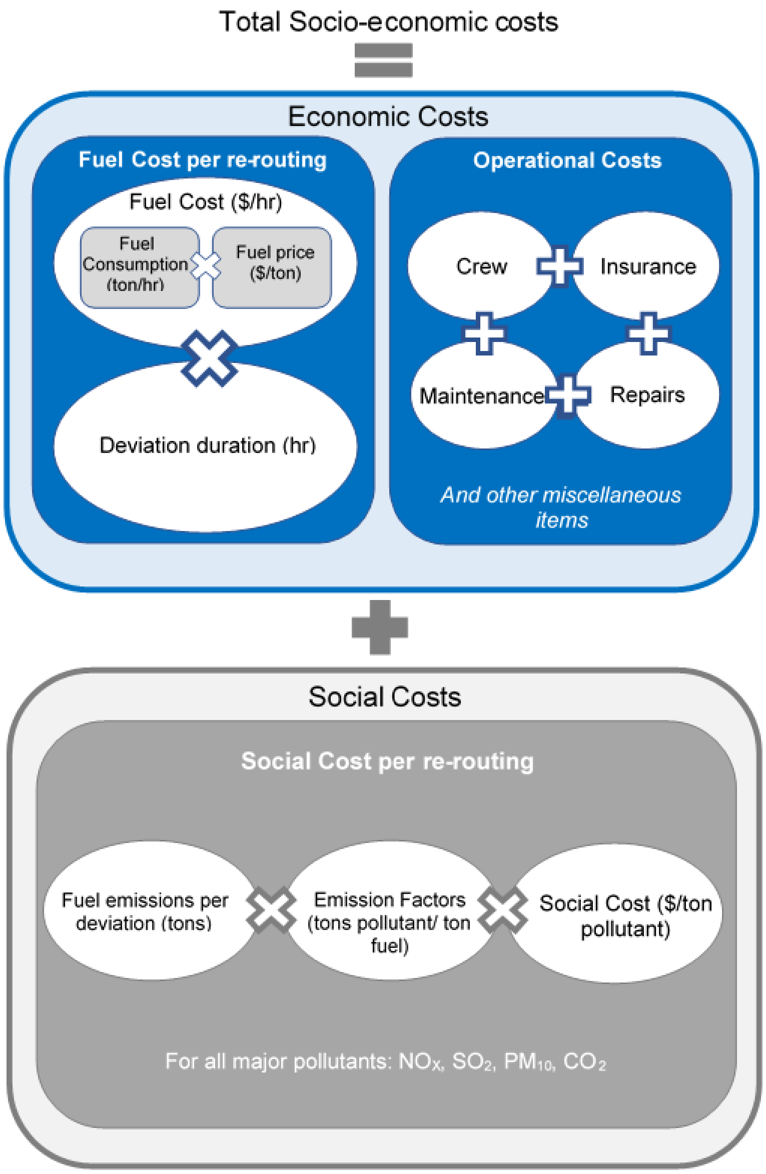
The following section describes the methodologies used to conduct the analyses required for Tasks 1 and 2. The equations used to support these methodologies are presented in appendix A and referenced throughout the report.

2.1 Task 1: Desktop Review

The scientific literature was reviewed to develop the assumptions underpinning estimates for economic costs (fuel and operational). These are cited through this report where relevant. In addition, literature on the costs, benefits, and greenhouse gas (GHG) emissions associated with social and societal benefits were also reviewed.

The formula for calculating the total socioeconomic costs of rerouting vessels around the Area for Consideration is visually represented in Figure 2.

Figure 2. Methodology for Calculating the Total Socioeconomic Costs



2.1.1 Economic Costs

Economic costs are made up of fuel and operational costs. These can also be considered as net costs—those that will directly impact the vessel operators.

Vessel rerouting could incur extra costs as more fuel is used and operational costs for crew, insurance, maintenance, repair, and other overhead items are applied increase as transit times increase accordingly (Gkonis & Psaraftis, n.d.).

Costs estimates associated with vessel transit duration can be calculated using several assumptions, including those outlined in studies conducted by Anon., n.d.; Murray, 2016; Parametrix, 2006; Greiner, 2013; Army Corps of Engineers, 2004; Samoteskul, 2013; U.S. DOT, Maritime Administration, 2011; Cruise Market Watch, 2015; Carnival Corporation & PLC, 2016. The following relates the methodology used by the Renewables Consulting Group for this study for calculating costs estimates and transit duration.

Geographical Information System (GIS) analysis and proprietary vessel traffic software[2] were used to determine the distance travelled and the deviation duration (from the original route) of a vessel.

Fuel and operational costs are highly variable and dependent on vessel engine size, vessel type, age and transit speed sea state, and weather conditions. For this study, cargo, tanker, passenger (cruise liner), and tugs and towing vessels were examined. Smaller boats, such as commercial fishing and recreational vessels, were not included in this analysis as they are more likely to transit through the wind farm, avoiding the need for significant rerouting.

2.1.1.1 Fuel costs

Estimating fuel costs requires data on fuel consumption rates of individual vessel types, the market price of fuel, and how these factors are influenced by transit duration.

Consumption rates

Fuel consumption rates (ton/hr) were calculated using the Specific Fuel Oil Consumption[3] (SFOC) rate of a typical two-stroke (g/kWh) engine (Faber, et al., 2012). However, because determining engine sizes from the literature was highly subjective and variable, the typical engine size (kW) for each vessel type (i.e., cargo, tanker, passenger, and tug and towing) were also identified. A typical engine size for each vessel type was identified from the literature and a minimum and maximum size range included (Table 1). For cargo vessels, the typical engine size is 45,000 kW. This was the most commonly occurring engine size in the 2013 global fleet data of nearly 5,000 cargo vessels (Alphaliner, n.d.). For tankers, based on 87 liner vessels (AET Tankers, n.d.), the typical engine size was 12,850 kW. Since no data were readily available on the engine sizes for passenger and tugs and towing vessels, the maximum value of 8,200 kW for passenger vessels and 4,600 kW for tug and towing vessels were used.

Table 1. Engine Sizes (kW) and Fuel Consumption Rates (tons/hr) by Vessel Type

	Engine Size (kW)			Fuel Consumption (tons/hr)			
Vessel Type	Min	Typical	Max	Min	Typical	Max	Source
Cargo	3,000	45,000	91,500	0.5	7.5	15.2	MAN Diesel & Turbo, *Propulsion Trends in Container Vessels*
Tanker	3,000	12,850	31,100	0.5	2.1	5.2	MAN Diesel & Turbo, *Propulsion Trends in Tanker Vessels*
Passenger	42,240	82,000	82,000	7.0	13.6	13.6	*Harmony of the Seas* – typical large cruise liner
Tugs and Towing	700	4,600	4,600	0.1	0.8	0.8	Seaspan Shipyards Report 2017

Market price

Fuel price varies depending upon type and market price. The main two fuel types available include:

- Marine Gasoil (MGO), which at the time of writing was $583/ton; and
- Heavy Fuel Oil (HFO), which was $343/ton.

For this study, HFO was selected because it represents the worst-case scenario for pollutant and GHG emissions[4]. At the time of writing, the current market price of HFO was $343/ton (Anon., n.d.). To calculate fuel costs in dollars per hour for vessel type, fuel consumption rates were multiplied by the HFO market price (Table 2 and appendix A—equation 1).

Table 2. Fuel Costs per Hour for Vessel Types

	Fuel cost ($) per hour		
Vessel Type	Min	Typical	Max
Cargo	171.5	2,569.1	5,223.9
Tanker	171.5	734.0	1,776.7
Passenger	2,411.3	4,682.0	4,682.0
Tugs and Towing	41.2	264.1	264.1

Transit Duration Costs

To calculate the duration (hours) a vessel may have to be rerouted, the distance of the route deviation was divided by vessel speed (appendix A—equation 2). The vessel speeds for individual vessel types are presented in Table 3. To obtain the fuel costs associated with rerouting, costs were multiplied by duration (appendix A—equation 3).

Table 3. Vessel Speeds (Knots) and Rerouting Speed (km/hr) by Vessel Type

Vessel Type	Vessel Speed (Knots)	Rerouting Speed (km/hr)	Source
Cargo	22.5	41.7	Notteboom, Cariou 2009
Tanker	15.0	27.8	MAN Diesel & Turbo: *Propulsion Trends in Tanker Vessels*
Passenger	22.0	40.7	Chanev 2015
Tugs and Towing	9.0	16.7	*ReCAAP/IFC Tug Boats and Barges (TaB) Guide*

2.1.1.2 Operational costs

Operational costs are highly variable between vessels. For this study, cost data were obtained from Murray, 2016; Parametrix, 2006; Greiner, 2013; Army Corps of Engineers, 2004; Samoteskul, 2013; U.S. DOT, Maritime Administration, 2011. For each vessel type, typical operational costs were calculated in dollars per hour [5] (Table 4).

Table 4. Operating Cost by Vessel Type

	Operating Cost ($/hr)			
Vessel Type	**Min**	**Typical**	**Max**	**Source**
Cargo	451	496	998	U.S. DOT, Maritime Administration 2011
Tanker	343	458	458	Greiner 2013
Tugs and Towing	201	365	365	Army Corps of Engineers 2004

The typical operating costs of passenger vessels is far greater than that of other vessel types due to the large number of people on board and variety of revenue streams and operational requirements onboard. For this study, revenue and expenses data were obtained from Cruise Market Watch (2015) and the 2016 financial report for passenger vessels (Carnival Corporation & PLC, 2016). The longer passenger vessels are at sea, the more revenue they generate from the services and activities they provide on board. The net increase in operating costs, after subtracting revenues, is summarized in Table 5.

Table 5. Revenue and Operational Costs for Passenger Vessels

	Revenue ($/hr)		Operational Cost ($/hr)		Net Operating Costs ($/hr)	
Vessel Type	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Passenger Vessels	5,372	7,014	16,177	22,251	10,805	15,237

2.1.2 Social Costs of Emissions and Rerouting

The social costs of commercial shipping are measured by their total greenhouse gas (GHG) emissions, which increase relative to transit distance and duration. For this study, social cost data were obtained from Samoteskul (2013) and Environmental Protection Agency (EPA 2016). The combination of social and economic costs, referred to as socioeconomic costs in this report, can be considered gross costs, as the social portion of the costs will not result in a direct financial burden on the navigation industry but rather indirectly affect society.

Vessel air pollutants identified as having the most impact on the environment include nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter ($PM_{10,}$)[6] and carbon dioxide (CO_2). These emissions are associated with HFO (ton of pollutant/ton of fuel burned) [2014 International Maritime Organization (IMO) GHG report, 2014] and were used to assess social costs (Table 6). Carbon dioxide emissions were taken forward in this study to calculate the carbon payback period and savings (see section 2.1.2[1]).

Table 6. Emission Factors from the Combustion of HFO Fuel (IMO 2014)

Emissions species	Marine HFO emission factor (ton / ton fuel)
NO_x	0.07269
SO_x	0.04908
PM_{10}	0.00699
CO_2	3.114

The EPA's social cost estimates for CO_2 are considered to increase over time because future emissions are expected to produce larger incremental damages.[7] The social costs per year were calculated using the extra tons of fuel burned for each vessel rerouting and multiplied by the number of vessels affected each year. The minimum and maximum limits for social costs over the life of the proposed New York offshore wind farm deployment program (31 years) to meet the New York State target of 2.4 GW were calculated (Table 7). The annual breakdown for these estimates is presented in appendix B.

Table 7. Social Costs of Air Pollutants (Adjusted to $2,017)

Emissions Species	Social Cost ($/ton pollutant) Min	Max	Source
NO_x	$2,131	$12,061	Samoteskul 2013
SO_2	$2,883	$28,112	Samoteskul 2013
PM_{10}	$1,653	$28,544	Samoteskul 2013
CO_2	$47.77	$74.31	EPA 2016

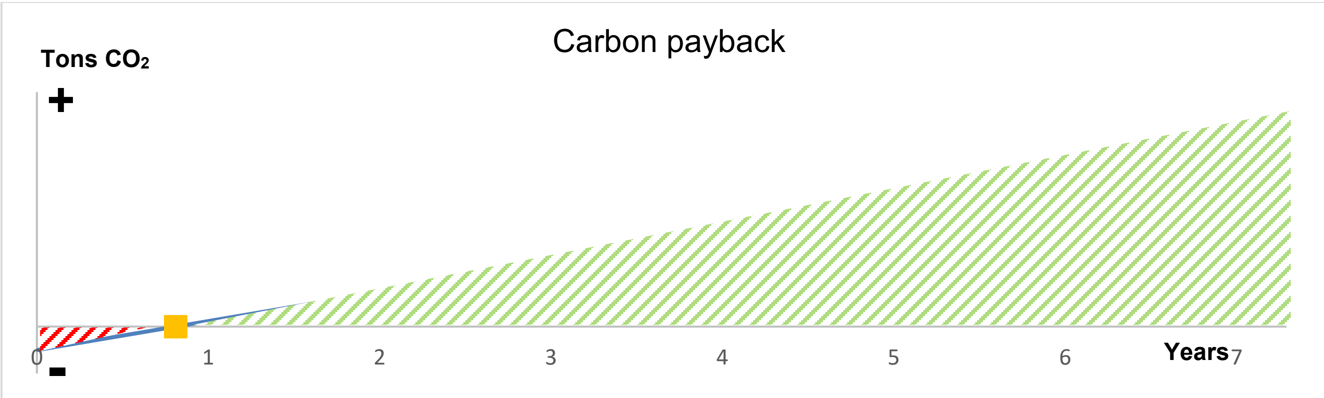
2.1.2.1 Carbon Payback and Lifetime net CO_2 Savings

To calculate the net cost or benefit of developing offshore wind farms in New York State from an emissions standpoint, the offset resulting from the CO_2 saved by the operational wind farms (societal benefits) needs to be considered. The estimate used in the Master Plan for the tons of CO_2 saved per megawatt-hours (MWh) of electricity produced by the wind farms of 0.538 was used to this end, subtracting the lifecycle carbon emissions of a wind farm, including from vessel rerouting, from the total CO_2 savings based on the MWh of electricity produced. Lifecycle carbon emissions were calculated as the sum of the carbon emissions emitted throughout the lifecycle of an offshore wind farm and the additional CO_2 emissions from vessel rerouting.

A study comparing various estimates of the lifecycle carbon emissions of offshore wind farms computed by a wide range of stakeholders (turbine manufacturers, wind farm operators, and academics) was used in this analysis to complement the emissions from rerouting (Thomson & Harrison, 2015). A mean value of the nine device estimates included in the study (see appendix B) of 13.3 gCO_2eq/kWh was used for the purpose of this analysis. The different estimates take into account the entire lifecycle of the wind farms from materials and manufacture of the components to transport and installation, operation and maintenance, and decommissioning. The gross CO_2 savings for the deployment of offshore wind farms in the Area for Consideration was based on generation numbers provided in NYSERDA's Master Plan (appendix A—equation 4).

The carbon payback period is defined as the time taken for the carbon savings from a wind farm to equal the net emissions released during the lifecycle of the project. To estimate the carbon payback period, the estimate of CO_2 emissions from the lifecycle of the wind farm (13.3 gCO2/kWh) and the vessel rerouting were divided by the CO_2 displaced by the wind farm annually (appendix A—equation 5). This concept is visually represented in Figure 3.

Figure 3. Carbon Payback Concept Representation



In addition to the societal benefit calculated in tons of CO_2 saved, a net socioeconomic benefit was calculated by subtracting the total annual socioeconomic costs from the average annual CO_2 savings (in dollars) resulting from the electricity produced (appendix A—equation 6).

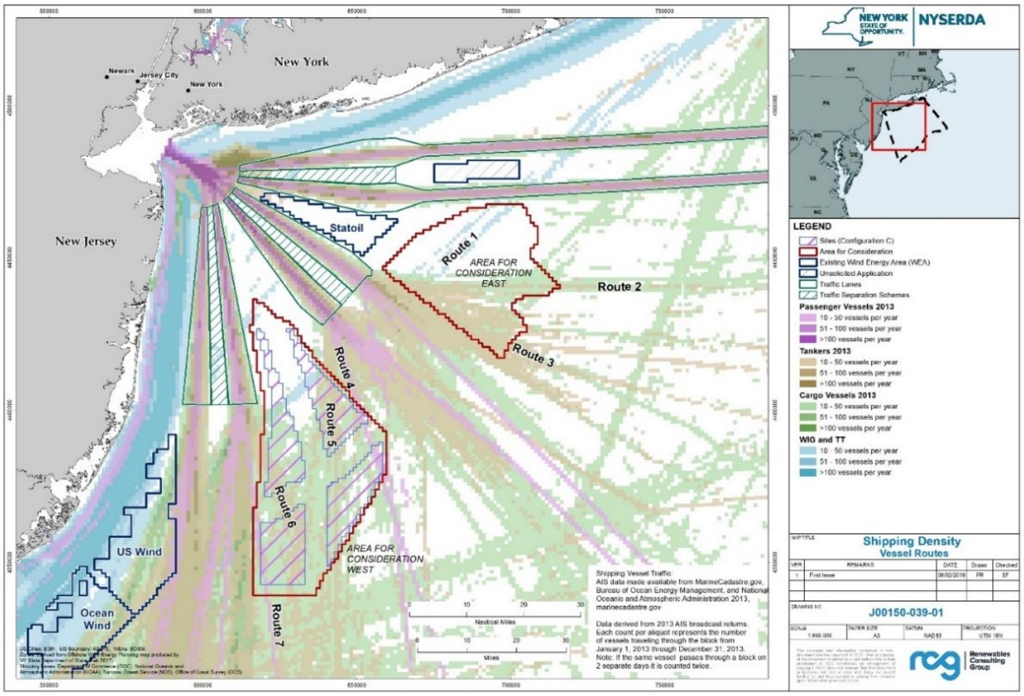
2.2 Task 2: Modeling Vessel Rerouting

Vessel rerouting was modeled using Marico Marine Ltd proprietary vessel traffic analysis software based on the 2013 AIS data records for U.S. coastal waters from the Marine Cadastre portal. These data were also used for the NYSERDA shipping and navigation study (NYSERDA, 2017d). AIS data from July were used to represent a typical seasonal peak in vessel traffic volumes.

Main-vessel routes for commercial traffic, that is, cargo, tanker, passenger and tugs and towing vessels identified in the NYSERDA Shipping and Navigation Study (2017), were used in this analysis. If these routes intersected the Area for Consideration, they were rerouted through one of the traffic separation schemes (TSS) to avoid the routes.[8]

Vessel traffic routes were only rerouted where traffic densities of more than 10 vessels per year were identified for a total of seven major routes (Figure 4). Individual vessel types using these routes are presented in appendix E.

Figure 4. Shipping Routes Across the Study Area



3 Socioeconomic Rerouting Findings

3.1 Background

There are few existing studies examining the socioeconomic costs of offshore wind farms on the shipping industry. Previous studies have focused on characterizing regional economic impacts associated with employment, property values, and gross domestic product (GDP). These include the following:

- Offshore wind farm Environmental Statements (ESs) from the United Kingdowm—East Anglia 1 and 3, Hornsea, Rampion, Galloper, and Burbo Bank extension
- The Hywind Statoil offshore wind farm in the U.S. (Optimat, 2014)
- The University of Delaware rerouting vessel traffic around offshore wind farms in the mid-Atlantic United States (Samoteskul, 2013)

Other studies have examined the impact of rerouting vessels as management measures to minimize ship strikes with the North Atlantic right whale (Nathan Associates Inc., 2008; Kite-Powell & Porter, 2002 and Betz, et al., 2011).

In the United Kingdom, ESs have analyzed only the navigation risks associated with vessel route deviations around wind farms and are, therefore, more focused on safety concerns rather than socioeconomics.

In the U.S., the Block Island Wind Farm did not need to evaluate the socioeconomics of vessel rerouting as no exclusions were established that required vessels to reroute. This is due to the small size of the project (only five turbines) and the significant setback from shipping and navigation routes. The Samoteskul (2013) study reported costs of less than one dollar were incurred for transporting a ton of goods around a wind farm and so the impact of rerouting vessels was considered minimal.

Rerouting measures and speed restrictions to reduce the threat of vessel strikes on endangered North Atlantic right whales were examined over a five-year period. When the measures were introduced in 2008, they were unpopular with commercial shippers, who argued that added costs and increased transit times would delay time-sensitive cargoes and significantly impact the industry. However, this was not the case as the initial perceived additional costs did not materialize.

3.2 Rerouting outcomes

Commercial vessels tend to take the most direct route between waypoints to optimize transit time and fuel costs (Toke, 2010). For some commercial vessels, the distances diverted can be insignificant compared to the total transit time; for example, some vessels on approach to New York can transit more than 5,000 nautical miles (nm) with an estimated trip duration of 19 days (pers. coms., Marico Ltd). The number of vessels potentially affected annually by rerouting could be evaluated for the seven major vessel routes identified from the 2013 AIS data (Table 8).

Table 8. Annual Number of Vessels Affected by Rerouting across Sever Major Routes

Vessel	Route 1	Route 2	Route 3	Route 4	Route 5	Route 6	Route 7
Cargo	0	80	108	64	124	122	133
Tanker	0	55	82	38	81	56	41
Passenger	0	2	3	46	8	7	25
Tugs and Towing	29	11	1	1	11	4	0

The average number of vessels per day transiting the seven major routes are presented in appendix C, and the findings summarized in Table 9. On average, less than one vessel per day would be affected by rerouting.

Table 9. Average Daily Number of Vessels Affected by Rerouting per Year

	Route 1	Route 2	Route 3	Route 4	Route 5	Route 6	Route 7
Average daily number of vessels	0.08	0.41	0.53	0.41	0.61	0.52	0.54

3.3 Rerouting scenarios

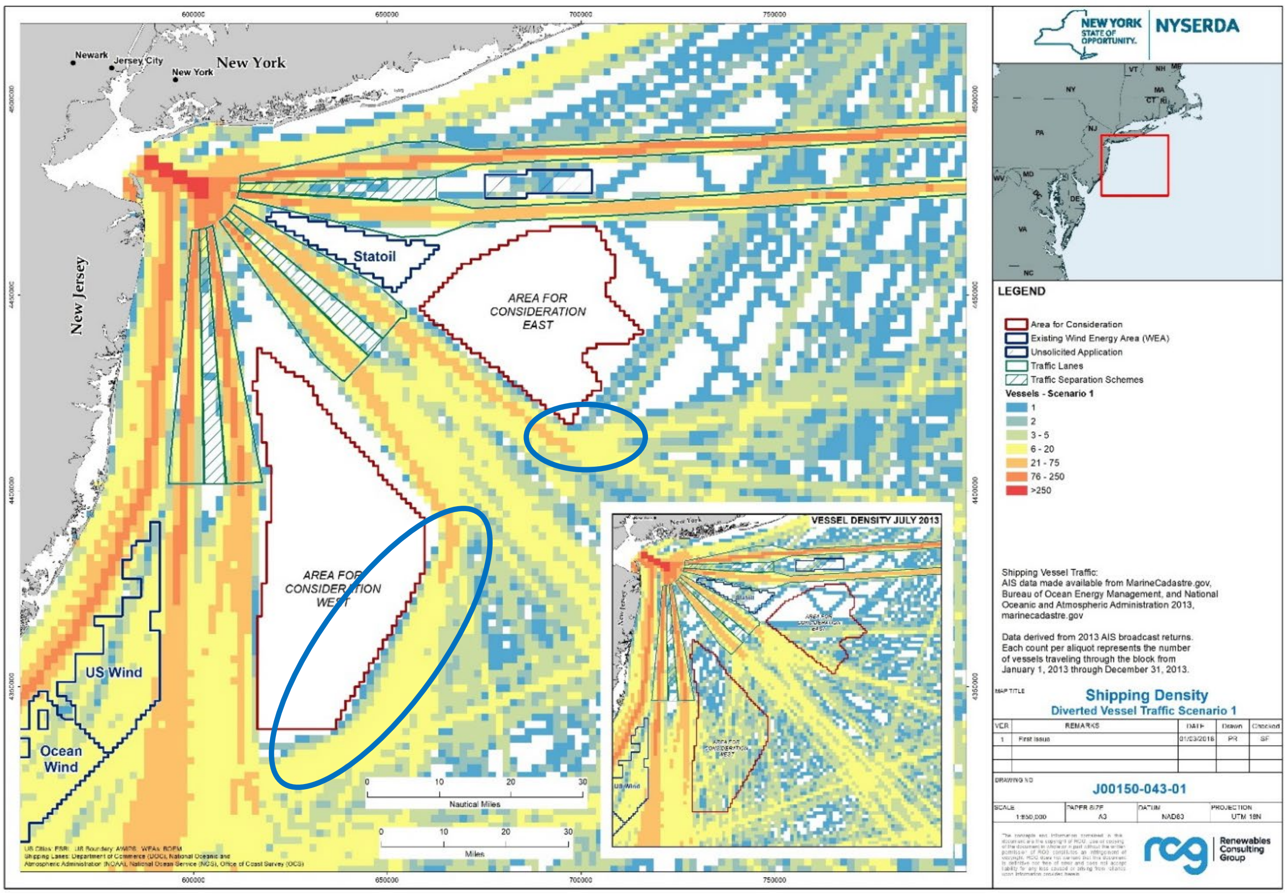
The following four different rerouting scenarios were assessed:

- Scenario 1: Rerouting around the entire Area for Consideration (West and East)
- Scenario 2: Rerouting around the Area for Consideration (West) only
- Scenario 3: Rerouting around the Area for Consideration (East) only
- Scenario 4: Rerouting around four potential sites within the Area for Consideration (West)

3.4 Scenario 1: Area for Consideration (West and East)

In this scenario, all vessels would reroute around the entire Area for Consideration (West and East). Traffic vessel analysis modeled commercial vessels taking the most direct passage between waypoints with no other constraints to minimize transit time and fuel costs. Consequently, the introduction of the Area for Consideration would reroute vessels to the next safe and optimal transit route between waypoints (Figure 5).

Figure 5. Vessel Traffic Before and After Rerouting Around Area for Consideration (West and East)



The two outbound routes 4 and 5, leaving the Ambrose-to-Hudson Canyon TSS, were rerouted around the eastern corner of the Area for Consideration (West). To the south of the Area for Consideration (West), the two inbound routes 6 and 7 were rerouted on approach to the Barnegat-to-Ambrose TSS.

Route 1 runs north to south across the Area for Consideration (West and East) and traffic rerouted inshore. In this scenario, it was assumed that captains of tug and towing vessels would prefer to increase sea room by taking a more inshore passage up the Barnegat to Ambrose TSS and out the Hudson Canyon to Ambrose TSS, as opposed to making multiple course changes to pass between the Statoil lease area and the western boundary of the Area for Consideration (East), thus avoiding the U.S. Wind and Ocean Wind lease areas. The more inshore route deviation is, therefore, considered the least desirable.

One of the consequences of deviating routes 4 and 5 is a greater concentration of vessels along the east-south eastern boundary (see Figure 4). Where vessels become concentrated, there are potential implications for navigational safety due to an increased risk of collision. Collision risks should be analyzed on a project-by-project basis via a site-specific Navigation Safety Risk Assessment (NSRA). Three of the seven main-vessel traffic routes (routes 1, 2, and 3) were diverted around the Area for Consideration (East). Inbound routes 2 and 3 to the Hudson Canyon to Ambrose TSS were rerouted south of the Area for Consideration.

Because commercial vessels can arrive early and need to wait for a pilot boat or for further orders, they may reduce speed on approach or wait on station to the south-east of New York's TSSs. Offshore wind farms within the Area for Consideration could potentially affect the location at which vessels meet pilots or affect the locations at which vessels reduce speed to kill time and conserve fuel.

3.4.1 Deviation Distances and Times

The deviation distances and duration of these deviations around the Area for Consideration are small (Table 10). Most vessels did not deviate for more than 30 minutes (Table 11).

The only exceptions were routes 1 and 2, which had much larger rerouting distances, 24 nm and 6 nm respectively, and so journey times increased accordingly. For route 2, tugs and towing vessels had increased journey times of 40 minutes and on route 1, journey times increased by more than 2 hours. This increase in time was due to their slow speed (the lowest of all vessel types) and the significant deviation distance to avoid the Area for Consideration (West and East).

Table 10. Net Increase in Vessel Route Distances

Route	1	2	3	4	5	6	7
Before Rerouting (nm)	129	112	40	36	102	61	46
After Rerouting (nm)	153	118	41	38	106	65	47
Net Increase (nm)	24	6	1	2	4	4	1
Net Increase (km)	44	11	2	4	7	7	2

Table 11. Deviation Durations (Minutes) by Vessel Type

Route	1	2	3	4	5	6	7
Cargo	N/A	16.0	2.7	5.3	10.7	10.7	2.7
Tanker	N/A	24.0	4.0	8.0	16.0	16.0	4.0
Passenger	N/A	16.4	2.7	5.5	10.9	10.9	2.7
Tugs and Towing	160.0	40.0	6.7	13.3	26.7	26.7	N/A

Table 12 shows the change in total annual distance travelled before and after vessel rerouting for each route. The total increase in transit distances associated with rerouting around the Area for Consideration is 7,273 km or 5.1% per year (on the worst-case assumption that the entirety of Area for Consideration is developed). In practice, it is very likely that a much smaller portion of the Area for Consideration would be developed, and careful siting of offshore wind farms could further reduce the potential need for vessel rerouting, particularly for route 1.

Table 12. Rerouting Distances Around the Area for Consideration by Route

Route	1	2	3	4	5	6	7	Total
Before (km)	6,928	30,699	14,372	9,934	42,314	21,352	16,953	**142,552**
After (km)	8,217	32,343	14,731	10,486	43,974	22,752	17,322	**149,825**
% Increase	18.6%	5.4%	2.5%	5.6%	3.9%	6.6%	2.2%	**5.1%**

To compare vessel rerouting around the Area for Consideration with vessel rerouting measures around offshore wind farms in Europe (appendix D),[9] fewer than five vessels per day transit around European offshore wind farms identified in this study, and at least one vessel per day is considered to be significantly impacted. For these impacted vessels, the maximum rerouting distance was estimated to be 5.6 km (3 nm). Given the average number of vessels per day on routes 3 and 4 was less than one and the distance vessels rerouted was 1 nm and 2 nm respectively, the situation is not too dissimilar to European wind farms where the impacts were deemed insignificant. However, for routes 1 and 2, the deviations were greater (24 nm and 6 nm respectively). Nonetheless, route 1 deviations would only affect 0.08 vessels per day and route 2 deviations would only affect 0.42 vessels per day (less than the European average).

3.4.2 Economic Costs

Fuel costs associated with the reroutings of vessels for all seven routes are presented in appendix F. Route 1 had the highest maximum costs. For instance, if cargo vessels were to use this route they would potentially incur the largest overall maximum fuel costs of $5,574/trip. This would be closely followed by passenger vessels with maximum fuel costs of $5,370/trip and tankers at $2,842/trip. Tugs and towing vessels do use this route but had the smallest fuel costs of $701/trip. This reflected their low fuel consumptions compared to other vessels. Route 2 had the second highest maximum costs, followed by routes 5 and 6, which had the same fuel costs. To estimate the total economic costs of rerouting vessels, operational costs were also factored in to the calculation (see appendix F).

When adding operational costs to fuel costs, the economic costs associated with route 1 effectively reversed the previous order with passenger vessels now the costliest vessel type $21,992/trip followed by cargoes $6,638/trip and then tankers $3,575/trip. Tugs and towing vessels remained with the smallest maximum operational costs $1,673/trip. For both fuel and operational costs, route 1 was overall the largest maximum cost for all vessel types, $14,486 and $33,877 respectively. The lowest economic costs were associated with routes 3 and 7, which had the same costs. The same is true for routes 5 and 6 which remain the third costliest routes after routes 1 and 2.

A summary of the total annual economic costs for all vessels across all seven routes are presented in Table 13 and illustrated in Figure 6. Route 5 had the highest (maximum) annual economic costs, which also reflected the high number of vessels using that route. This was closely followed by route 2, route 6, and route 4. Route 3 had the smallest economic costs. A breakdown of the economic cost per vessel type is included in appendix F.

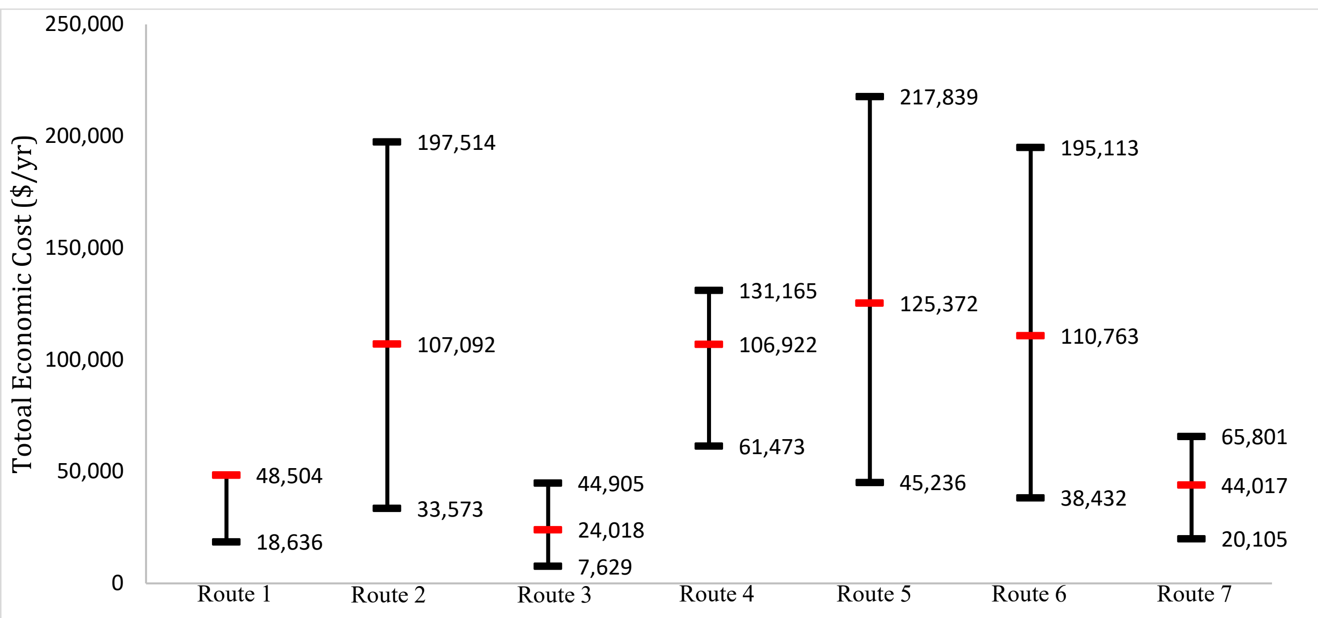
Overall, cargo vessels across all seven routes had the highest annual (maximum) economic cost ($506,975/yr) of all vessel types. Passenger vessels had the next highest annual (maximum) economic costs ($175,934/yr), followed by tankers ($160,439/yr) and tugs and towing ($57,501/yr). For individual routes, cargo vessels had the largest economic costs associated with routes 5 ($137,185/yr), route 6 ($134,972/yr) and route 2 ($132,760/yr) compared to all other routes and vessel types. Passenger vessels had the next highest annual economic costs, which was associated with route 4 ($84,301/yr), then tankers on route 1 ($49,159/yr) and closely followed by tugs and towing also on route 1 ($48,504/yr). Route 1 had the largest rerouting distance (24 nm) and so the longest duration times for tugs and towing vessels (up to 160 min). This was followed by tankers (96 min). However, route 1 had the least number of vessels transiting the route (average number of vessels per day 0.08) compared to all other routes. Each tug and towing vessel could incur annual costs ranging between $643/yr and $1,673/yr.

Table 13. Summary of the Annual Rerouting Economic Costs by Route

Route	Total Annual Economic Cost ($/yr)		
	Min	Typical	Max
1	18,636	48,504	48,504
2	33,573	107,096	197,514
3	7,629	24,018	44,905
4	61,473	106,922	131,165
5	45,236	125,372	217,839
6	38,432	110,763	195,113
7	20,105	44,017	65,801

Figure 6. Annual Economic Costs ($/yr) of Rerouting Vessels by Route

Includes mimimum,maximum, and typical values (typical economic cost for each route is represented by a red horizontal line).



3.4.2.1 Summary of Rerouting and Economic Costs

The distance, duration, and economic costs for vessels rerouting around the Area for Consideration under scenario 1 are summarized in Figure 7. Rerouting paths in this figure are illustrative; further detailed route deviation information can be found in appendix E.

Figure 7. Summary of Costs and Rerouting Under Scenario 1

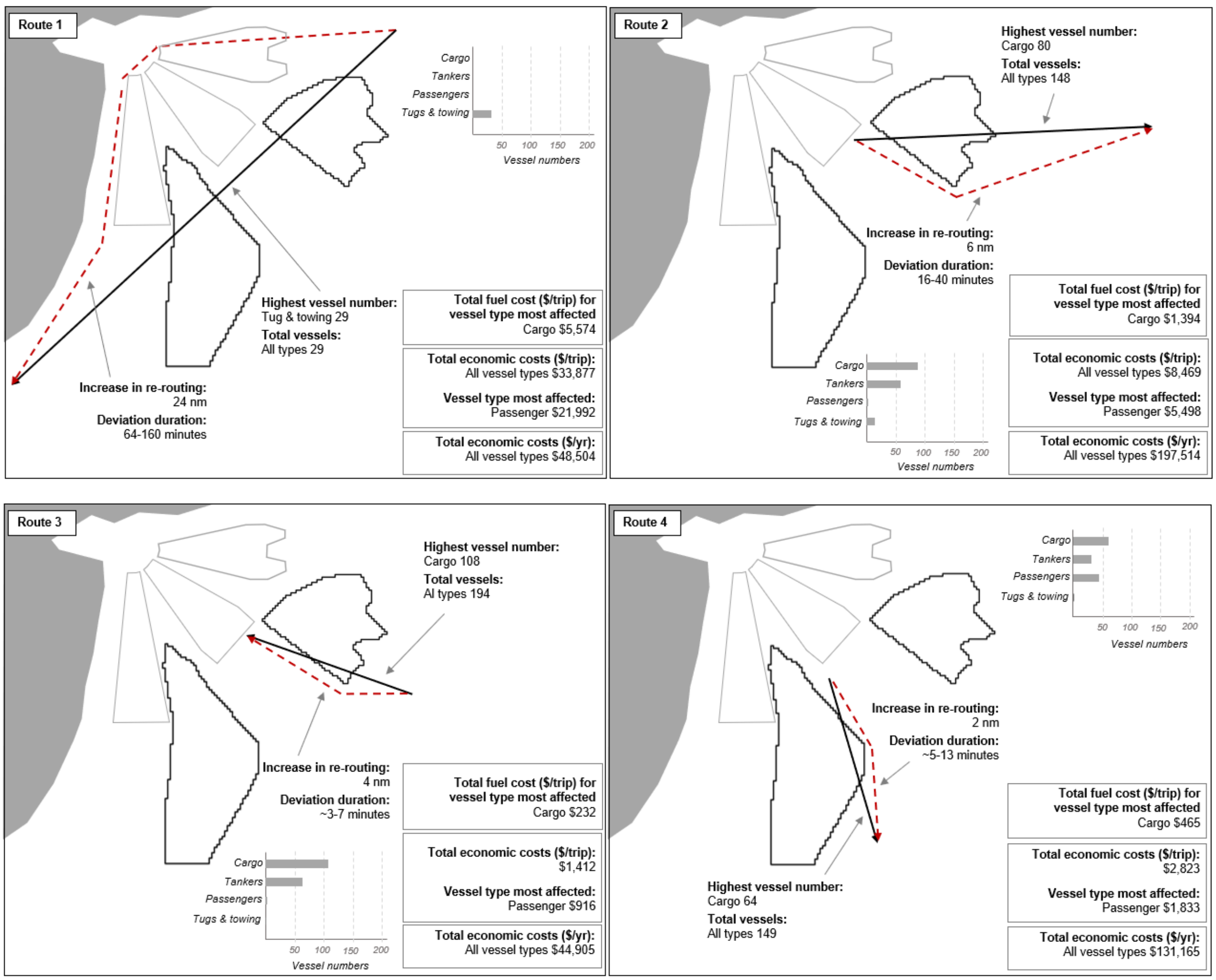
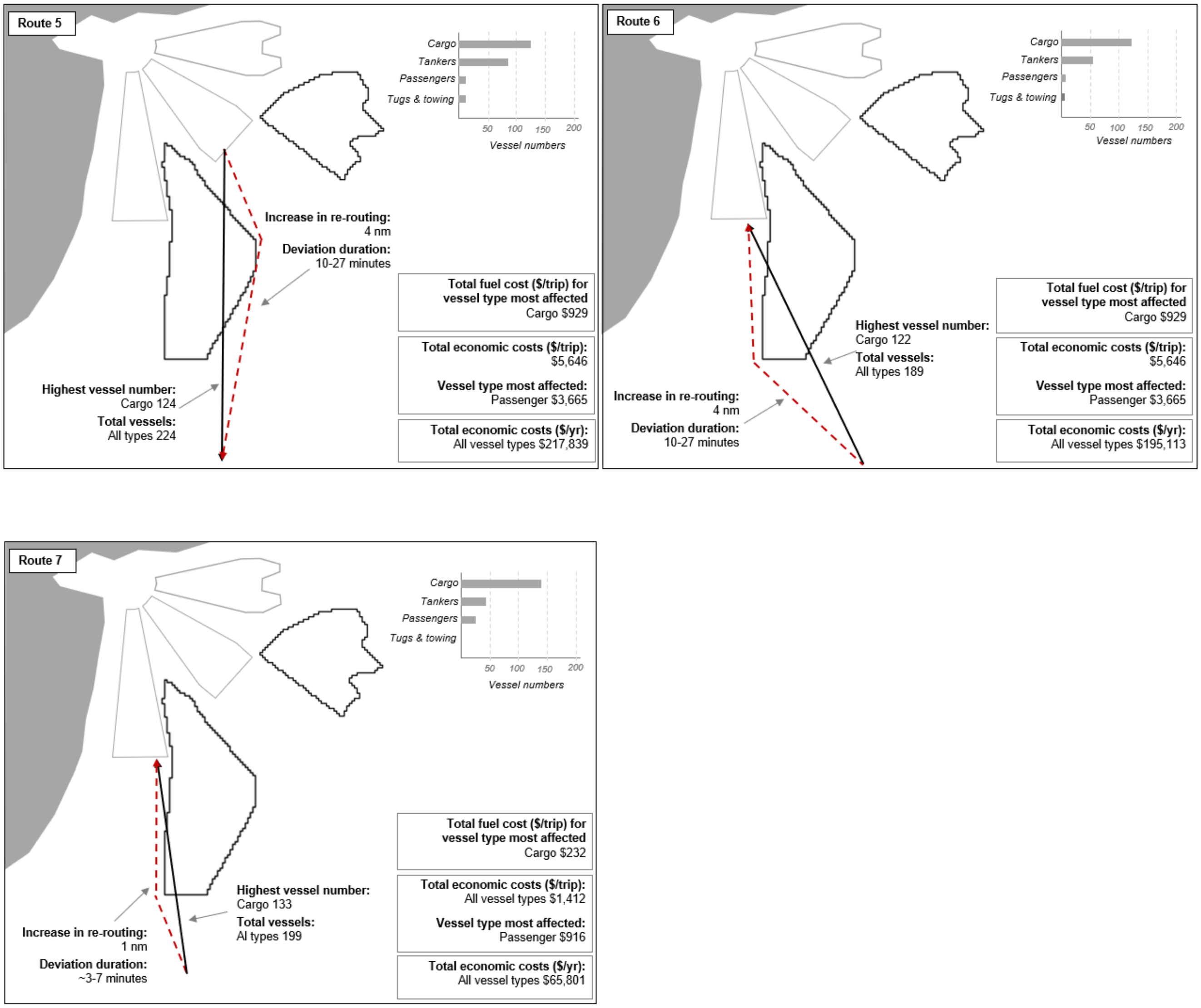


Figure 7. (continued)



3.4.3 Social Costs and Benefits

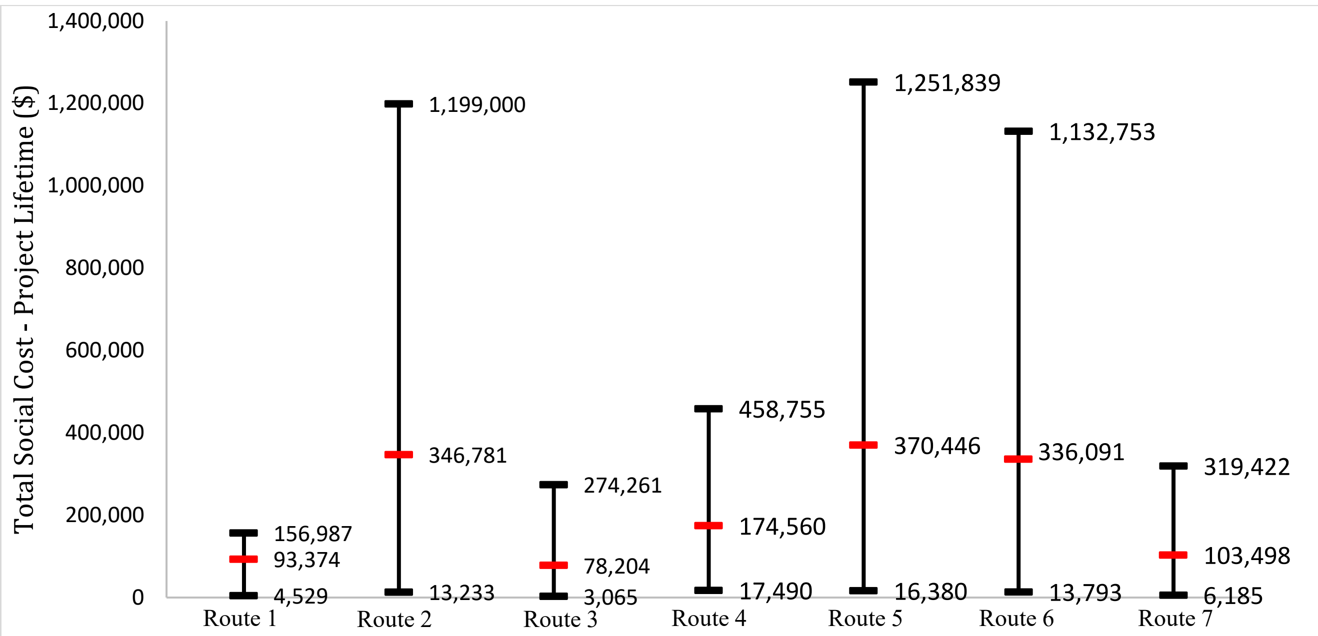
The additional emissions from rerouting are presented in appendix F along with social costs per vessel type. Route 5 had the highest overall maximum social costs per year, closely followed by routes 2 and 6 (Table 14, Figure 8). The annual maximum social costs for the remaining routes 1, 3, 4, and 7 were less than half a million dollars.

Table 14. Annual Social Costs Associated with Rerouting

Route	Annual Social Cost ($/yr)		
	Min	Typical	Max
1	4,529	93,374	156,987
2	13,233	346,781	1,198,910
3	3,065	78,204	274,261
4	17,490	174,560	458,755
5	16,380	370,446	1,251,839
6	13,793	336,091	1,132,753
7	6,185	103,498	319,422

Figure 8. Total Social Costs ($/year) for each route

Typical economic cost for each route is represented by a red horizontal line.



The overall maximum CO_2 emissions (Table 15) and the annual social costs (around $4.8 million) due to all rerouting measures were considered high. However, the high social cost will be offset by the CO_2 savings from the deployment and operational period of offshore wind farms over 31 years[10] (appendix G).

The societal benefits of New York State's 2.4 GW of offshore wind farm development was captured in the carbon payback period and the net CO_2 emissions savings for all seven routes (Table 15). An average value of the annual CO_2 savings (around 4.2 million tons CO_2/yr) was used to calculate the annual net CO_2 savings. This is because the construction of the wind farms will be phased with 2.4 GW only becoming fully operational after year 6 and remaining operational for 19 years.

Table 15. Carbon Payback Period and Lifetime CO_2 Savings

Social benefits	Min	Typical	Max
Carbon Payback Period (yrs)	0.77	0.79	0.81
Annual CO_2 emissions from rerouting (tons CO_2/yr)	463	2,969	5,631
Net annual CO2 savings (tons CO_2/yr)	5,063,181	5,062,286	5,061,395
Net CO_2 savings over lifetime (tons CO_2)	126,578,746	126,551,006	126,523,371

The emissions savings from New York State offshore wind farms are forecasted to recover the carbon emissions associated with the life cycle of the offshore wind farms, including vessel rerouting after only 10 months of operation. For every additional ton of CO_2 emitted by the vessels during their rerouting around the Area for Consideration, between 899 and 10,936 tons of CO_2 are displaced by the offshore wind farms. At this point, the switch from social costs to social benefits will occur.

3.4.4 Summary of Socioeconomic Costs

In scenario 1, economic costs (fuel and operational) and social costs, when added together, form the total socioeconomic costs of rerouting vessels around the Area for Consideration (Table 16). Route 5 had the highest costs followed by routes 2 and 6 (Figure 9). However, the costs are reasonable when compared with the societal benefits resulting from the emissions offset from operational wind farms. Figure 9 presents the breakdown of the total annual socioeconomic costs and shows how the costs are highly dependent on the social component. These total socioeconomic costs are offset by the societal benefits associated with the CO_2 savings.

Table 16. Summary Table of Annual Socioeconomic Costs for Each Route

Route	Total economic cost of rerouting ($/yr)			Total social cost of rerouting ($/yr)			Total socioeconomic cost ($/yr)		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	18,636	48,504	48,504	4,529	93,374	156,987	**23,164**	**141,877**	**205,491**
2	33,573	107,096	197,514	13,233	346,781	1,199,000	**46,805**	**453,877**	**1,396,514**
3	7,629	24,018	44,905	3,065	78,204	274,261	**10,694**	**102,222**	**319,166**
4	61,473	106,922	131,165	17,490	174,560	458,755	**78,963**	**281,482**	**589,920**
5	45,236	125,374	217,839	16,380	370,446	1,251,839	**61,616**	**495,820**	**1,469,678**
6	38,432	110,764	195,113	13,793	336,091	1,132,753	**52,225**	**446,855**	**1,327,866**
7	20,105	44,017	65,801	6,185	103,498	319,422	**26,290**	**147,515**	**385,223**

Figure 9. Range of Total Annual Socioeconomic Costs for Each Rerouting

Typical economic cost for each route is represented by a red horizontal line.

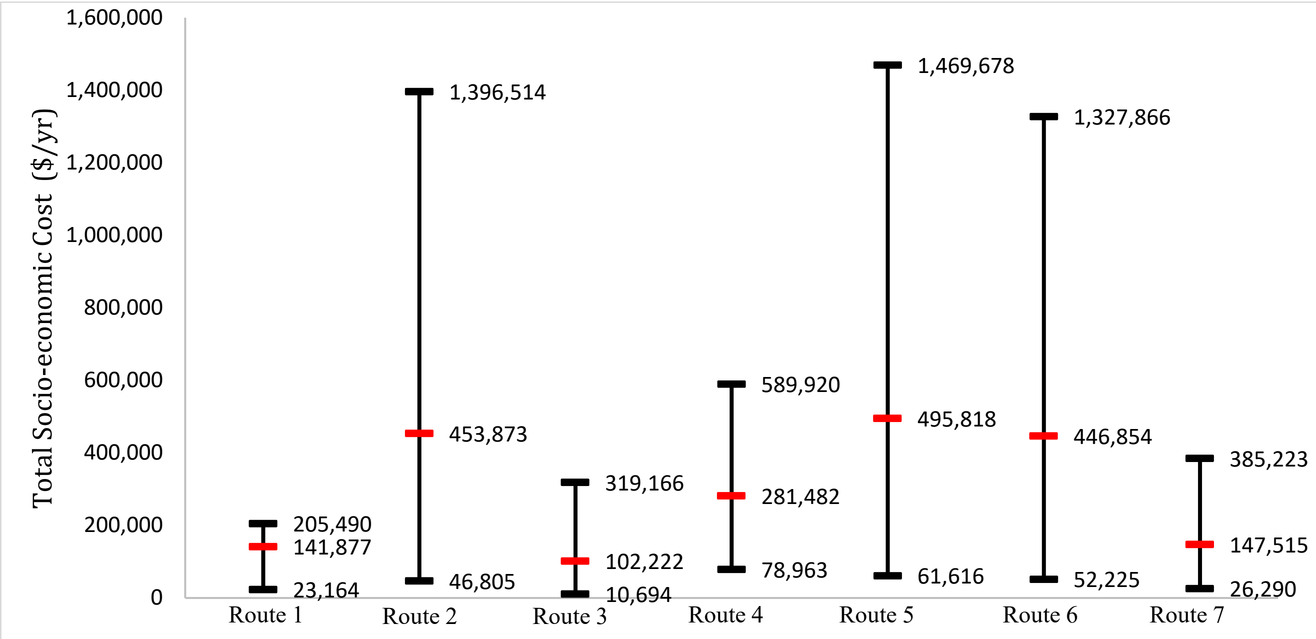
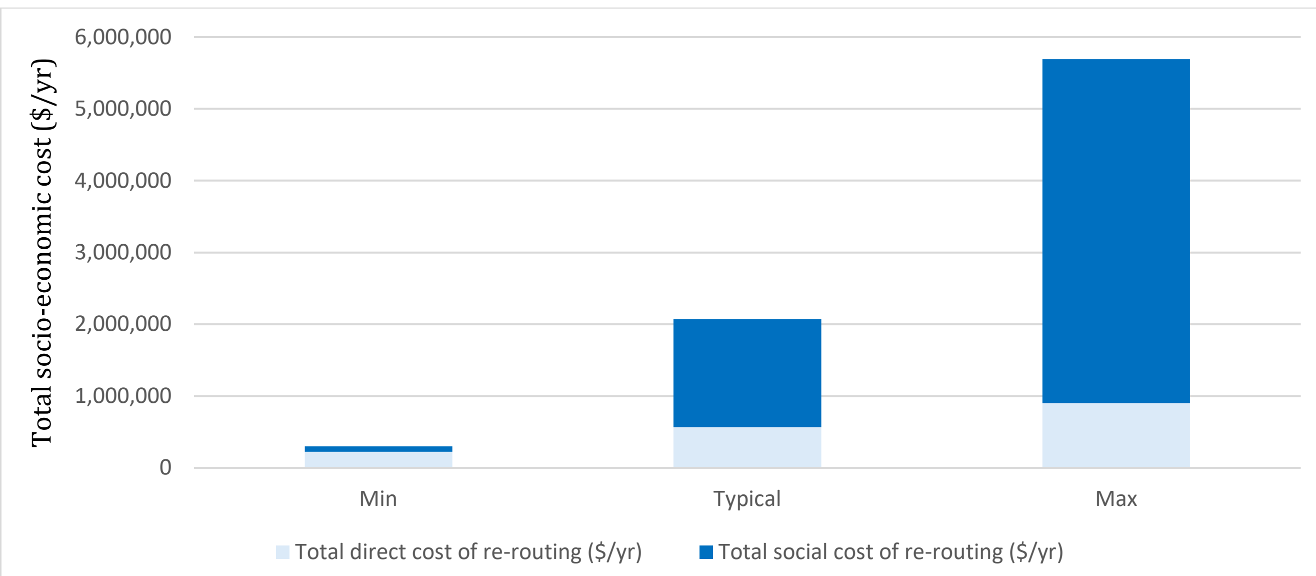


Figure 10. Summary and Breakdown of Total Annual Socioeconomic Costs



The net socioeconomic benefit is calculated as the annual CO_2 savings (data provided in NYSERDA's Master Plan) minus the annual socioeconomic costs (Table 17). The maximum socioeconomic costs are very small compared to the total potential socioeconomic benefit resulting from offshore wind development in New York State. The socioeconomic costs are only 2.2% (maximum) of the total annual societal benefits and over the lifetime of the development could represent an $8 billion saving (see appendix G).

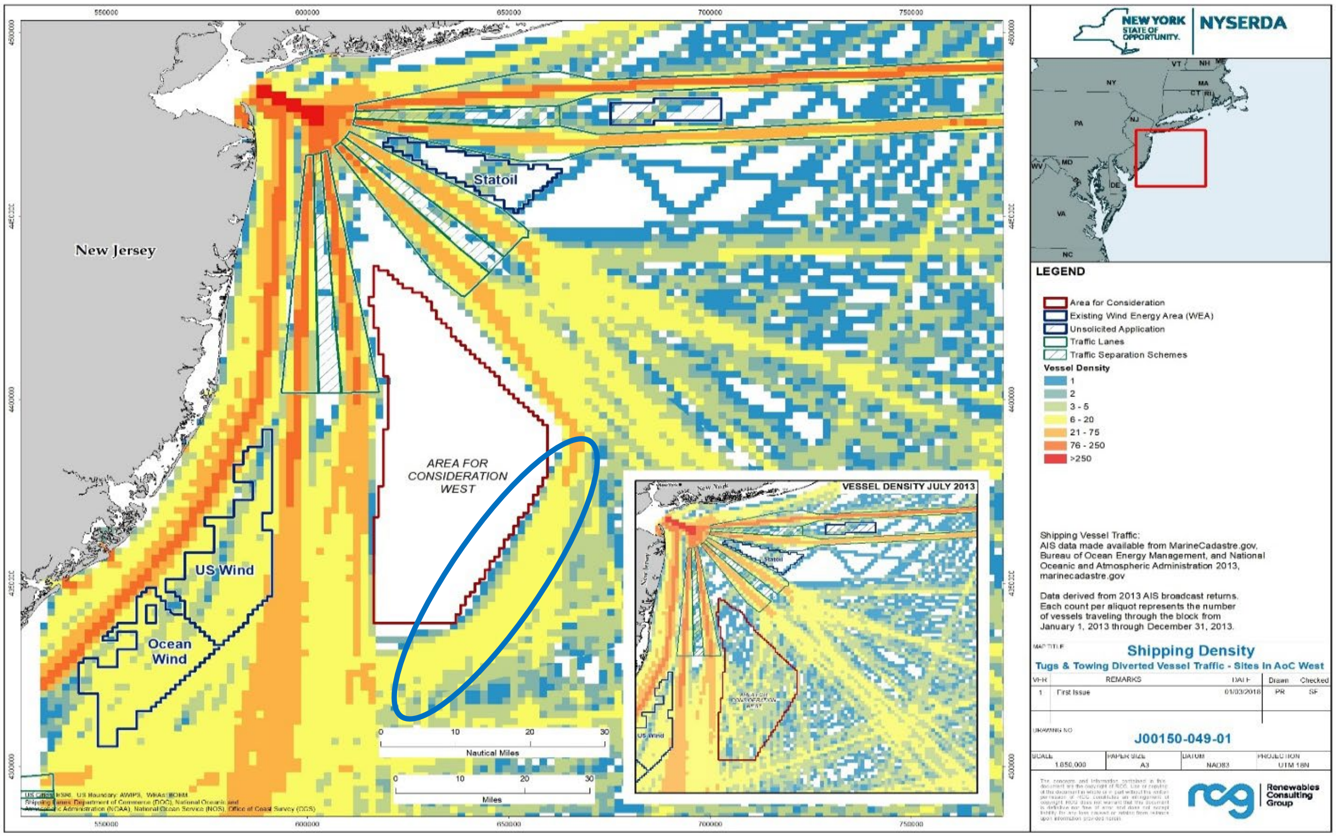
Table 17. Scenario 1. Annual Socioeconomic Costs and Benefits

	Min	Typical	Max
Total socioeconomic cost ($/yr)	299,759	2,069,641	5,693,857
Net socioeconomic benefit ($/yr)	262,652,897	260,883,015	257,258,799
% of total annual societal benefit	0.1%	0.8%	2.2%

3.5 Scenario 2. Area for Consideration (West Only)

In this scenario, all vessels reroute around the western Area for Consideration only. Modeling scenario 2 showed four main-vessel traffic routes were deviated around the Area for Consideration (West), although most vessels routes within the region were unaffected (Figure 11).

Figure 11. Vessel Traffic Before and After Rerouting Around Area for Consideration (West)



Rerouting around the Area for Consideration (West) showed a similar rerouting pattern to that in scenario 1. Two outbound routes 4 and 5, leaving the Ambrose to Hudson Canyon TSS, were rerouted around the eastern corner of the Area for Consideration (West). To the south of the Area for Consideration (West), two inbound routes 6 and 7 were rerouted on approach to the Barnegat to Ambrose TSS. Routes 3 and 2 remained unaffected. Route 1 was rerouted to the eastern corner. In this case, it was assumed that tug and towing vessel captains would prefer to reroute along the northern tip of the Area for Consideration (West) and across the TSS lanes (Hudson Canyon to Ambrose and vice versa) to pass to the east of the Statoil development area (see appendix E). In all cases, rerouting represented the shortest diversion possible. One of the consequences of rerouting routes 4 and 5 was a greater concentration of vessels along the east-south eastern boundary. Where vessel numbers become concentrated, there is potential implications for navigational safety and increased collision risk. To better understand this risk would require a NSRA at the project level.

Because some commercial vessels can arrive early and need to wait for a pilot boat or further orders, they can reduce steaming speed on approach or wait on station to the southeast of New York State's TSSs. The presence of offshore wind farms within the Area for Consideration could overlap with the location of waiting or affect slow-steaming vessels.

3.5.5 Deviation Distances and Times

The increase in distances travelled by vessels rerouting around the Area for Consideration (West) and their duration was small (Table 18). Most vessels did not exceed a deviation time of more than 27 minutes (Table 19). The only exception was route 1, which had the largest rerouting distance of 6 nm and journey time of 40 minutes for tugs and towing vessels. This increase in time was associated with their speed (i.e., the lowest of all vessel types) and the large rerouting deviation needed by these vessels to safely avoid the Area for Consideration (West).

Table 18. Net Increase in Distances of Vessel Routes

Route	1	4	5	6	7
Before Rerouting (nm)	113	36	102	61	46
After Rerouting (nm)	119	38	106	65	47
Net Increase (nm)	6	2	4	4	1
Net Increase (km)	11	4	7	7	2

Table 19. Deviation Duration (Minutes)

Route	*1*	4	5	6	7
Cargo	N/A	5	11	11	3
Tanker	N/A	8	16	16	4
Passenger	N/A	6	11	11	3
Tugs and Towing	40	13	27	27	N/A

Table 20 shows the change in total annual distance travelled before and after vessel rerouting for each route. The total increase in transit distances associated with rerouting across the Area for Consideration is 4,302 km or 4.5% per year (based on the worst-case assumption that the entirety of Area for Consideration is developed). In practice, a much smaller portion of the Area for Consideration would be developed, and careful siting of offshore wind farms could further reduce potential vessel rerouting, particularly for route 2.

Table 20. Distance Impact for Vessel Transits in the Entire Area for Consideration

Route	1	4	5	6	7	Total
Before (km)	6,069	9,934	42,315	21,352	16,953	96,623
After (km)	6,391	10,486	43,974	22,752	17,322	100,925
% Increase	5.3%	5.6%	3.9%	6.6%	2.2%	4.5%

To compare rerouting vessels around the Area for Consideration with vessels rerouting around offshore wind farms in Europe, the average number of vessels per day on routes 4-7 was less than one, and the distance they were rerouted was 2 nm, 4 nm, 4 nm, and 1 nm, respectively. This is proportionate to that experience with European wind farms where such impacts are assessed as insignificant. However, for route 1 the deviation was 6 nm but only affected 0.08 vessels a day. While this is larger than that documented in Europe, a NSRA would be required at the project level to determine significance.

3.5.6 Economic Costs

A summary of the total annual economic costs for all vessels combined and across all four routes are presented in Table 21 and illustrated in Figure 12. Fuel costs associated with the reroutings of all vessel types across all five routes are presented in appendix F. Route 1 had the highest maximum fuel costs. For instance, if cargo vessels were to use this route they would potentially incurred the largest overall maximum fuel costs $1,393/trip. This was closely followed by passenger vessels with a maximum fuel costs of $1,342/trip and tankers at $710/trip. Tugs and towing vessels had the smallest maximum fuel costs of $175/trip which reflected their low-fuel consumptions compared to other vessel types. Routes 5 and 6 had equal costs and the second-highest fuel costs after route 1. To estimate the total economic costs of rerouting vessels, operational costs were also factored in to the calculation (see appendix F).

When adding operational costs to fuel costs, the economic costs associated with route 1 effectively reversed the previous order with passenger vessels now the costliest vessel type ($5,498/trip), followed by cargoes ($1,659/trip), and then tankers ($894/trip). Tugs and towing vessels remained with the smallest maximum economic costs at $418/trip. For the economic costs, route 1 was overall the largest cost, followed by routes 5 and 6. The lowest economic costs were associated with route 4 ($2,823/trip). Figure 12 shows that rerouting of all vessel types on route 5 had the highest annual maximum economic costs which also reflected the high number of vessels using that route. This was closely followed by routes 6 and 7. Route 1 had the smallest economic costs. A breakdown of the economic cost per vessel type is included in appendix F.

Overall, cargo vessels across all five routes had the highest annual (maximum) economic costs ($344,345/yr) of all other vessel types. Passenger vessels had the next highest overall annual (maximum) economic costs ($230,913/yr) followed by tanker ($99,064/yr), and tugs and towing ($16,447/yr) vessels. For individual routes, cargo vessels had the largest maximum economic costs associated with route 5 ($137,185/yr) compared to other routes and vessel types. Passenger vessels had the next highest maximum annual economic costs associated with route 7 ($91,632/yr), tankers on route 5 ($48,266/yr), followed by tugs and towing on route 1 ($12,126/yr).

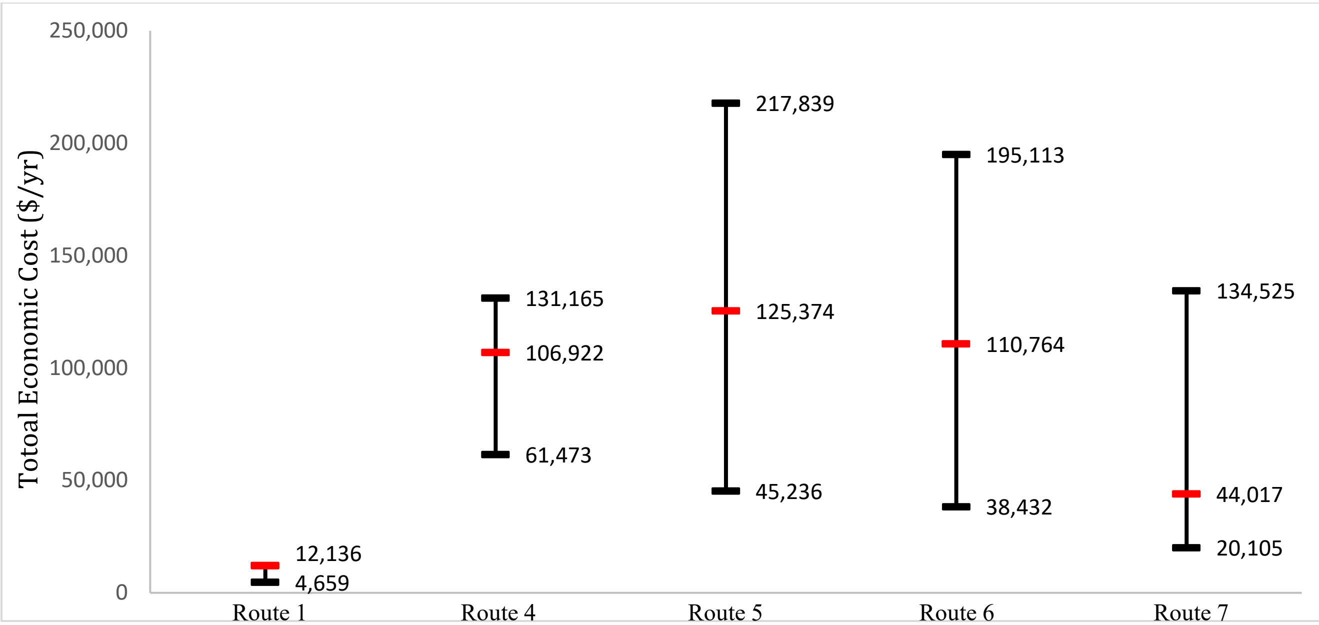
Route 1 had the largest rerouting distance (6 nm) and so the longest duration time for tugs and towing vessels (40 min), with an annual cost for each vessel ranging between $161/yr and $418/yr. Route 5 had the largest annual maximum economic costs compared to all other routes, but annual cost to vessels is estimated between $202/yr and $972/yr. This is because cargo vessels had the highest number of vessels using that route.

Table 21. Summary of the Annual Rerouting Economic Costs by Route

Route	Total Annual Economic Cost ($/yr)		
	Min	Typical	Max
1	4,659	12,136	12,126
4	61,473	106,922	131,165
5	45,236	125,374	217,839
6	38,432	110,764	195,113
7	20,105	44,017	134,525

Figure 12. Annual Economic Costs ($/yr) of Rerouting Vessels by Route

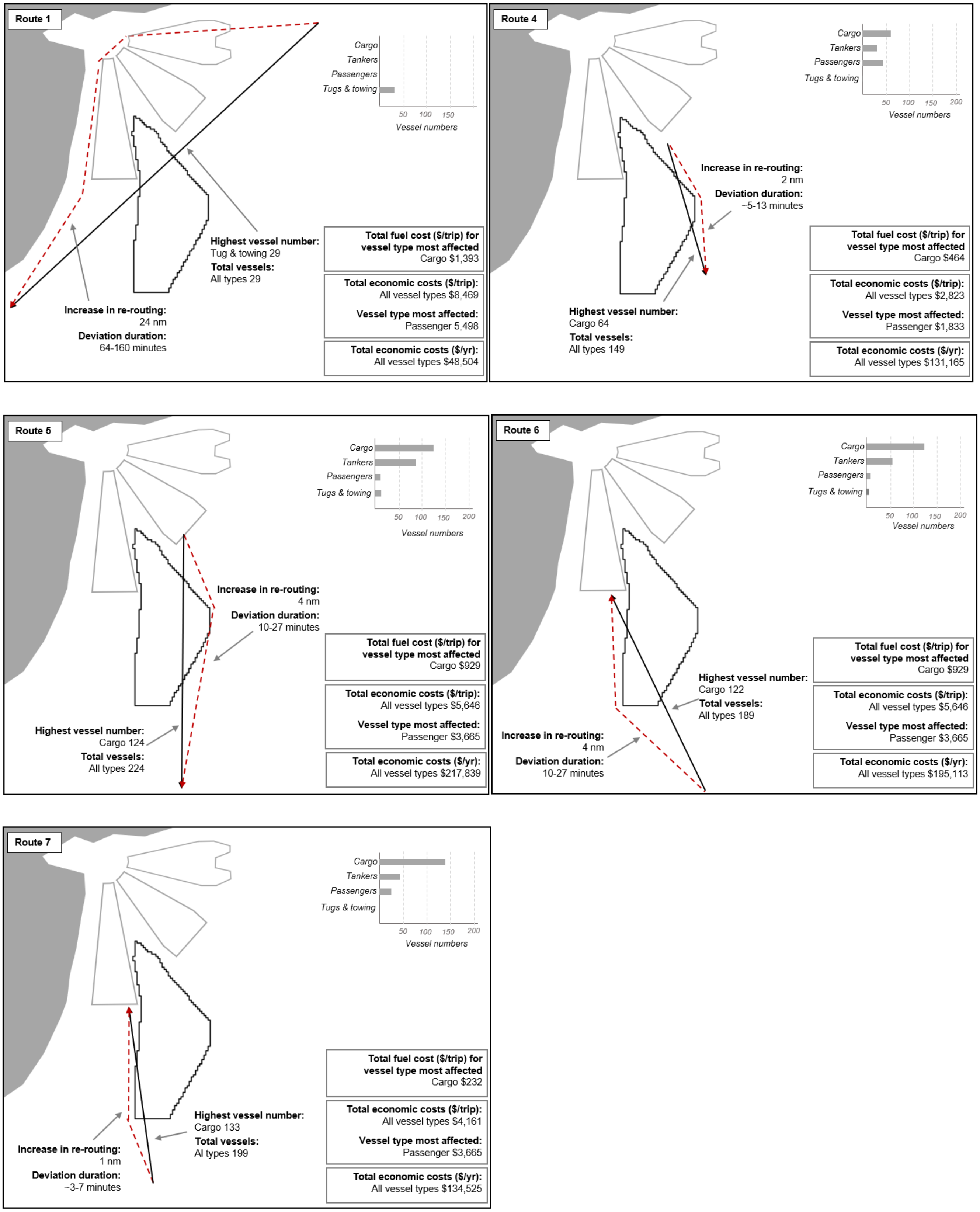
Includes mimimum, maximum, and typical values. Typical economic cost for each route is represented by a red horizontal line.



3.5.6.1 Summary of Rerouting and Economic Costs

The distance, duration, and economic costs for vessels rerouting around Area for Consideration under scenario 2 are summarized in Figure 18. Rerouting paths in this figure are illustrative and further detailed route deviation can be found in appendix E.

Figure 13. Summary of Cost and Rerouting Under Scenario 2



3.5.7 Social Costs and Benefits

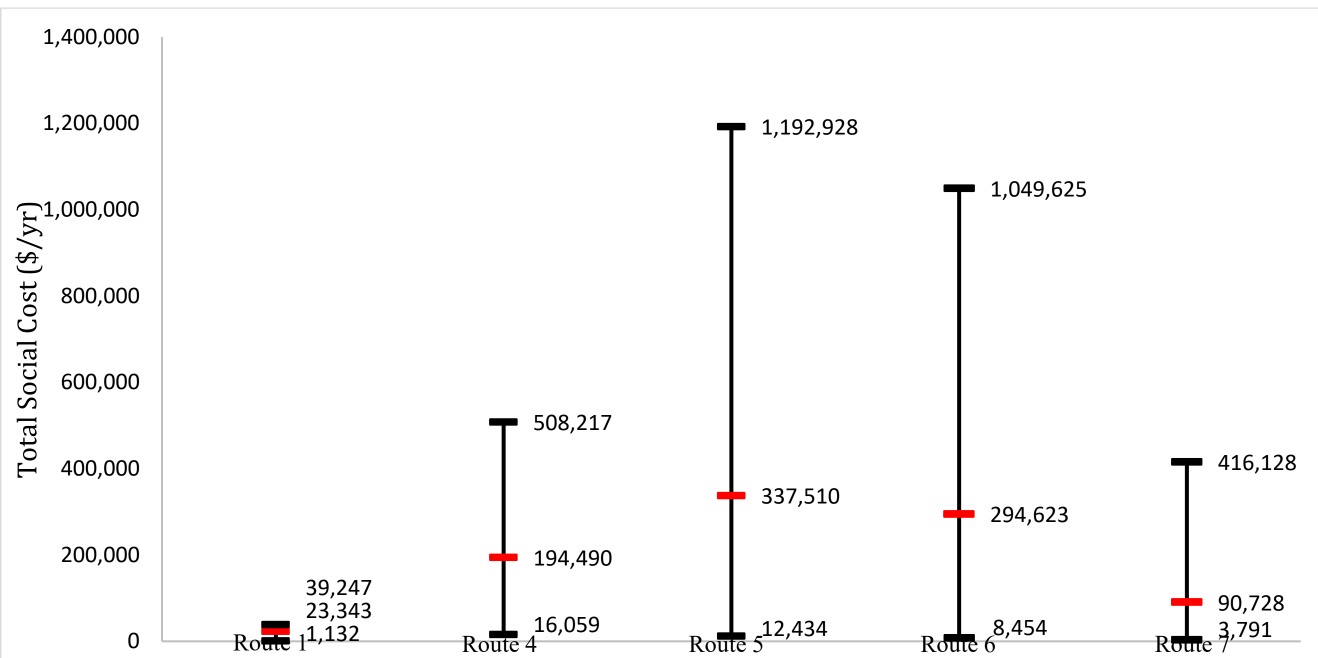
The annual social costs are shown in Table 22 and illustrated in Figure 14. The additional emissions resulting from rerouting are presented in appendix F along with social costs per vessel type. Route 5 had the highest overall maximum social costs per year, followed by route 6. The smallest annual maximum social cost was associated with route 1.

Table 22. Annual Social Costs Associated with Rerouting

Route	Annual Social Cost ($/yr)		
	Min	Typical	Max
1	1,132	23,343	39,247
4	16,059	194,490	508,217
5	12,433	337,510	1,192,928
6	8,453	294,623	1,049,625
7	3,791	90,728	416,128

Figure 14. Total Social Costs ($/year) for Each Route

Typical economic cost for each route is represented by a red horizontal line.



The overall maximum CO_2 emissions (Table 23) and the corresponding annual social costs (around $3.2 million/yr) due to all rerouting measures were considered high. However, the high-social cost will be offset by the CO_2 savings resulting from the deployment and operational period of offshore wind farms over 31 years[11] (appendix G).

The societal benefits of New York State's 2.4 GW of offshore wind farm development was captured in the carbon payback period[12] and the net CO_2 emissions savings for all routes (Table 23). An average value of the annual CO_2 savings (around 4.2 million tons CO_2/yr) was used to calculate the annual net CO_2 savings. This is because the construction of the wind farms will be phased with 2.4 GW only becoming fully operational after year 6 and remain operational for 19 years.

Table 23. Carbon Payback Period and Lifetime CO_2 Savings

Social benefits	Min	Typical	Max
Carbon Payback Period (yrs)	0.77	0.78	0.80
Annual CO_2 emissions from rerouting (tons CO_2/yr)	341	1,991	3,914
Net annual CO2 savings (tons CO_2/yr)	5,191,437	5,190,531	5,189,598
Net CO_2 savings over lifetime (tons CO_2)	129,784,619	129,756,541	129,727,612

The emissions savings from New York State offshore wind farms will have compensated for all the additional carbon emissions associated with vessel rerouting after about nine to 10 months of operation, at which point the switch from social costs to social benefits will occur. This is because for every additional ton of CO_2 emitted by the vessels rerouting around the Area for Consideration, between 1,326 and 15,224 tons of CO_2 are displaced by the offshore wind farms. In this scenario, offshore wind farms are considered a good public investment from an emissions standpoint as over 129 million tons of CO_2 would be saved over the 31 years of development and operation.

3.5.8 Summary of Socioeconomic Costs

In scenario 2, economic costs (fuel and operational) and social costs, when added together, form the total socioeconomic costs of rerouting vessels around the Area for Consideration (Table 24). Route 5 had the highest costs, followed by route 6 (Figure 15). However, the costs are reasonable when compared with the societal benefits resulting from the emissions offset from operational wind farms. Figure 16 presents the breakdown of the total annual socioeconomic costs and shows how the costs are highly dependent on the social component. These total socioeconomic costs are offset by the societal benefits associated with the CO_2 savings.

Table 24. Summary Table of Annual Socioeconomic Costs for Rerouting

Route	Total economic cost of rerouting ($/yr)			Total social cost of rerouting ($/yr)			Total socioeconomic cost ($/yr)		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	4,659	12,136	12,126	1,132	23,343	39,247	**5,791**	**35,479**	**51,373**
4	61,473	106,922	131,165	16,0589	194,490	508,217	**77,532**	**301,412**	**639,382**
5	45,236	125,374	217,839	12,434	337,510	1,192,928	**57,670**	**462,884**	**1,410,767**
6	38,432	110,764	195,113	8,454	294,623	1,049,625	**46,886**	**405,387**	**1,244,738**
7	20,105	44,017	134,525	3,791	90,728	416,128	**23,896**	**134,745**	**550,653**

Figure 15. Range of Total Annual Socioeconomic Costs for Each Rerouting

Typical economic cost for each route is represented by a red horizontal line.

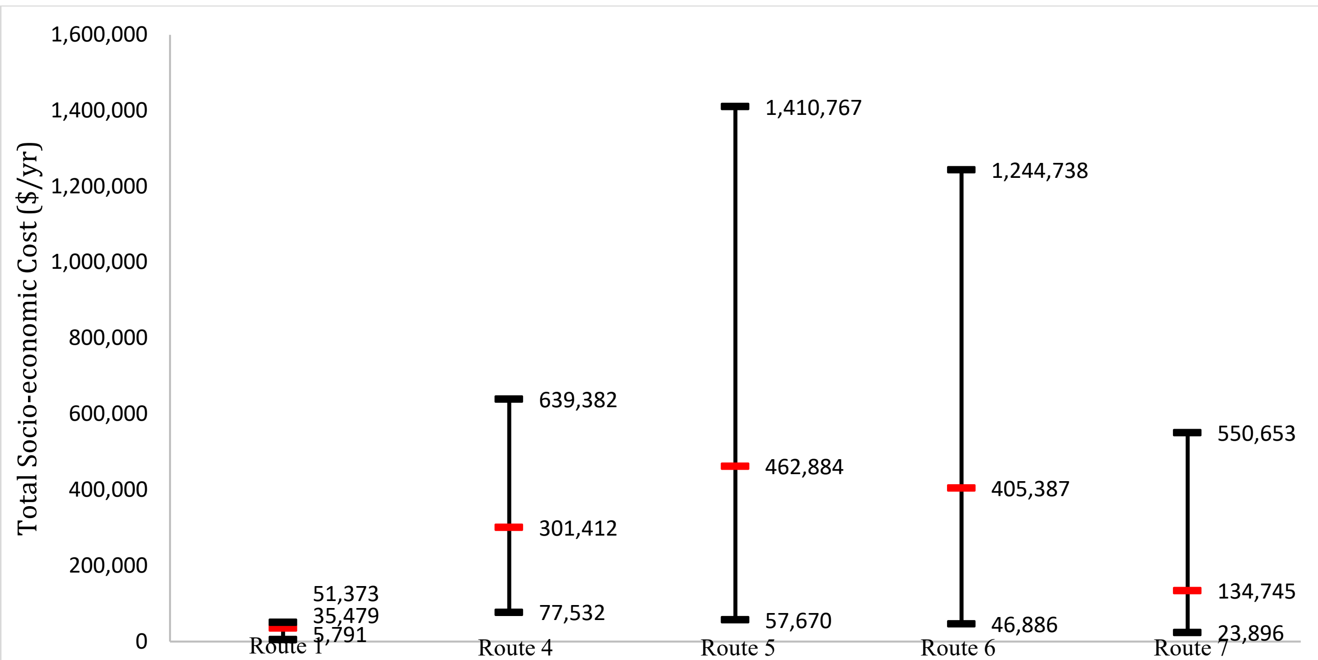
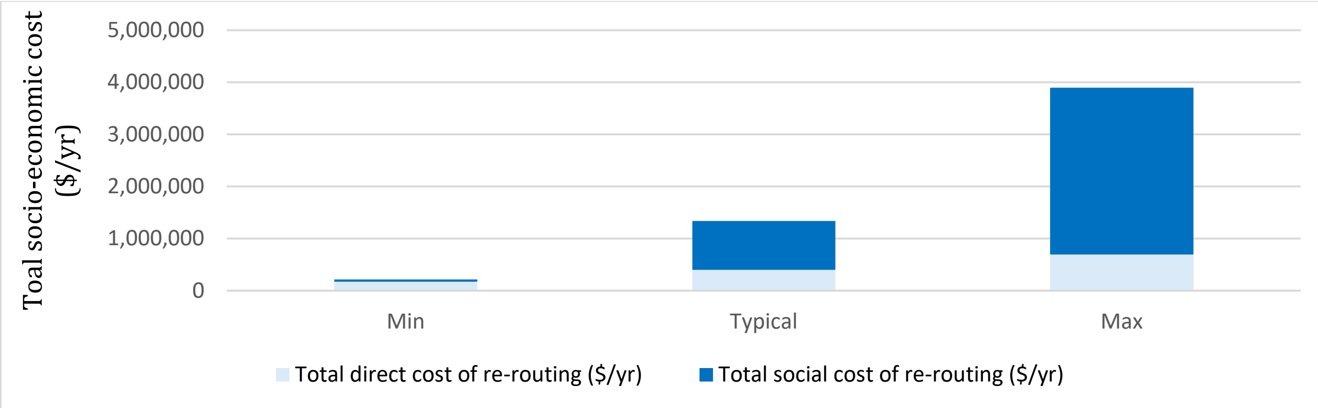


Figure 16. Summary and Breakdown of Total Annual Socioeconomic Costs



The net socioeconomic benefit is calculated as annual CO_2 savings (data provided in NYSERDA's Master Plan) minus the annual socioeconomic costs (Table 25). The maximum socioeconomic costs are very small compared to the total potential socioeconomic benefit resulting from offshore wind development in New York State. The socioeconomic costs are only 1.5% (maximum) of the total annual societal benefits and over the lifetime of the development could represent $8 billion savings (see appendix G).

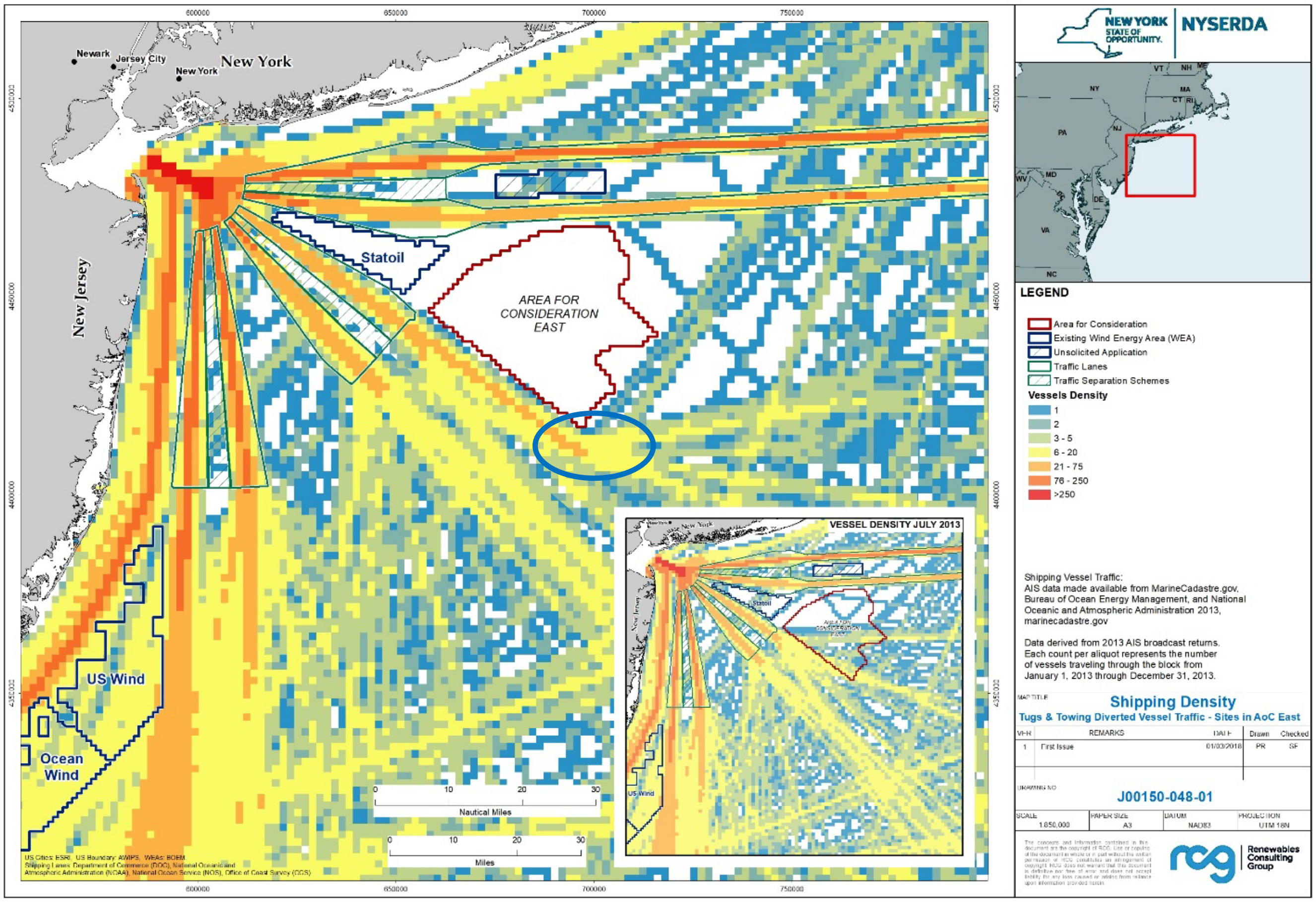
Table 25. Scenario 2. Annual Cost and Benefit Summary

	Min	Typical	Max
Total socioeconomic cost ($/yr)	211,775	1,339,907	3,896,913
Net socioeconomic benefit ($/yr)	262,740,881	261,612,749	259,055,743
% of total annual societal benefit	0.1%	0.5%	1.5%

3.6 Scenario 3. Area for Consideration (East Only)

In this scenario, all vessels must reroute around the Area for Consideration (East). Traffic vessel analysis modeled commercial vessels taking the most direct passage between waypoints with no other constraints to minimize transit time and fuel costs. The introduction of the Area for Consideration (East) would reroute vessels to the next safe and optimal transit route between waypoints (Figure 17).

Figure 17. Vessel Traffic Before and After Rerouting Around the Area for Consideration (East)



Rerouting around the Area for Consideration (East) showed a similar rerouting pattern to scenario 1. Outbound routes 2 and 3,[13] leaving the Hudson Canyon to Ambrose TSS were rerouted further south of the Area for Consideration. Route 1 which runs north to south across the Area for Consideration (East), was rerouted between the Statoil development area and the Area for Consideration (East). In this scenario, as the Area for Consideration (West) was not present, it was possible for vessels to cross the TSS lanes at a right angle before safely passing between the Statoil development area and the Area for Consideration (East) without too many alterations in course. This might be different in bad weather, where tugs and towing vessels might prefer to pass inshore (west of the Statoil development area) to avoid having to navigate the narrow passage between the Statoil development and the Area for Consideration (East) as seen in appendix E. The more inshore deviation, therefore, is considered the least desirable. In all cases, rerouting represented the shortest diversion possible.

Because some commercial vessels can arrive early and need to wait for a pilot boat or further orders, they can reduce steaming speed on approach or wait on station to the southeast of New York State's TSSs. The presence of offshore wind farms within the Area for Consideration could overlap with the location of waiting or affect slow steaming vessels.

3.6.9 Deviation Distances and Times

The increase in distances travelled by vessels rerouting around the Area for Consideration and their duration were small (Table 26). Most vessels did not exceed a deviation time of more than 14 minutes (Table 27). The only exception was route 2. This route had a slightly larger rerouting distance of around 6 nm, and so journey times increased accordingly. For this route, tugs and towing vessels had increased journey times of 40 minutes. The increase in time was associated with their speed (i.e., the lowest of all vessel types) and the large rerouting deviation needed by these vessels to safely avoid the Area for Consideration.

Table 26. Net Increase in Distances of Vessel Routes

Route	1	2	3
Before Rerouting (nm)	85	112	40
After Rerouting (nm)	87	118	41
Net Increase (nm)	2	6	1
Net Increase (km)	4	11	2

Table 27. Deviation Duration (Minutes)

Route		1	2	3
Deviation duration (min)	Cargo	N/A	16	3
	Tanker	N/A	24	4
	Passenger	N/A	16	3
	Tugs and Towing	13	40	7

Table 28 shows the change in total annual distance travelled before and after vessel rerouting for each route. The total increase in transit distances associated with rerouting across the Area for Consideration is 2,112 km or 4.3% per year (based on the worst-case assumption that the entirety of Area for Consideration is developed). In practice, a much smaller portion of the Area for Consideration would be developed, and careful siting of offshore wind farms could further reduce potential vessel rerouting, particularly for route 2.

Table 28. Distance Impact for Vessel Transits in the Entire Area for Consideration

Route	1	4	5	Total
Before (km)	4,565	30,699	14,372	**49,635**
After (km)	4,673	32,343	14,731	**51,747**
% Increase	2.4%	5.4%	2.5%	**4.3%**

To compare rerouting vessels around the Area for Consideration with vessels rerouting around offshore wind farms in Europe, the average number of vessels per day on routes 1 and 3 was less than one and the distance they were rerouted was 2 nm and 1 nm, respectively. This is proportionate to that experience with some European wind farms where the impacts are assessed as insignificant. Route 2 had a slightly larger rerouting distance of 6 nm but only affects 0.42 vessels a day. However, to assess the full impact, an NSRA would be required at the project level.

3.6.10 Economic Costs

A summary of the total annual economic costs for all vessels combined and across all three routes are presented in Table 37 and illustrated Figure 23. Much lower costs were associated with route 3 and route 1. A breakdown of the economic cost per vessel type is included in appendix F.

Fuel costs associated with the reroutings of vessel types across all three routes are presented in appendix F. Route 2 had the highest maximum fuel costs of $197,514/trip. Cargo vessels had the maximum fuel costs of $1,393/trip, which was closely followed by passenger vessels with maximum fuel costs of $1,342/trip. Tanker vessels fuel costs were $710/tip, and tugs and towing vessels had the smallest fuel costs at $175/trip, which reflected their low-fuel consumptions compared to other vessel types. To estimate the total economic costs of rerouting vessels, operational costs were also factored in to the calculation (see appendix F).

When adding operational costs to fuel cost, the economic costs associated with route 2 effectively reversed the previous order with passenger vessels now the costliest vessel type ($5,498/trip), followed by cargoes ($1,659/trip), and then tankers ($894/trip). Tugs and towing vessels remained with the smallest maximum operational costs at $418/trip. In terms of economic costs, route 2 was overall the largest maximum cost for all vessel types, followed by route 1. The lowest overall economic costs for all vessel types were associated with routes 3 ($1,412).

Overall, cargo vessels across all three routes had the highest annual (maximum) economic costs with just over $1 million compared to all other vessel types. Tanker vessels had the next highest annual (maximum) economic costs ($376,968/yr), followed by tugs and towing vessels ($28,194/yr), and passenger vessels ($25,933/yr). For individual routes, cargo vessels had the largest maximum economic costs associated with route 2 ($106,764/yr) compared to other routes and vessel types. Tanker vessels had the next highest economic costs ($73,400/yr). The smallest costs for route 2 was passenger vessels ($2,669/yr), which reflected the small number of vessel transiting that route.

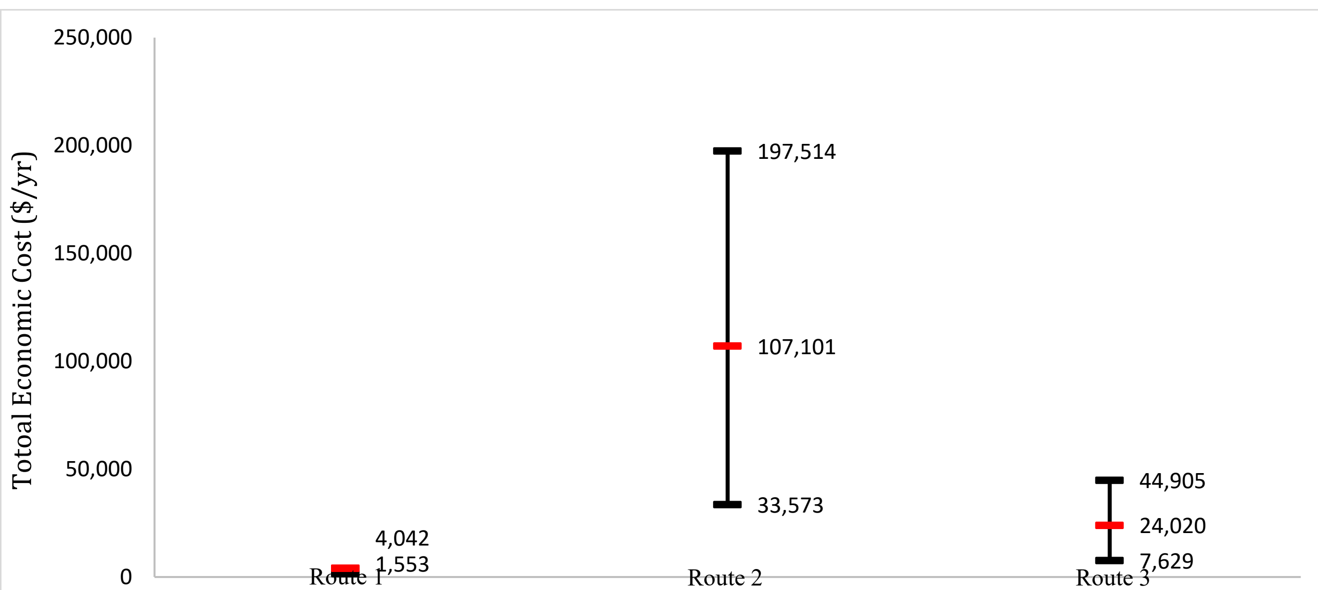
Each tug and towing vessel on route 1 could incur an annual cost ranging from between $54 and $139. Although route 2 had the largest annual maximum economic costs compared to all other routes, each vessel on the route could incur an annual cost ranging between $150 and $882.

Table 29. Summary of the Annual Rerouting Economic Costs for all Affected Vessels

Route	Total Annual Economic Cost ($/yr)		
	Min	Typical	Max
1	1,553	4,045	4,042
2	33,573	107,096	197,514
3	7,629	24,018	44,905

Figure 18. Annual Economic Costs ($/yr) of Rerouting Vessels by Route

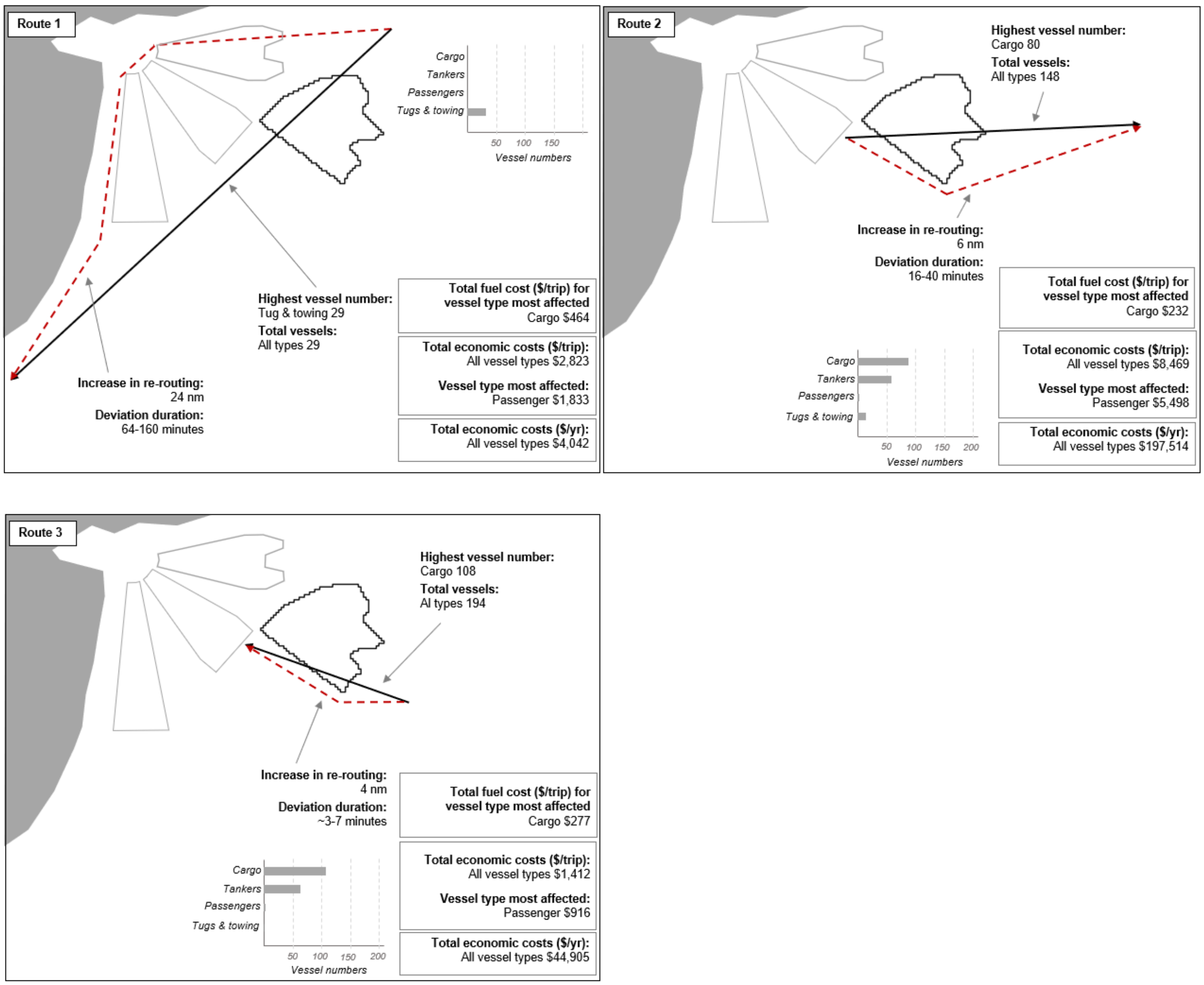
Includes mimimum, maximum, and typical values. Typical economic cost for each route is represented by a red horizontal line.



3.6.10.1 Summary of Rerouting and Economic Costs

The distance, duration, and economic costs for vessels rerouting around Area for Consideration under scenario 3 are summarized in Figure 24. Rerouting paths in this figure are illustrative and further detailed route deviation can be found in appendix E.

Figure 19. Summary of Cost and Rerouting under Scenario 3



3.6.11 Social Costs and Benefits

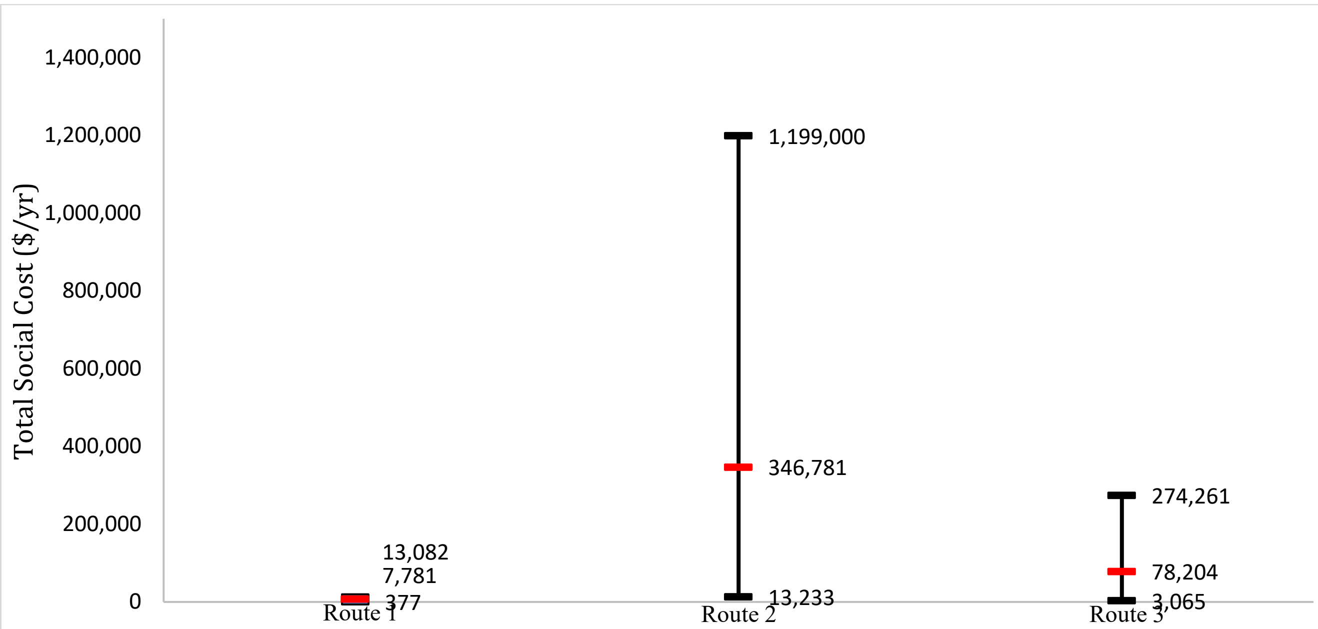
The annual social costs are shown in Table 30 and illustrated in Figure 25. The additional emissions resulting from rerouting are presented in appendix F along with social costs per vessel type. Route 2 had the highest overall maximum social costs per year (up to $1.2 million). The annual maximum social costs for the remaining routes 1 and 3 are below $300,000.

Table 30. Annual Social Costs Associated with Rerouting

Route	Annual Social Cost ($/yr) Min	Typical	Max
1	377	7,781	13,082
2	13,233	346,781	1,199,000
3	3,065	78,204	274,261

Figure 20. Total Social Costs ($/year) for each Route

Typical social cost for each route is represented by a red horizontal line.



The overall maximum CO_2 emissions (Table 31) and the corresponding annual social costs (around $1.5 million/yr) due to all rerouting measures were considered high. However, the high-social cost will be offset by the CO_2 savings from the deployment and operational period of offshore wind farms over 31 years[14] (appendix G). The societal benefits of New York State's 2.4 GW of offshore wind farm development was captured in the carbon payback period[15] and the net CO_2 emissions savings for all three routes (Table 31). An average value of the annual CO_2 savings (around 4.2 million tons CO_2/yr) was used to calculate the annual net CO_2 savings. This is because the construction of the wind farms will be phased, with 2.4 GW only becoming fully operational after year 6 and remain operational for 19 years.

Table 31. Carbon Payback Period and Lifetime CO_2 Savings

Social benefits	Min	Typical	Max
Carbon Payback Period (yrs)	0.77	0.77	0.78
Annual CO_2 emissions from rerouting (tons CO_2/yr)	103	855	1,746
Net annual CO2 savings (tons CO_2/yr)	5,191,550	5,190,799	5,189,908
Net CO_2 savings over lifetime (tons CO_2)	129,788,140	129,764,843	129,737,209

The emissions savings from New York State offshore wind farms will have compensated for all the additional carbon emissions associated with vessel rerouting after about 9 months of operation, at which point the switch from social costs to social benefits will occur. This is because for every additional ton of CO_2 emitted by the vessels rerouting around the Area for Consideration, between 2,972 and 50,403 tons of CO_2 are displaced by the offshore wind farms. In this scenario, offshore wind farms are considered a good public investment from an emissions standpoint as over 129 million tons of CO_2 would be saved over the 31 years of development and operation.

3.6.12 Summary of Socioeconomic Costs

In scenario 3, economic costs (fuel and operational) and social costs, when added together, form the total socioeconomic costs of rerouting vessels around the Area for Consideration (Table 32). Route 2 had the highest costs (Figure 21). However, the costs are reasonable when compared with the societal benefits for emissions offset from operational wind farms.

Figure 22 presents the breakdown of the total annual socioeconomic costs and shows how the costs are highly dependent on the social component. These total socioeconomic costs are offset by the societal benefits associated with the CO_2 savings.

Table 32. Summary Table of Annual Socioeconomic Costs for Each Rerouting

Route	Total economic cost of rerouting ($/yr)			Total social cost of rerouting ($/yr)			Total socioeconomic cost ($/yr)		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	1,5523	4,042	4,042	377	7,781	13,082	**1,930**	**11,823**	**17,124**
2	33,5723	107,101	197,514	13,233	346,781	1,194,000	**46,805**	**453,882**	**1,396,514**
3	7,629	24,020	44,905	3,065	78,204	274,261	**10,694**	**102,224**	**319,166**

Figure 21. Range of Total Annual Socioeconomic Costs for Each Rerouting

Typical economic cost for each route is represented by a red horizontal line.

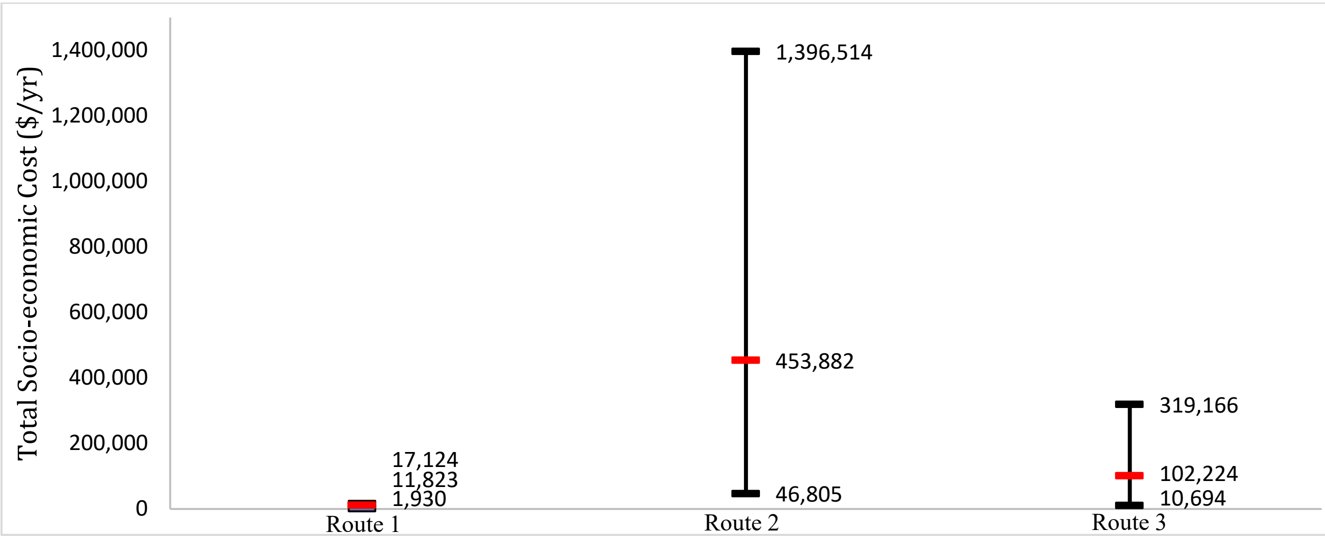
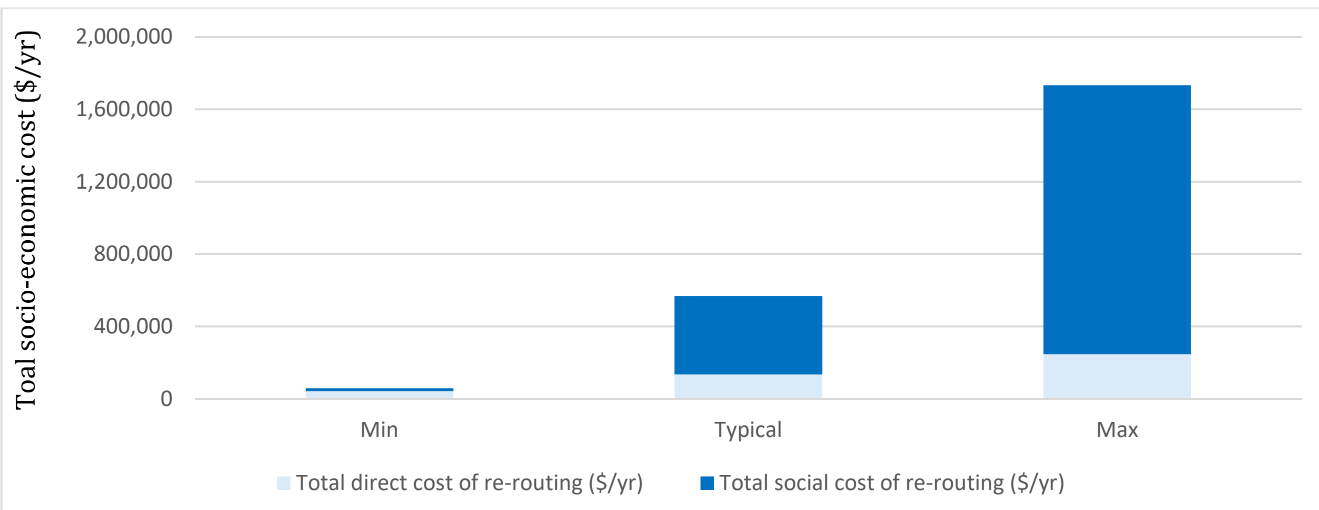


Figure 22. Summary and Breakdown of total Annual Socioeconomic Costs



The net socioeconomic benefit is calculated as annual CO_2 savings (data provided in NYSERDA's Master Plan) minus the annual socioeconomic costs (Table 33). The maximum socioeconomic costs are very small compared to the total potential socioeconomic benefit resulting from offshore wind development in New York State. The socioeconomic costs are only 0.7% (maximum) of the total annual societal benefits and over the lifetime of the development could represent $8 billion in savings (see appendix G).

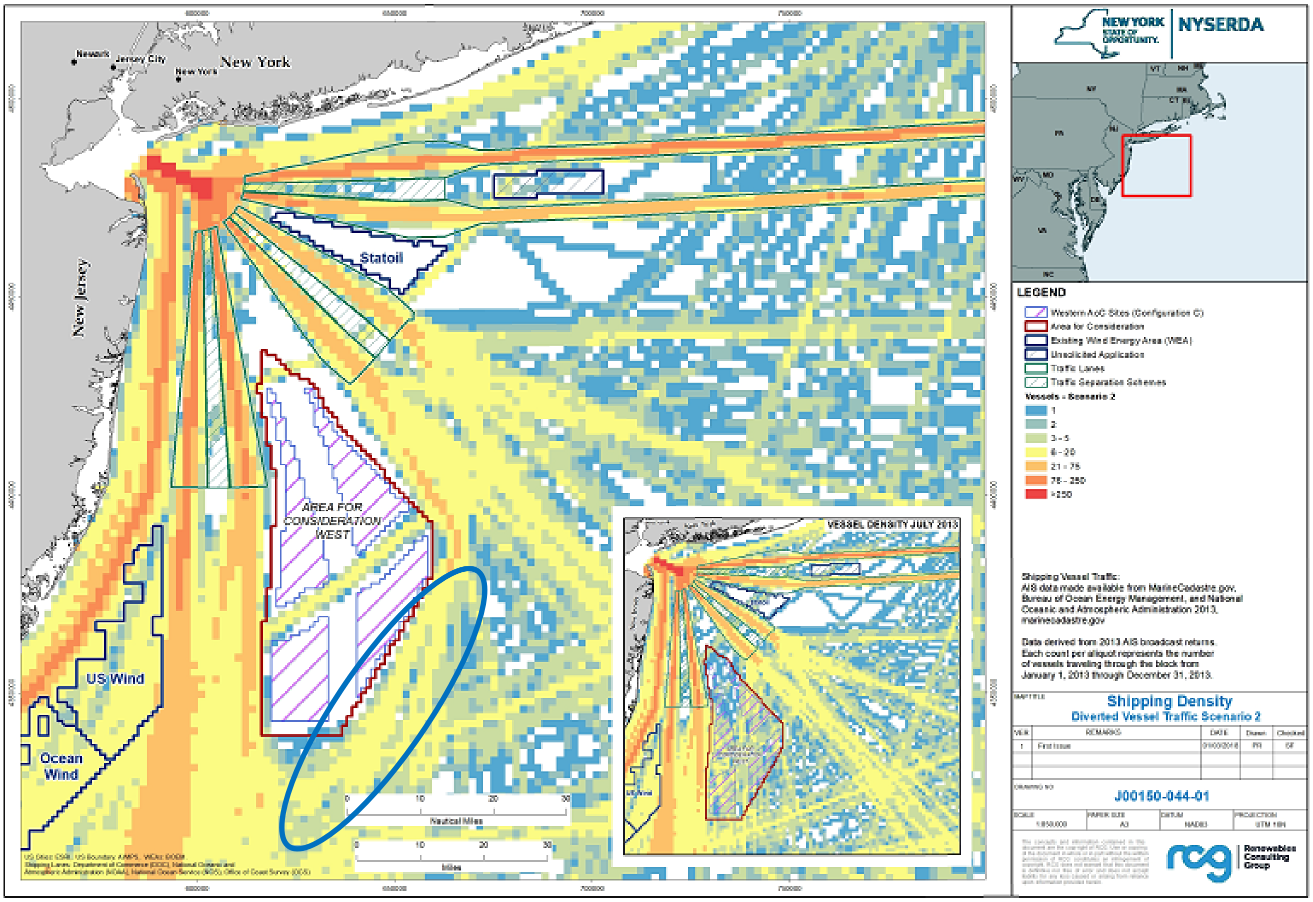
Table 33. Scenario 3. Annual Cost and Benefit Summary

	Min	Typical	Max
Total socioeconomic cost ($/yr)	59,430	567,929	1,732,804
Net socioeconomic benefit ($/yr)	262,893,226	262,384,727	261,219,852
% of total annual societal benefit	<0.1%	0.2%	0.7%

3.7 Scenario 4. Sites within Area for Consideration (West)

In this scenario, all vessels must reroute around four sites located in the Area for Consideration (West). These sites represent one possible layout option for fitting 2.4 GW within the Area for Consideration and is a best-case scenario. In this scenario, only routes 1, 4, 5, 6, and 7 would be affected (see Figure 4). Traffic vessel analysis modeled commercial vessels taking the most direct passage between waypoints with no other constraints to minimize transit time and fuel costs. The site layout created a five-nautical mile fairway laterally and longitudinally within the Area of Consideration. When rerouting traffic under this scenario, very few vessels were aligned with the fairways and so would not take them. This is despite fairways being large enough to enable vessels to navigate. For example, the north-south route would not be used by commercial vessels that already utilize either the inbound Barnegat to Ambrose TSS or outbound Ambrose to Hudson Canyon TSS. The east-west fairway may be preferred by some vessels, although the largest commercial vessels would generally not pass through offshore farms as they would prefer to have sufficient sea room for safety considerations. Under scenario 4, five main-vessel traffic routes would be potentially deviated around or through the Area for Consideration (West) as seen in Figure 23.

Figure 23. Vessel Traffic Before and After Rerouting Site Layouts in Area for Consideration (West)



Two outbound routes4 and 5,[16] leaving the Ambrose to Hudson Canyon TSS, were rerouted around the eastern corner of the Area for Consideration (West). One of the consequences of rerouting 4 and 5 was a greater concentration of vessels along the east-south eastern boundary. Where vessel numbers become concentrated there is potential implications for navigational safety and increased collision risk. To better understand this risk would require a full NSRA at the project level.

To the south of this Area for Consideration (West), two inbound routes, 6 and 7, were rerouted on approach to the Barnegat to Ambrose TSS. However, some individual vessels did utilize fairways between site layouts. Route 1, which runs north to south across the Area for Consideration (West) was rerouted. In this scenario, some tugs and towing vessels opted to navigate the lateral fairway between sites, while others rerouted along the northern tip of the Area for Consideration (West) and across the TSS lanes (Hudson Canyon to Ambrose and vice versa) at right angles to pass to the east of the Statoil development area.[17]

Because some commercial vessels can arrive early and need to wait for a pilot boat or further orders, they can reduce steaming speed on approach or wait on station to the south-east of New York State's TSSs. The presence of offshore wind farms within the Area for Consideration could overlap with the location of waiting or affect slow steaming vessels.

3.7.13 Deviation Distances and Times

The net increases in distances caused by vessel rerouting are mostly considered small (Table 34). The deviation for route 7 does not incur any additional distance travelled, hence no costs and so was disregarded in this analysis. The duration of the other route deviations was very small with most vessels, not exceeding a deviation time of more than 20 minutes, although the only exceptions were tugs and towing vessels on route 1 with an increase of just under 30 minutes (Table 35).

Table 34. Net Increase in Distances of Vessel Routes

Route	1	4	5	6	7
Before Rerouting (nm)	122	36	102	92	46
After Rerouting (nm)	126	37	105	94	46
Net Increase (nm)	4	1	3	2	0
Net Increase (km)	7	2	6	4	0

Table 35. Deviation Duration (Minutes)

Route 7 had no net increase in duration, so was not taken forward.

Route	1	4	5	6
Cargo	N/A	3	8	5
Tanker	N/A	4	12	8
Passenger	N/A	3	8	5
Tugs and Towing	27	7	20	13

Table 36 shows the change in total annual distance travelled before and after vessel rerouting for each route. The total increase in transit distances across the Area for Consideration is 2,425 km or 2.7% per year. The impact to vessel route deviations is relatively modest. Careful siting of wind farms within this representative site layout could further reduce potential vessel rerouting.

Table 36. Distance Impact for Vessel Transits in Entire Area for Consideration under Scenario 4

Route	1	4	5	6	Total
Before (km)	6,552	9,934	42,315	32,203	***91,004***
After (km)	6,767	10,210	43,559	32,903	***93,439***
% Increase	3.3%	2.8%	2.9%	2.2%	***2.7%***

The transit times and distances for traffic rerouting around offshore wind farms in Europe are proportionate to that modeled in this study. Tugs and towing vessels using route 1 had the largest increase of 4 nm, but this route has the lowest number of vessel transiting per year (29 vessels/yr); it is therefore likely to be considered insignificant. To assess the full impact, an NSRA would be required at the project level.

3.7.14 Economic Costs

A summary of the total annual economic costs for all vessels combined and across all four routes is presented in Table 37 and illustrated in Figure 24. Fuel costs associated with the reroutings of vessel types across all five routes are presented in appendix F. Route 1 had the highest maximum costs. For instance, if cargo vessels were to use this route they would potentially incur the largest overall maximum fuel costs of $929/trip, followed by passenger vessels with maximum fuel costs of $895/trip. The next highest cost was tankers at $474/trip. Tugs and towing vessels had the smallest maximum fuel costs of $117/trip, which reflected their low-fuel consumptions compared to other vessel types using route 1. After route 1, routes 5 and 6 had the highest fuel costs. To estimate the total economic costs of rerouting vessels, operational costs were also factored in to the calculation (see appendix F).

When adding operational costs to fuel costs, the economic costs associated with route 1 effectively reversed the previous order with passenger vessels now the costliest vessel type ($3,665/trip) followed by cargoes ($1,106/trip), and then tankers ($596/trip). Tugs and towing vessels remained with the smallest maximum economic costs of $279/trip. In terms of economic costs, route 1 had the largest costs for all vessel types, followed by routes 5 and 6. The lowest economic costs were associated with route 4 ($1,412/trip). Table 37 shows route 5 had the highest annual maximum economic costs, which also reflected the high number of vessels using that route. This was closely followed by route 6, and route 4. Route 1 had the smallest maximum economic costs. A breakdown of the economic costs per vessel type is included in appendix F.

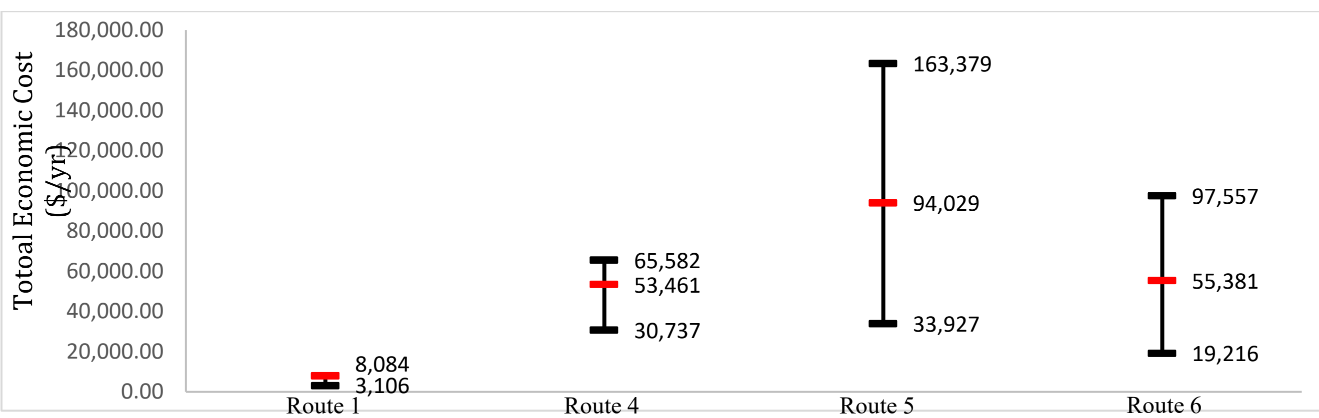
Overall, cargo vessels across all four routes had the highest annual (maximum) economic costs ($188,076/yr) of all vessel types. Passenger vessels had the next highest overall annual (maximum) economic costs ($76,971/yr), followed by tanker ($58,544/yr), and tugs and towing ($11,011/yr) vessels. For individual routes, cargo vessels had the largest economic costs associated with route 5 ($102,889/yr) compared to other routes and vessel types. Passenger vessels had the next highest economic costs associated with route 4 ($42,151/yr), tanker vessels on route 5 ($36,199/yr), followed by tugs and towing vessels on route 1 ($8,084/yr). Route 1 had the largest rerouting distance (4 nm) and so the longest duration times for tugs and towing vessels (27 min). However, route 1 has the least number of vessels transiting that route (average number of vessels per day of 0.08) compared to all other routes. Each tugs and towing vessel on route 1 could incur annual costs ranging between $107/yr and $279/yr. Route 5, with the largest number of cargo vessels operating on it, had the largest annual economic costs compared to all other routes with each vessel potentially incurring an annual cost between $151 and $729.

Table 37. Summary of the Annual Rerouting Economic Costs by Route

Route	Annual Economic Cost ($/yr)		
	Min	Typical	Max
1	3,106	8,090	8,084
4	30,737	53,461	65,583
5	33,927	94,031	163,379
6	19,216	55,382	97,557

Figure 24. Annual Economic Costs ($/yr) of Rerouting Vessels by Route

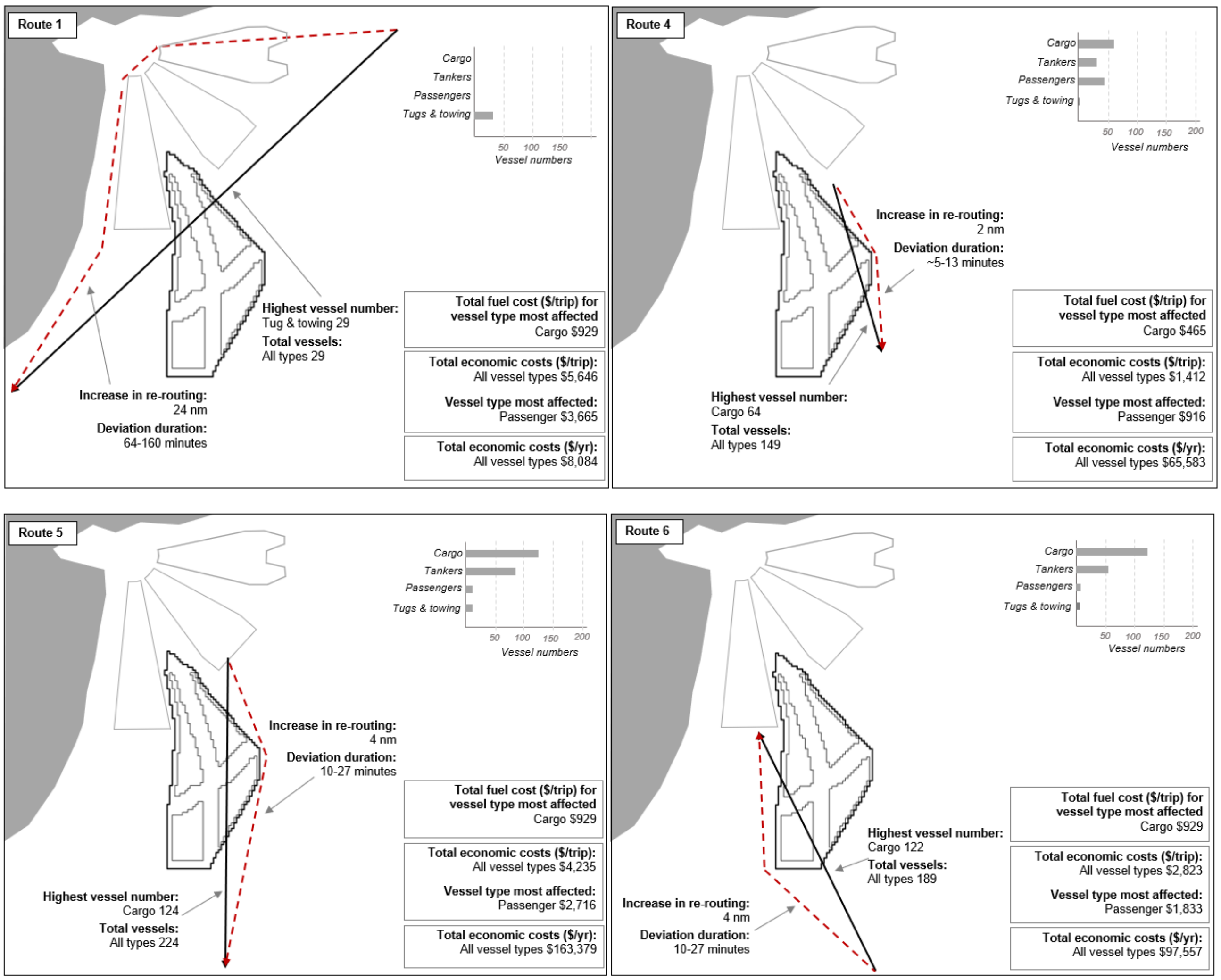
Includes mimimum, maximum, and typcial values. Typical economic cost for each route is represent by a red horizontal line.



3.7.14.1 Summary of Rerouting and Economic Costs

The distance, duration, and economic costs of rerouting vessels around Area for Consideration are presented in Figure 25. The rerouting paths in this figure are illustrative only and further detailed route deviations can be found in appendix E.

Figure 25. Summary of Cost and Rerouting under Scenario 4



3.7.15 Social Costs and Benefits

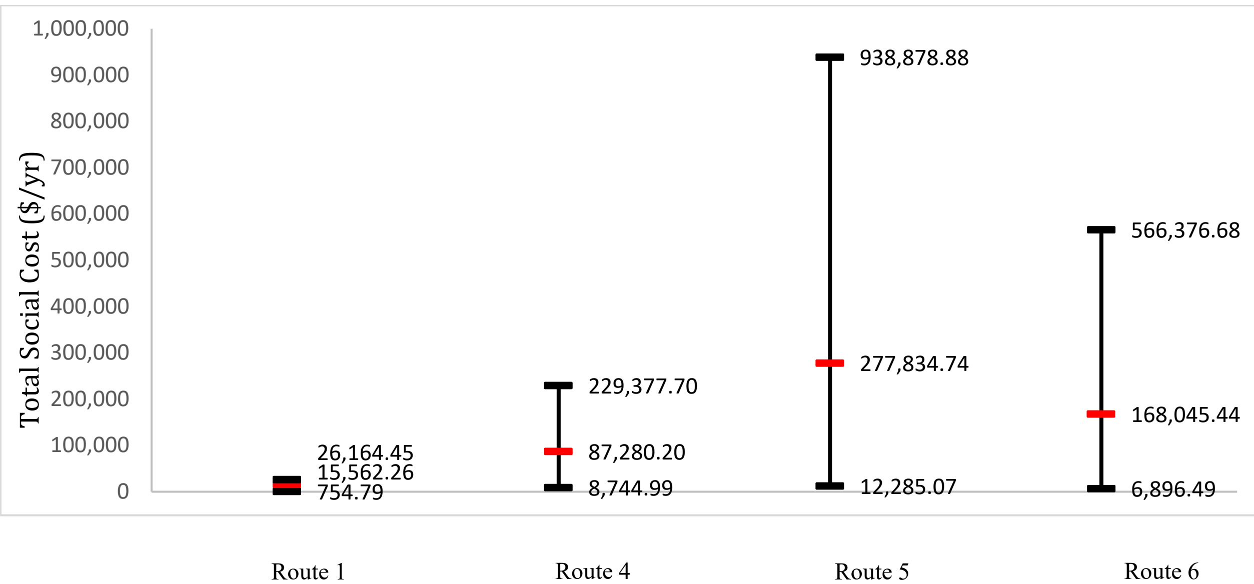
The annual social costs are shown in Table 38 and illustrated in Figure 26. The additional emissions resulting from rerouting are presented in appendix F along with social costs per vessel type. Route 5 had the highest overall maximum social costs per year, followed by route 6. The smallest annual maximum social cost was associated with route 1.

Table 38. Annual Social Costs Associated with Rerouting

Route	Annual Social Cost ($/yr)		
	Min	Typical	Max
1	755	15,562	26,164
4	8,745	87,280	229,378
5	12,285	277,835	938,879
6	6,896	168,045	566,377

Figure 26. Total Social Costs ($/year) for Each Route

Typical economic cost for each route is represented by a red horizontal line.



The overall maximum CO_2 emissions (Table 39) and the corresponding annual social costs (around $1.8 million), due to all rerouting measures, were considered high. However, the high-social costs will be offset by the CO_2 savings spanning the entire deployment and operational period of offshore wind farms over 31 years[18] (appendix G). The societal benefits of New York State's 2.4 GW of offshore wind target was captured in the carbon payback period[19] and the net CO_2 emissions savings for all four routes (Table 39). An average value of the annual CO_2 savings (around 4.2 million tons CO_2/yr) was used to calculate the annual net CO_2 savings. This is because the construction of the wind farms will be phased with 2.4 GW, only becoming fully operational after year 6 and remaining operational for 19 years.

Table 39. Carbon Payback Period and Lifetime CO_2 Savings

Social benefits	Min	Typical	Max
Carbon Payback Period (yrs)	0.77	0.78	0.79
Annual CO_2 emissions from rerouting (tons CO_2/yr)	178	1,084	2,069
Net annual CO_2 savings (tons CO_2/yr)	5,191,519	5,190,902	5,190,250
Net CO_2 savings over lifetime (tons CO_2)	129,787,158	129,768,033	129,747,841

The emissions savings from New York State offshore wind farms will have compensated for all the additional carbon emissions associated with vessel rerouting after about 9 months of operation, at which point the switch from social costs to social benefits will occur. This is because for every additional ton of CO_2 emitted by the vessels rerouting around the Area for Consideration, between 2,508 and 29,166 tons of CO_2 are displaced by the offshore wind farms. In this scenario, offshore wind farms are considered a good public investment from an emissions standpoint as over 129 million tons of CO_2 would be saved over the 31 years of development and operation.

3.7.16 Summary: Total Socioeconomic Impact

In scenario 4, economic costs (fuel and operational costs) and social costs, when added together, form the total socioeconomic costs of rerouting vessels around the Area for Consideration (Table 40). Route 5 had the highest costs followed by route 6 (Figure 27). However, the costs are reasonable when compared with the societal benefits for emissions offset from operational wind farms. Figure 28 presents the breakdown of the total annual socioeconomic costs and shows how the costs are highly dependent on the social component. These total socioeconomic costs are offset by the societal benefits associated with the CO_2 savings.

Table 40. Summary Table of Annual Socioeconomic Costs for Rerouting

Route	Total economic cost of rerouting ($/yr)			Total social cost of rerouting ($/yr)			Total socioeconomic cost ($/yr)		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	3,106	8,084	8,084	755	15,562	26,1645	3,861	23,646	34,248
4	30,737	53,461	65,583	8,745	87,280	229,378	39,482	140,741	294,960
5	33,927	94,031	163,379	12,285	277,835	938,879	46,212	371,865	1,102,258
6	19,216	55,382	97,557	6,897	168,045	566,377	26,113	223,427	663,933

Figure 27. Range of Total Annual Socioeconomic Costs for Each Rerouting

Typical economic cost for each route is represented by a red horizontal line.

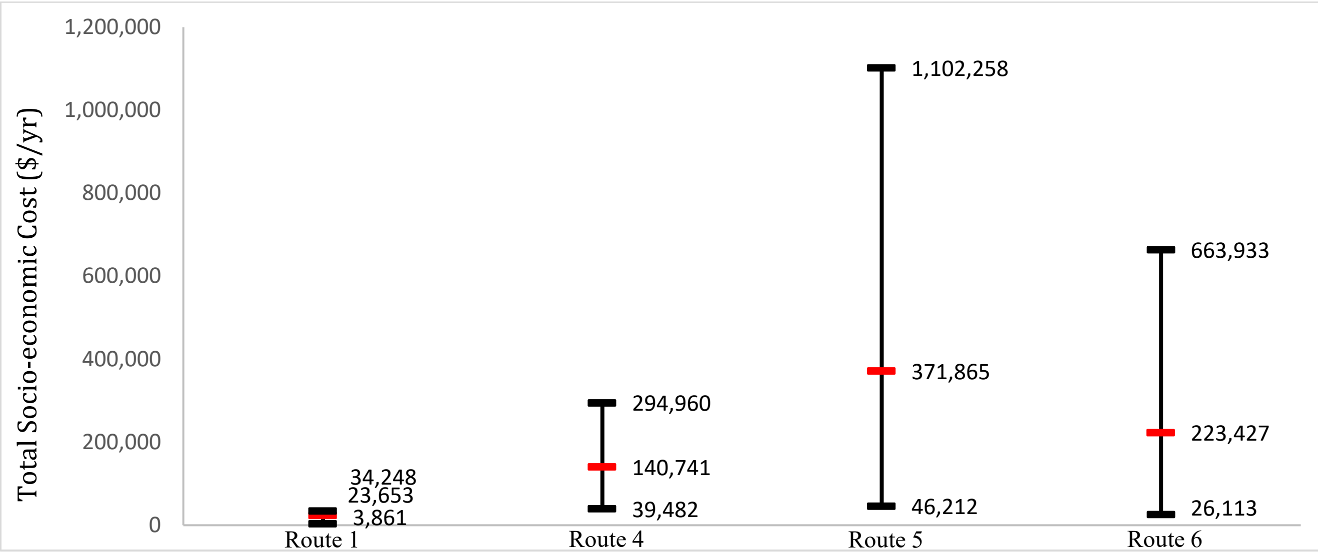
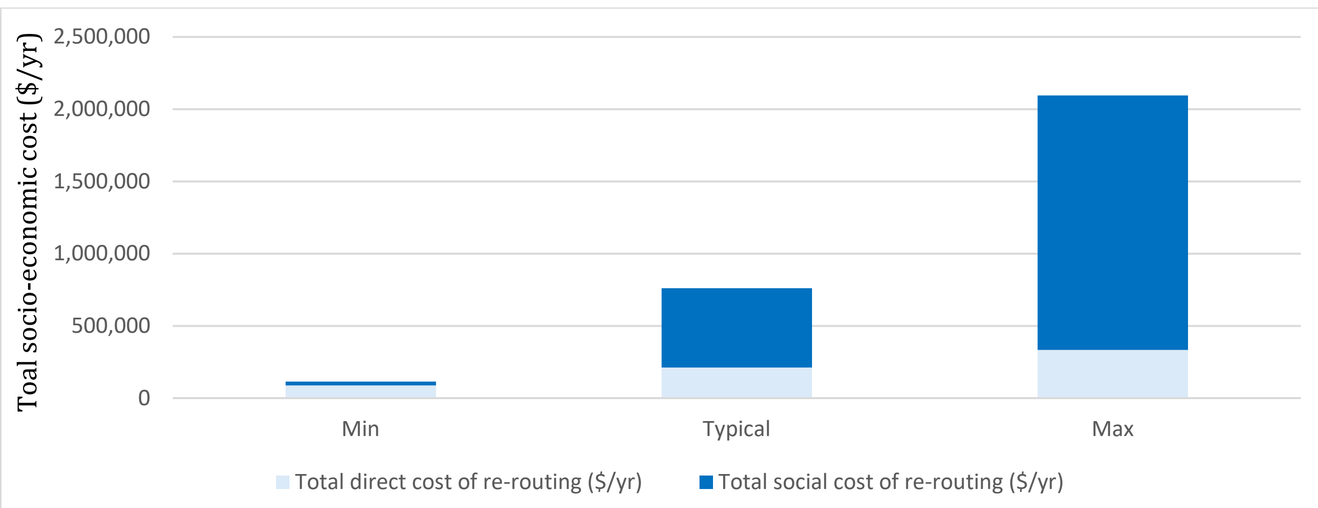


Figure 28. Summary and Breakdown of Total Annual Socioeconomic Costs



The net socioeconomic benefit is calculated as the annual CO_2 savings (data provided in NYSERDA's Master Plan) minus the annual socioeconomic costs (Table 41). The maximum socioeconomic costs are very small (around $2 million) compared to the total potential socioeconomic benefit (around $261 million) resulting from offshore wind development in New York State. The socioeconomic costs are only of 0.8% (maximum) of the total annual societal benefits, and over the lifetime of the development could represent $8 billion in savings (see appendix G).

Table 41. Scenario 4. Annual Cost and Benefit Summary

	Min	Typical	Max
Total socioeconomic cost ($/yr)	115,667	759,678	2,095,400
Net socioeconomic benefit ($/yr)	262,836,989	262,192,978	260,857,256
% of total annual societal benefit	0.1%	0.3%	0.8%

3.8 Cost of Goods

As mentioned in Section 4.3, consumers might be affected by the rerouting measure as the costs of goods could be increased by the shippers to make up for the increase in freight rates charged by the shipping company. These have been calculated for cargoes by dividing the additional annual direct costs by the tons of goods transported by the vessels annually. The tonnage of goods transported by the cargoes affected by the rerouting measures were calculated based on three parameters:

- The number of cargoes affected per year.
- The total number of cargoes entering/exiting the two ports of interest annually—New York and Philadelphia—obtained using the same Gate analysis method used in Section 4 of the Navigation and Shipping study with the AIS data.
- The total tonnage throughput (cargoes) of the two ports of interest for 2016 (U.S. Department of Transportation 2016).

The total tonnage of goods affected was calculated as the product of the percentage of cargoes affected by the total tonnage throughput (appendix A—equation 7). This is a high-level estimation of the total tonnage of goods affected every year and assumes all cargoes carry the same tonnage. The annual direct costs were then divided by the total tons of goods affected for each route annually to determine the increase in the cost of a ton of goods for the shippers (Tables 42-45).

Table 42. Scenario 1. Increase in the Cost of Transporting a Metric Ton of Goods

	Cost increase (cents/ton of good)		
Route	Min	Typical	Max
2	0.4	1.9	3.9
3	0.1	0.4	0.9
4	0.1	0.5	1.1
5	0.3	1.7	3.4
6	0.3	1.7	3.3
7	0.1	0.5	0.9

Table 43. Scenario 2. Increase in the Cost of Transporting a Metric Ton of Goods

Route	Cost increase (cents/ton of good)		
	Min	Typical	Max
4	0.1	0.5	1.1
5	0.4	2.0	4.1
6	0.3	1.7	3.3
7	0.1	0.5	0.9

Table 44. Scenario 3. Increase in the Cost of Transporting a Metric Ton of Goods

Route	Cost increase (cents/ton of good)		
	Min	Typical	Max
2	0.4	1.9	3.9
3	0.1	0.4	0.9

Table 45. Scenario 4. Increase in the Cost of Transporting a Metric Ton of Goods

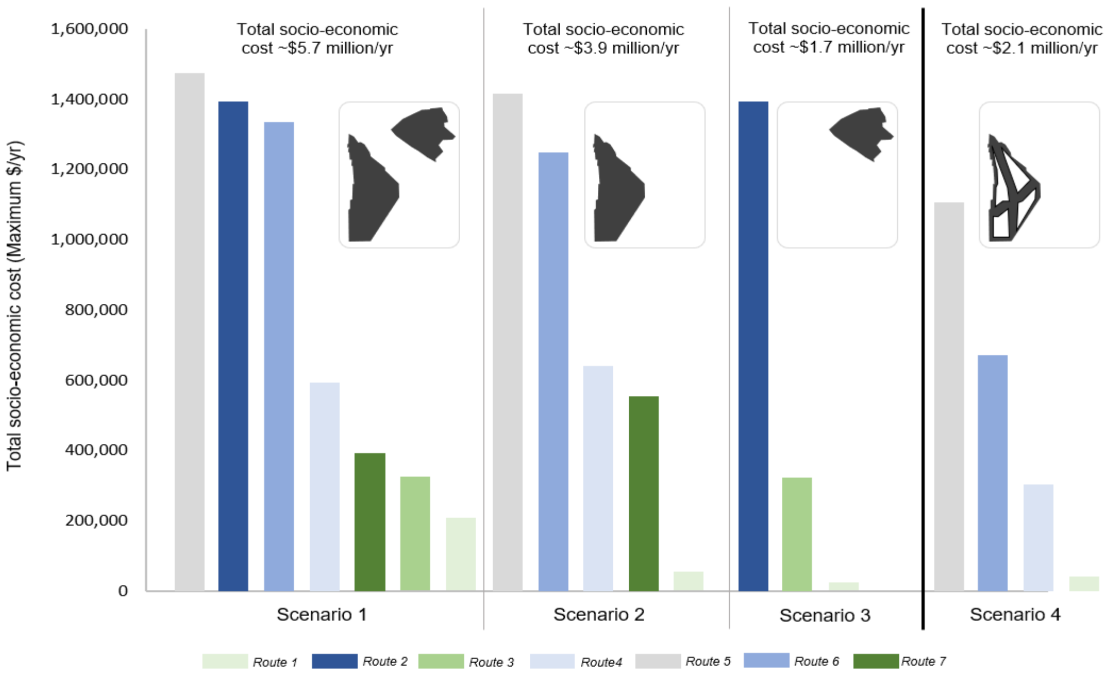
Route	Cost increase (cents/ton of good)		
	Min	Typical	Max
4	0.1	0.3	0.5
5	0.3	1.5	3.1
6	0.2	0.8	1.7

Should they decide to pass this increase on to the consumers, the increase would be minimal for the individual goods (likely to weigh less than a ton).

3.9 Comparison of Scenarios

Scenario 1 had the largest socioeconomic costs at ~$5.7 million/yr compared to the other three scenarios and was almost three-times greater than scenario 3 ~$1.7 million/yr (Figure 29).

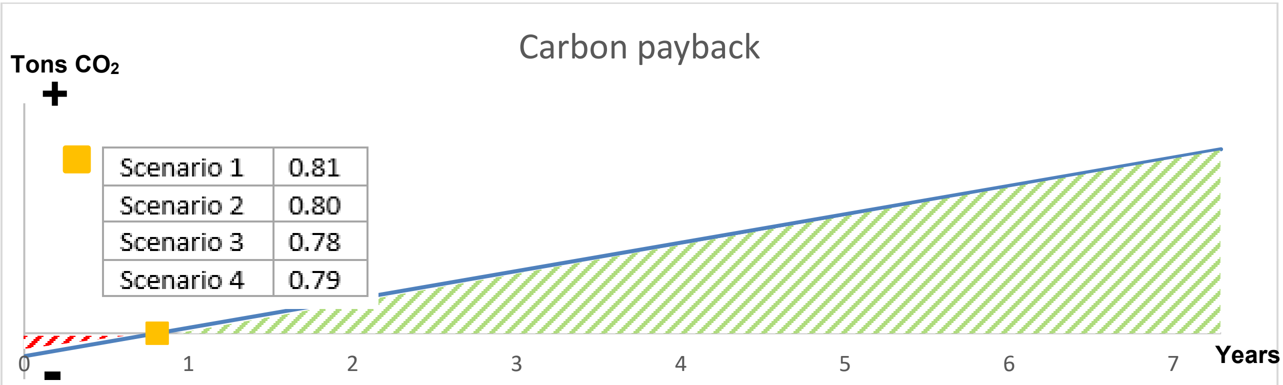
Figure 29. Comparison of the Total Annual Socioeconomic Costs for Four Scenarios and all Routes



While the socioeconomic costs show differences between scenarios, the carbon payback periods calculated for each scenario are broadly similar, with paybacks ranging from 8 to 10 months from the first day of wind farm operation (Figure 30). This is because the avoided life cycle carbon emissions of the offshore wind farms (Section 2.1.2.1) are significantly larger than the emissions from vessel rerouting. Consequently, the carbon payback period is largely insensitive to vessel rerouting. The small carbon payback periods calculated for all four scenarios show how quickly the CO_2 displaced by the offshore wind farms will offset the total lifetime emissions of the wind farms, including those from vessel rerouting.

Figure 30. Carbon Payback Period for Scenarios 1 to 4

(Not to scale)



Scenario 1 included both Area for Consideration (West and East) and so had the greatest distance and duration deviations as well as number of routes affected of all the scenarios. It was also the most unrealistic as no wind farm development would build out the entire area. Scenario 3 had the next largest costs ~\$3.9 million/yr and like scenario 1 had a high number of traffic vessels routes affected (five). This scenario included the Area for Consideration (West) and also represented an unrealistic case for wind farm development.

The next costliest scenario was scenario 4 with ~\$2.1 million/yr, which included the four site layouts within Area for Consideration (West). This scenario provided fairways for some traffic to pass and so, unlike the previous scenarios, was not necessarily the worst case. In addition, the scenario only affected four vessel traffic routes. Scenario 3 was the least costly and included only the Area for Consideration (East) with only three vessel traffic routes affected. The socioeconomic costs for scenario 3 and 4 were considered broadly similar when compared to scenarios 1 and 2. A comparison between scenario 1 (base case) and scenario 4 (realistic case) shows a 77% reduction in socioeconomic costs. This is largely because the Area for Consideration (East) is about half the size of Area for Consideration (West); therefore overall, vessels in scenario 4 only had to navigation around a third of the size of the area compared to scenario 1. Also, noticeably fewer routes were affected by rerouting in scenario 4.

There were some common patterns across all scenarios and routes. Cargo vessels, for instance, were calculated to have the highest fuel costs compared to all other vessel types. This was because overall, there were more vessels transiting across all routes compared to other vessel types. However, the downstream impact on the cost of goods was minimal (in the cents range) and should not severely affect customers or cargo companies. By comparison, passenger vessels had the highest economic costs across all scenarios and routes. Route 5 had the highest number of vessels using the route and consistently had the highest socioeconomic costs across all scenarios. This was closely followed by routes 2 and 6. Despite the worst-case socioeconomic costs estimated in this study, they will all be offset by the societal benefit of the deployment of 2.4 GW of offshore wind farms.

4 Other Impact Findings

Traffic management regulations pertaining to wind farms are typically static. Once in place, they will not change for the lifetime of a given wind farm. It is reasonable to assume that vessel operators will respond to those static measures by taking any measures to deviate around the wind farm and associated potential delays into account when planning schedules. This will limit the impact to shipping and navigation activities beyond the direct costs calculated herein.

If delays are not predictable, then the following impacts could occur:

- Missing the tidal window: Large vessels often need to arrive and depart from a port during the period from a few hours before high tide to a few hours after high tide when the water depth will accommodate the draught of the ship (generally about 2 hours before and after). Missing the window can therefore cause an 8-hour delay.
- Increased costs for scheduled, but unused labor in ports: All personnel are on standby at the scheduled time and a delay will result in increased costs.
- Intermodal costs: If the delays result in the goods missing rail or truck connections, additional costs will be incurred. The goods might have to switch means of transportation which results in additional delays in the supply chain.
- Increased port fees: Cruise ships, for instance, are often charged a penalty for a significantly late arrival (more than three hours generally) at the port. These vary from port to port.

However, it is assumed that these risks can be mitigated for an offshore wind farm where the rerouting is permanent. These impacts are therefore not considered in this study.

4.1 Loss of Adverse Weather Routing

Passenger vessels (ferries and cruise ships) are the most significantly affected vessel type in adverse weather due to the large number of people on board. The effects include (Anatec, 2014):

- Reduced safety and comfort of passengers on board, including motion sickness or difficulty moving around the vessel.
- Risk of vessel damage such as damage caused by longitudinal or torsional stresses, special effects of waves in shallow water or current, collision, and/or stranding.

To mitigate vessel movement in adverse weather and the associated impacts, passenger vessels tend to adjust their course. These adjusted routes are referred to as adverse weather routes. ESs from UK offshore wind farms show that commercial ferries are generally the most affected vessel type. However, AIS data used in this NYSERDA study indicated that cruise ships don't typically deviate from their routes no matter the weather conditions.

4.2 Value of Personal and/or Business Time

The value of personal and/or business travel time is another impact to be considered with any rerouting measure. However, the distance to shore is significant enough that passenger ferries are not affected by the rerouting therefore, this is not considered in this study.

4.3 Reduction in Cargo/Tanker Volume

The only other impact to shipping activities that can result from this rerouting is a reduction in cargo/tanker volume, which would reduce the companies' profits. This results from a complicated cause and effect chain: the increased operational costs of the vessels caused by the increased journey time could result in an increase in freight rates for shippers who, depending on the degree of the increase, could either pass on the extra cost to the consumers by increasing the cost of the goods or decide to reduce the cargo volume sent via that route and select an alternate. Alternatively, the shipping company may absorb the cost increase. This will be determined by the price elasticity of shipping service supply and demand in the port region, an economic concept describing how the quantity of goods shipped and the market price for this service will change in response to a change in the cost of providing the service. A full-price elasticity analysis was not conducted for this study. However, due to the relatively small delays calculated compared to the total journey length (most cargoes and passenger vessels are assumed to embark upon transatlantic journeys when transiting through the Area for Consideration), this should not occur in this case.

4.4 Impact to Local Economy from Vessel Cancellation/Diverting

The impact of vessel cancellation and diversion to a different port on the local economy is a broader impact and depends on whether the delay is significant enough that the alternatives become more attractive. Kite-Powell estimates a $900,000 (2005 dollars) impact to the local economy for a single containership call cancellation at a major port, that is, New York/New Jersey, Boston, Philadelphia amongst others (Kite-Powell, 2005). This includes the loss of direct/indirect jobs, port revenue, and local taxes. Adjusting the loss to 2017 dollars, cancelling a single port call could cause a negative impact to the local economy of more than a million dollars (roughly $1,139,717). It would likely take the vessels as much or more time to redirect to alternate ports; therefore, impact to local economy from vessel cancellation or diversion should not occur.

5 Conclusion and Recommendations

This study examined four scenarios for rerouting commercial vessels around the Area for Consideration and the associated socioeconomic costs to accommodate increased voyage distance and time. All four scenarios represented varying degrees of work-case. Future analysis of these areas would allow wind farms to reduce their footprint and be positioned in a manner that would further minimize the socioeconomic costs presented in this report.

The total increase in transit distances associated with rerouting around the Area for Consideration is greatest for scenario 1 (5.1% per year). The next greatest increase occurred for scenario 2 (4.5%/yr), followed by scenario 3 (4.3%/yr), and lastly, scenario 4 (2.7%/yr). This shows that a more realistic scenario with only some sites in the Area for Consideration (scenario 4) would have a much smaller impact on distance travelled by vessels than the base-case scenario would.

A comparison of the total annual socioeconomic costs for the four scenarios showed that scenario 1 had the largest costs, almost three-times greater than for scenario 3. This is largely because the Area for Consideration (East) is around a third of the size of the entire Area for Consideration considered in scenario 1. The next costliest scenario was scenario 2, followed by 4, and then 3. Noticeably, fewer routes were affected by rerouting in scenario 3 compared to other scenarios. Careful siting of offshore wind farms to accommodate major traffic routes—especially tugs and towing vessels, which were considered the most sensitive to rerouting because they tend to transit slower than other commercial vessels—could further reduce these costs. Across all scenarios, cargo vessels had consistently the highest fuel costs compared to all other vessel types. This was attributed to cargo vessels being the most numerous across all routes. Yet, economic costs were highest for passenger vessels across all scenarios and routes. Route 5 had the highest socioeconomic costs across all scenarios and was closely followed by routes 2 and 6. Despite the worst-case socioeconomic costs estimated, it should be noted that they can all be offset by the societal benefit of the wind farm and so represent a positive investment in terms of emissions. In fact, the socioeconomic costs were found to equate to only between 0.7% (scenario 3) and 2.2% (scenario 4) of the total annual emissions savings. Over the lifetime of the development, $8 billion in savings could result overall.

5.1 Recommendations

It is recommended that relevant stakeholders are consulted to validate the assumptions relating to fuel and operational costs for commercial vessels as well as the deviation routes considered. In particular, tugs and towing vessel transits are more sensitive to route deviations as they tend to travel at slower speeds than those of other commercial vessels examined in this study.

It is also recommended that the U.S. Coast Guard is consulted to evaluate the potential for alterations to be made to TSSs (particularly, the Hudson Canyon and Ambrose TSS) to manage and guide vessel traffic beyond the extents of any offshore wind farms located along the boundaries of the Area for Consideration that currently border main-vessel traffic routes inbound and outbound.

Finally, it is recommended that this, and additional analysis, be used for locating future offshore wind farms with the goal of minimizing impact to navigation.

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Appendix A. Equations

The following equations were used in this study and are referenced in the main body of the report.

Equation 1: To estimate fuel price for each vessel type, fuel consumption rate was multiplied by the HFO market price.

$$\boldsymbol{Fuel\ Consumption\ \left(\frac{tons}{hour}\right) \times HFO\ market\ price\ \left(\frac{\$}{ton}\right) = Fuel\ cost\ \left(\frac{\$}{hour}\right)}$$

Equation 2: To estimate the duration of vessel route deviation, the distance of the vessel route deviation was divided by vessel speed.

$$\boldsymbol{\frac{Vessel\ route\ devition\ (km)}{Vessel\ speed\ (km/hr)\text{[20]}} = Duration\ (hour)}$$

Equation 3: Fuel costs associated with the route deviation were multiplied by the duration of the deviation.

$$\boldsymbol{Fuel\ Cost\ \left(\frac{\$}{hr}\right) \times Duration\ of\ deviation\ (hr) = Fuel\ cost\ of\ deviation\ (\$)}$$

Equation 4: To estimate the net emissions savings over the lifetime of a wind, the difference between emissions displacement minus, lifecycle emissions including the additional CO_2 emitted from vessel rerouting for each year the wind farm is operating was used.

$$\begin{aligned} &\boldsymbol{Net\ GHG\ savings\ (gCO2)} \\ &\quad \boldsymbol{= Total\ CO2\ savings\ \left(\frac{ton\ CO2}{yr}\right) - CO2\ from\ rerouting\ \left(\frac{gCO2}{yr}\right)} \\ &\quad \boldsymbol{- \left(Lifecycle\ emissions\ \left(\frac{ton\ CO2}{kWh}\right) * output\ \left(\frac{kWh}{yr}\right)\right)} \end{aligned}$$

Equation 5: The carbon payback period is defined as the time taken for the carbon savings from the wind power produced to equal the life cycle carbon emissions of the wind farm development including emissions from vessels rerouting. To estimate payback period the total CO_2 emissions from both the lifecycle of the wind farm and the vessel rerouting were divided by the CO_2 displaced annually by the wind farm.

$$\textit{Payback Period}\ (\textit{years}) = \frac{\textit{Lifecycle emissions}\ \left(\frac{gCO2}{kWh}\right) + CO2\ \textit{from rerouting}\ \left(\frac{gCO2}{kWh}\right)}{\textit{Displacement}\ \left(\frac{gCO2}{kWh}\right)} * \textit{Design Life}$$

Equation 6: The monetary net benefit is defined as the dollar value of the emission savings. To estimate this net benefit, the total socioeconomic costs ($/yr) were subtracted from the cost of the average annual CO_2 savings resulting solely from electricity production.

$$\textit{Net socio} - \textit{economic benefit}\ \left(\frac{\$}{yr}\right) = \left(\textit{Annual CO2 savings}\left(\frac{tons}{yr}\right) * \textit{Social cost of carbon}\ \left(\frac{\$}{tons}\right)\right) - \textit{Annual socio} - \textit{economic costs}\ \left(\frac{\$}{yr}\right)$$

Equation 7: The tonnage of goods transported by the cargoes affected by the rerouting measures was calculated as the product of the percentage of cargoes affected by the total tonnage throughput.

$$\textit{Total tons of goods affected} = \frac{\textit{number of cargoes affected}}{\textit{total number of cargoes}} * \textit{total tonnage throughput}$$

Appendix B. Social Cost of CO_2 and Lifecycle Emissions

B.1 Social Cost of CO_2

Year	Social cost of CO_2 ($/ton)	Year	Social cost of CO_2 ($/ton)
2024	$47.77	**2040**	$63.70
2025	$48.83	**2041**	$64.76
2026	$49.89	**2042**	$65.82
2027	$50.96	**2043**	$66.88
2028	$52.02	**2044**	$67.94
2029	$52.02	**2045**	$69.00
2030	$53.08	**2046**	$70.06
2031	$54.14	**2047**	$71.13
2032	$55.20	**2048**	$72.19
2033	$56.26	**2049**	$73.25
2034	$57.33	**2050**	$74.31
2035	$58.39	**2051**	$74.31
2036	$59.45	**2052**	$74.31
2037	$60.51	**2053**	$74.31
2038	$61.57	**2054**	$74.31
2039	$62.63		

B.2 Lifecycle Carbon Emissions of Offshore Wind Farms

Device	Rating (MW)	Capacity factor (%)	Design life (years)	Carbon emissions (g CO_2eq/kWh)	Type of Analysis	References
Nordic wind farms	Mixed	32 (19 to 44)	20	14	Environmental Product Declaration	(Vattenfall, 2013)
Vestas v90 farm	3.0	54.16	20	5.23	Process LCA	(Vestas, 2006)
Alpha Ventus wind farm	5	44	20	32	Process LCA	(Wagner et al., 2011)
Offshore farm (Vestas v90)	3	54.16	20	5.98	Process LCA	(Wang and Sun, 2012)
Floating power plant (Recycled content method)	5	53	20	11.52	Process LCA	(Weinzettel et al., 2009)
Floating power plant (Closed loop method)	5	53	20	12.24	Process LCA	(Weinzettel et al., 2009)
Single turbine in Baltic Sea	2	30	20	13	Process LCA	(Jungbluth et al., 2005)
Offshore wind farm	2	30	20	14.4	Process LCA	(Ecoinvent, 2010; IPCC, 2007)
Danish wind farm	0.5	29	20	16.5	Process LCA	(Schleisner, 2000)
Mean	Mixed	Mixed	Mixed	13	Review	(Dolan and Heath, 2012)
Harmonised mean	Mixed	40	20	12	Review and harmonisation	(Dolan and Heath, 2012)
Median	Mixed	Mixed	Mixed	12	Review	(Dolan and Heath, 2012)
Harmonised median	Mixed	40	20	11	Review and harmonisation	(Dolan and Heath, 2012)

Appendix C. Number of Vessels per Day

Figure C-1. Route 1 Daily Vessel Numbers (Red: Average of 0.08 Vessels per Day)

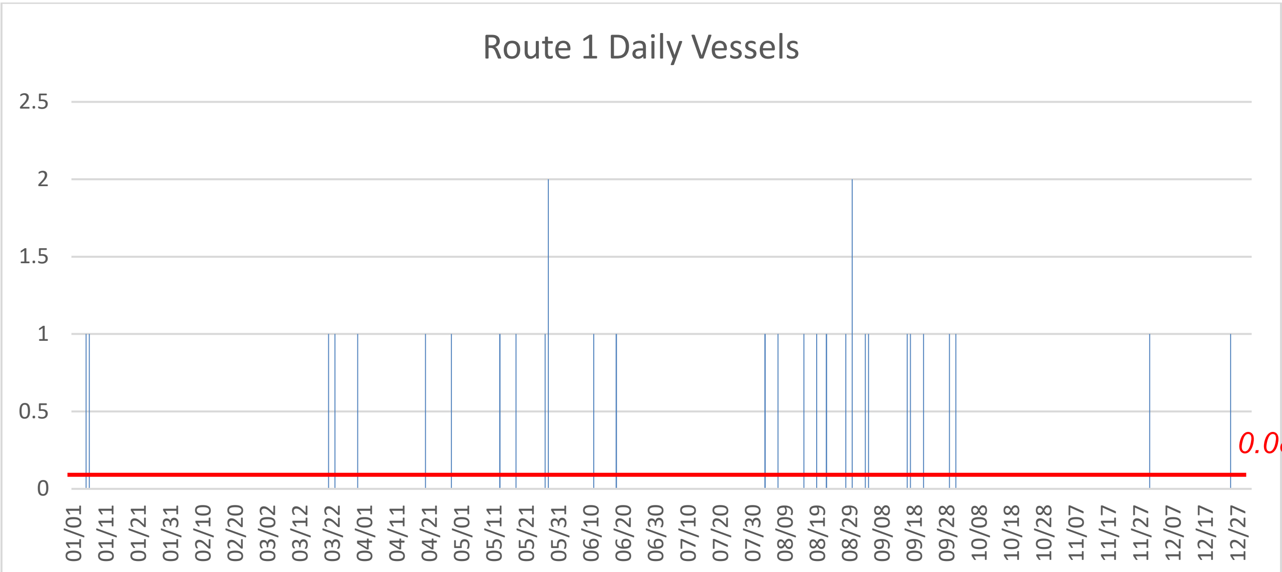


Figure C-2. Route 2 Daily Vessel Numbers (Red: Average of 0.41 Vessels per Day)

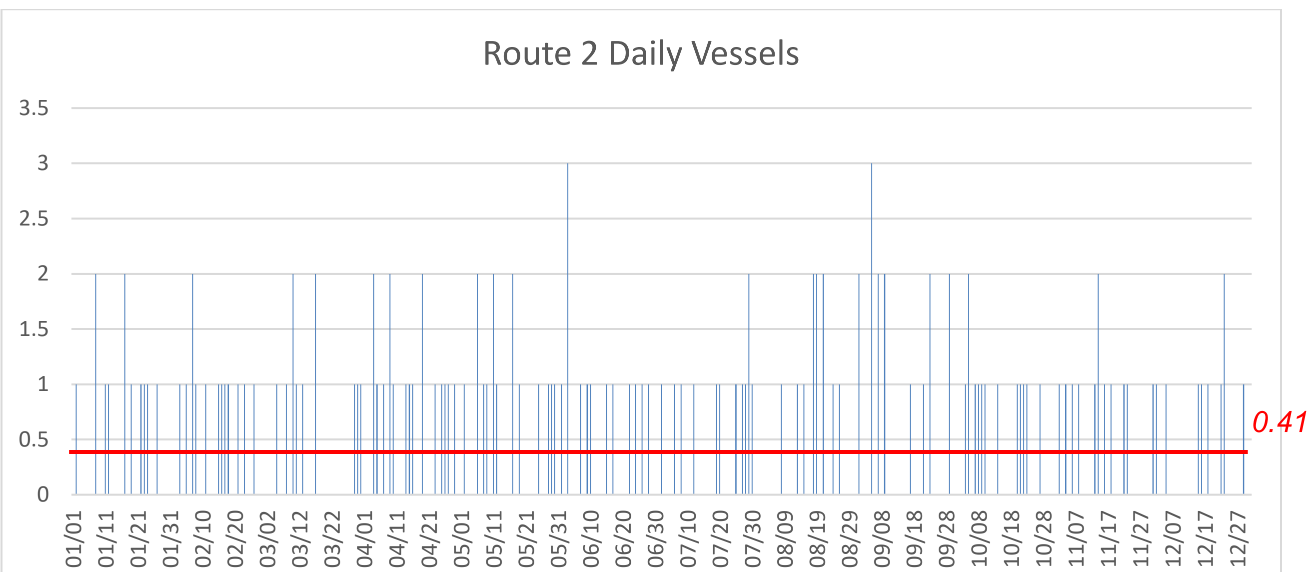


Figure C-3. Route 3 Daily Vessel Numbers (Red: Average of 0.53 Vessels per Day)

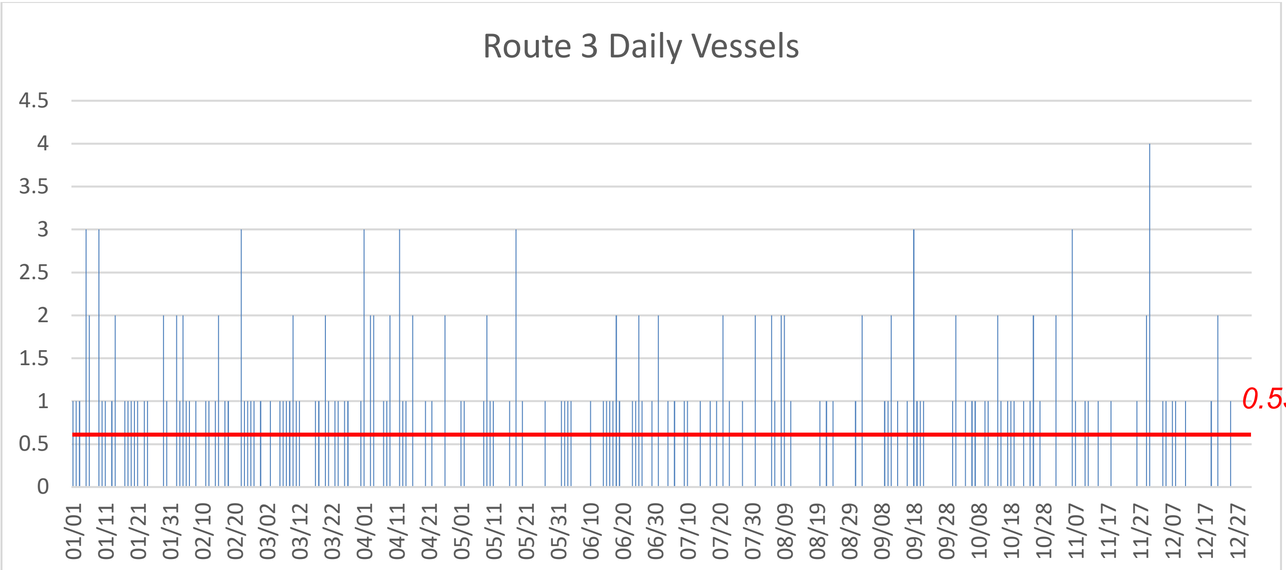


Figure C-4. Route 4 Daily Vessel Numbers (Red: Average of 0.41 Vessels per Day)

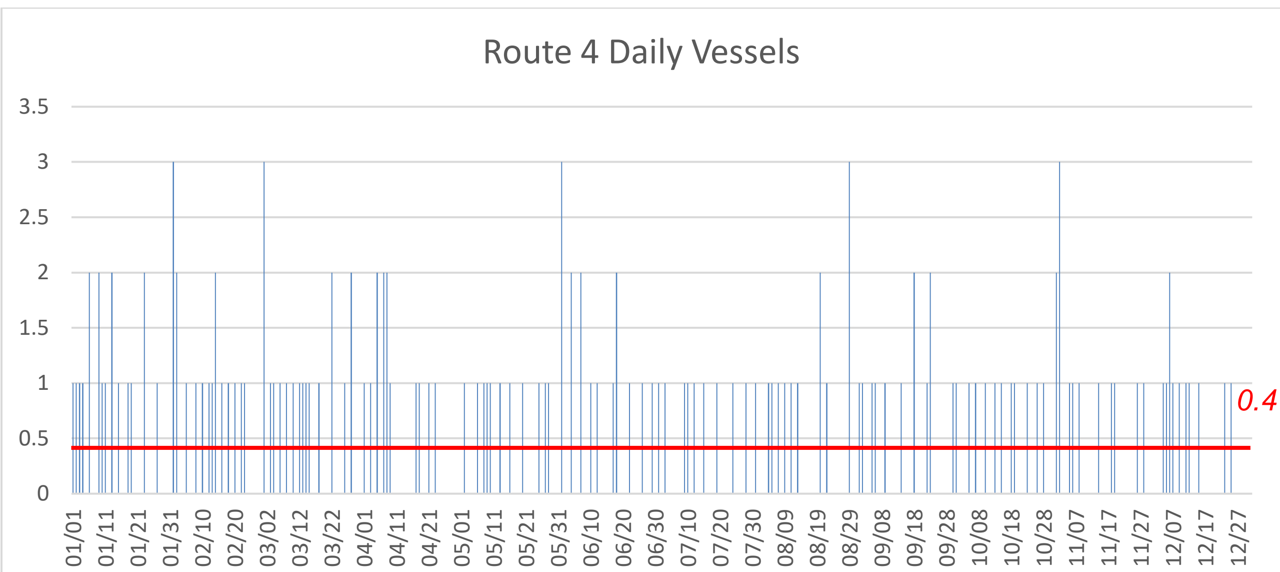


Figure C-5. Route 5 Daily Vessel Numbers (Red: Average of 0.61 Vessels per Day)

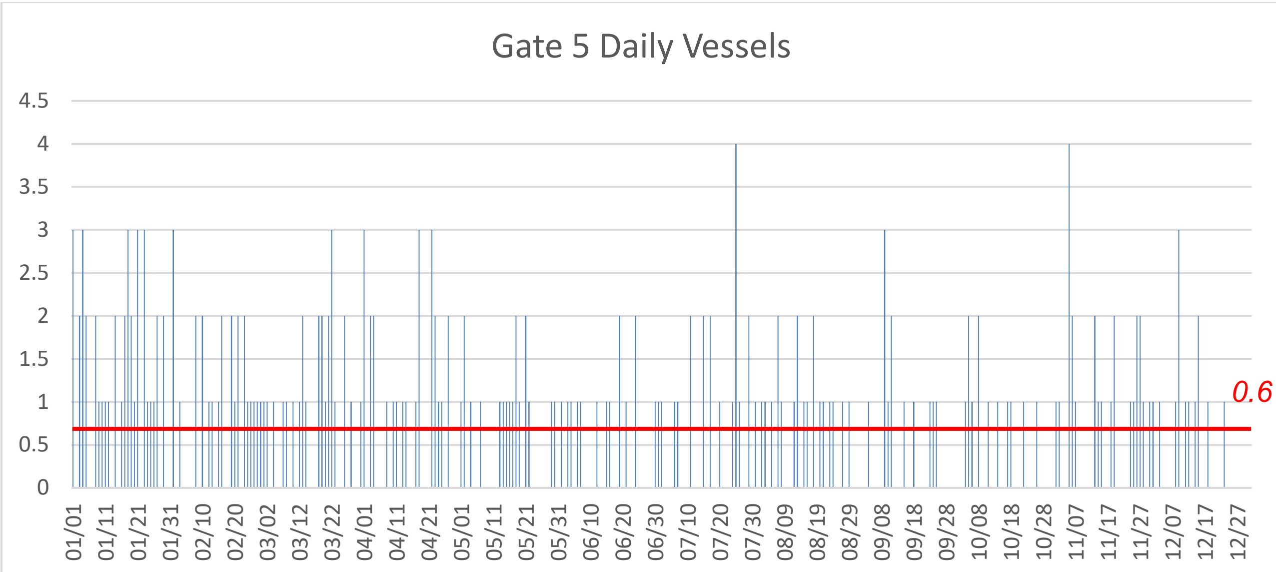


Figure C-6. Route 6 Daily Vessel Numbers (Red: Average of 0.52 Vessels per Day)

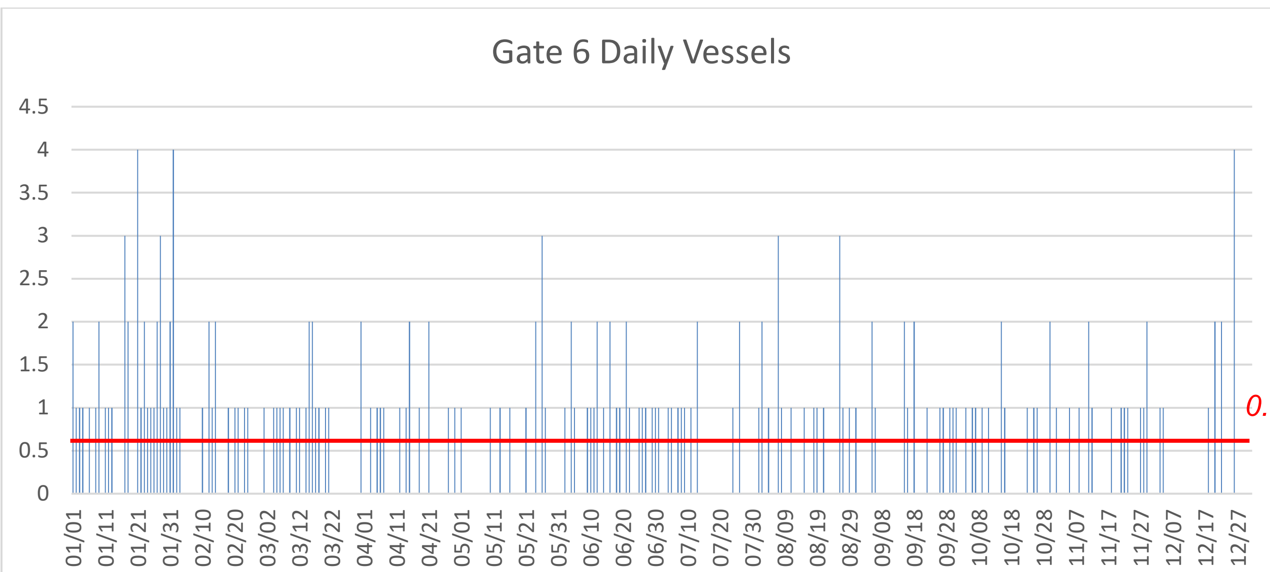
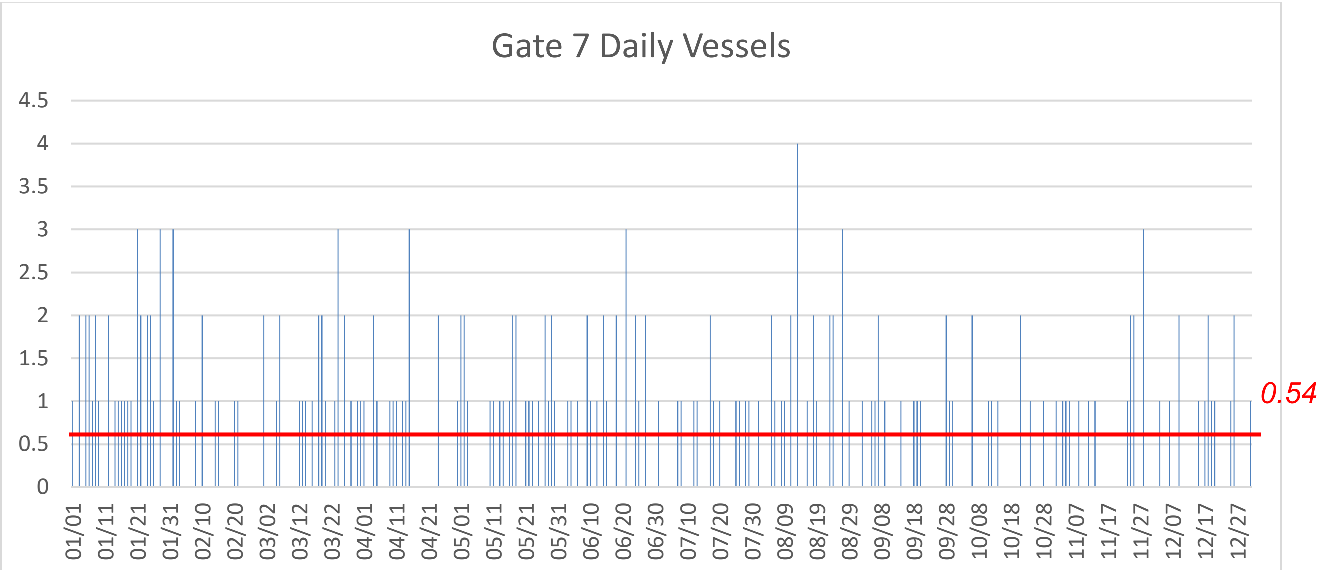


Figure C-7. Route 7 Daily Vessel Numbers (Red: Average of 0.54 Vessels per Day)



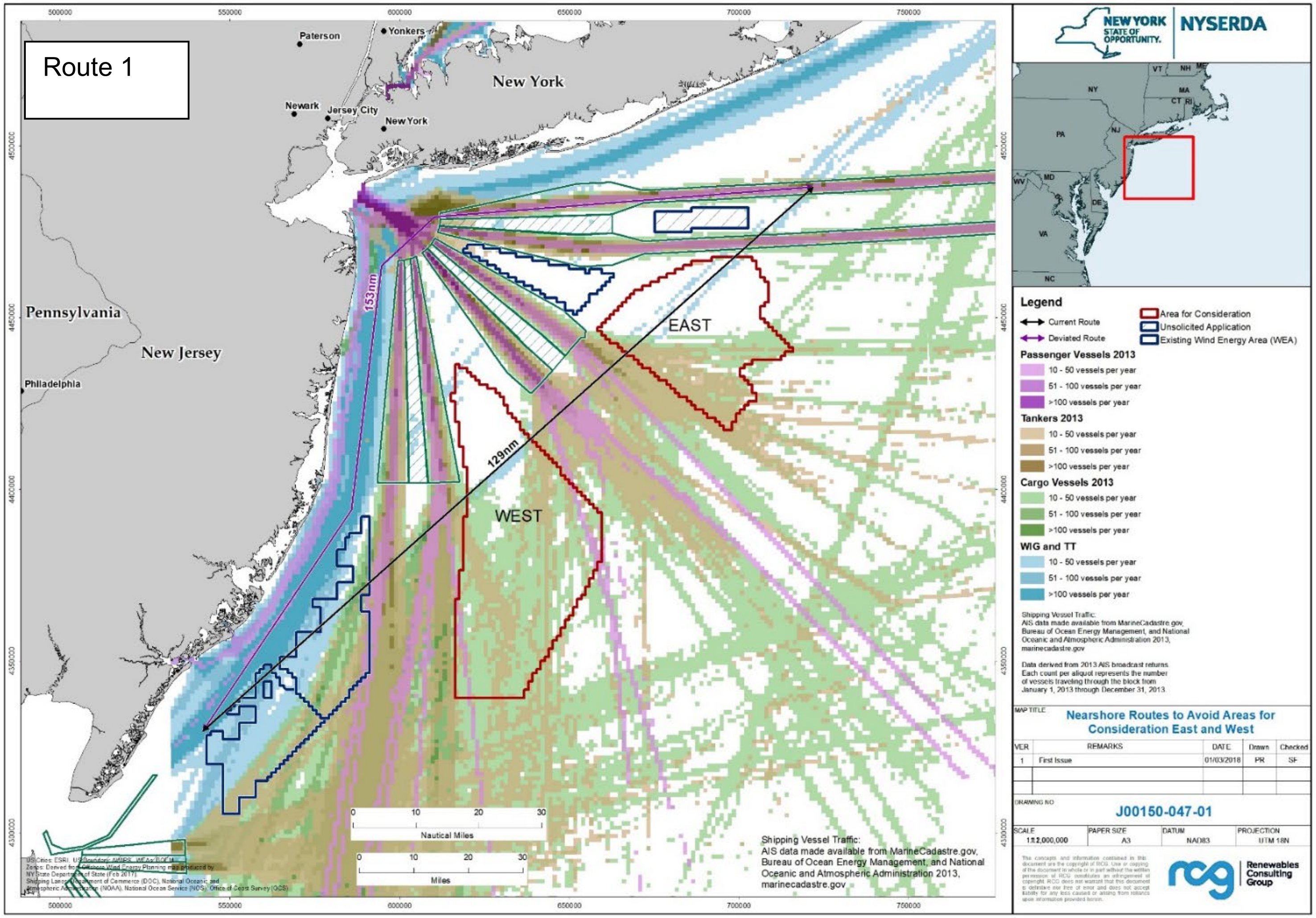
Appendix D. European Environmental Statements Review

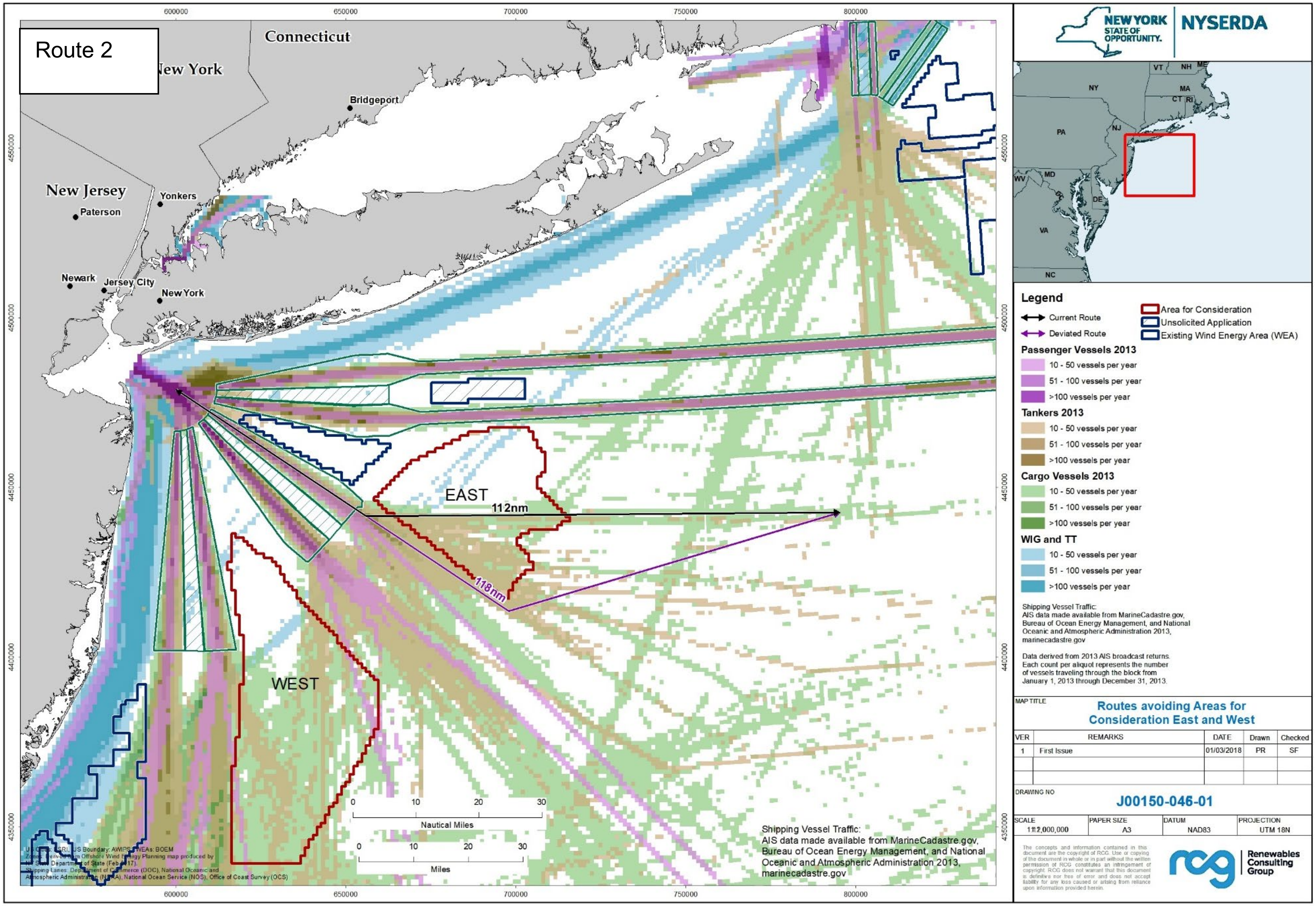
Table D-1. Key ES findings on vessel rerouting around UK offshore wind farms

Offshore wind farm	Vessels affected per day	Largest deviation (NM)	% increase on total journey time	Increase in sailing time (min)	ES significance given	Source
Navitus Bay	n/d	2.31	n/d	13	Tolerable	(Anatec, 2014)
Burbo Bank Extension	1	n/d	n/d	n/d	Insignificant	(DONG Energy, 2013)
East Anglia 1	1-3	3	n/d	n/d	Moderate Significant Impact	(Environmental Resource Management, 2012)
East Anglia 3	1-5	1-1.6	3-4	n/d	n/d	(Anatec, 2015)
Hornsea Project One	1-4	2.28	2.9	n/d	Minor Significance	(SMart Wind, 2013)
Rampion	n/d	8.5	4	64	Potential Impacts	(E.ON Climate & Renewables, 2012)
Triton Knoll	n/d	4.9	2.43	23	n/d	(Strategic Marine Services, 2011)
Walney Extension	1	n/d	n/d	n/d	Insignificant	(DONG Energy, 2013)
Galloper	4	2.2	<1%	10	Minor Adverse Impact	(Galloper Wind Farm Ltd. , 2011)

Appendix E. Deviation Routes and Distances

E.1 Scenario 1—Entire Area for Consideration




Route 2
Connecticut
New York
New Jersey
Bridgeport
Yonkers
Paterson
Newark
Jersey City
New York
EAST
WEST
112nm
118nm
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
NY
VT
NH
ME
MA
CT
RI
PA
NJ
MD
DE
WV
VA
NC
Legend
Current Route
Deviated Route
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
MAP TITLE
Routes avoiding Areas for Consideration East and West
VER
REMARKS
DATE
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First Issue
01/03/2018
PR
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SCALE
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A3
DATUM
NAD83
PROJECTION
UTM 18N
Renewables Consulting Group
0 10 20 30
Nautical Miles
0 10 20 30
Miles
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
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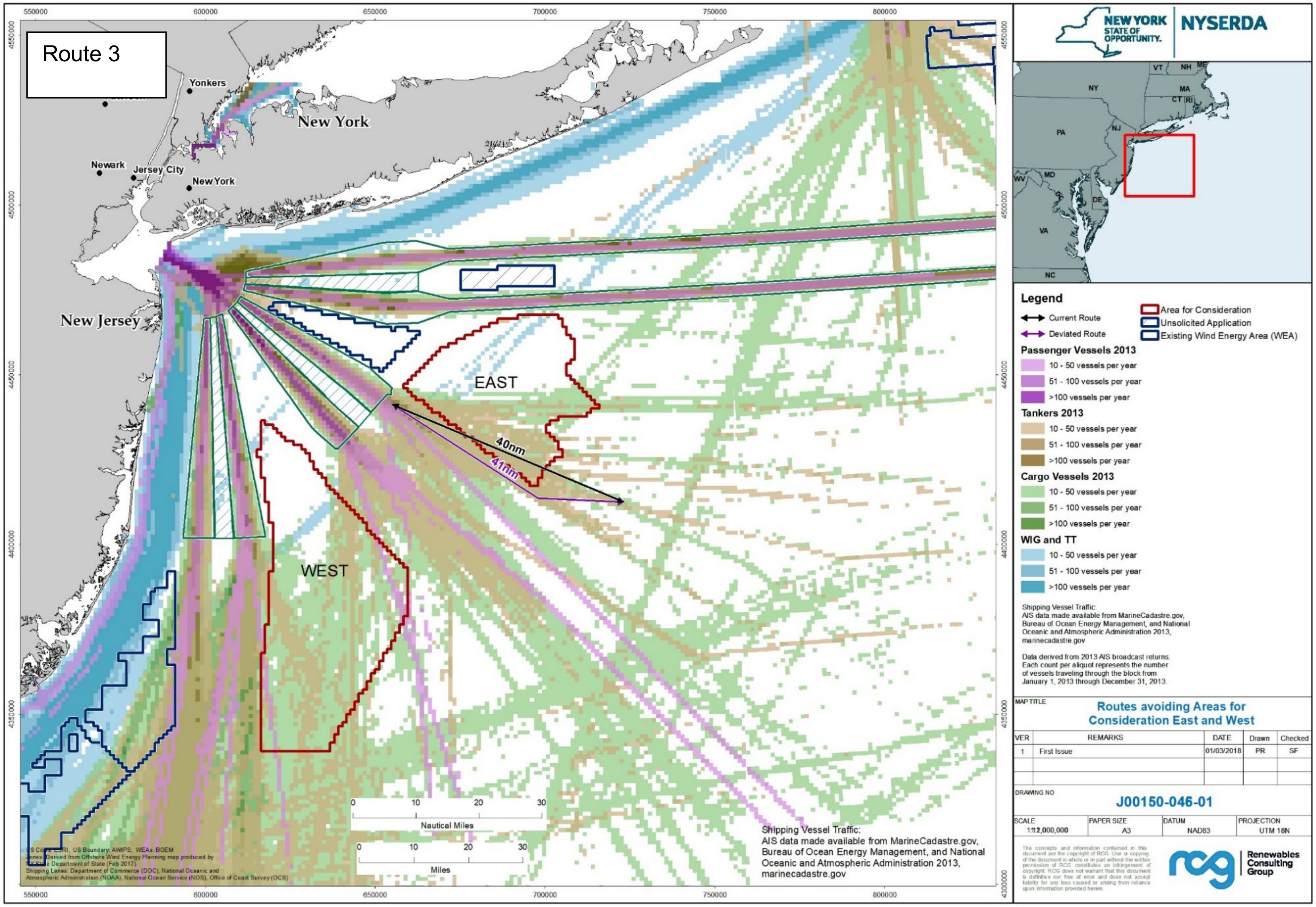
700000
750000
800000
4550000
4500000
4450000
4400000
4350000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Yonkers
New York
Newark
Jersey City
New York
New Jersey
EAST
WEST
40nm
41nm
Nautical Miles
Miles
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AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
US Boundary: AWIPS, WEAs: BOEM
Department of State (Feb 2017)
Shipping Lanes: Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office of Coast Survey (OCS)
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
Legend
Current Route
Deviated Route
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
MAP TITLE
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VER | REMARKS | DATE | Drawn | Checked
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DRAWING NO
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SCALE 1:2,000,000
PAPER SIZE A3
DATUM NAD83
PROJECTION UTM 18N
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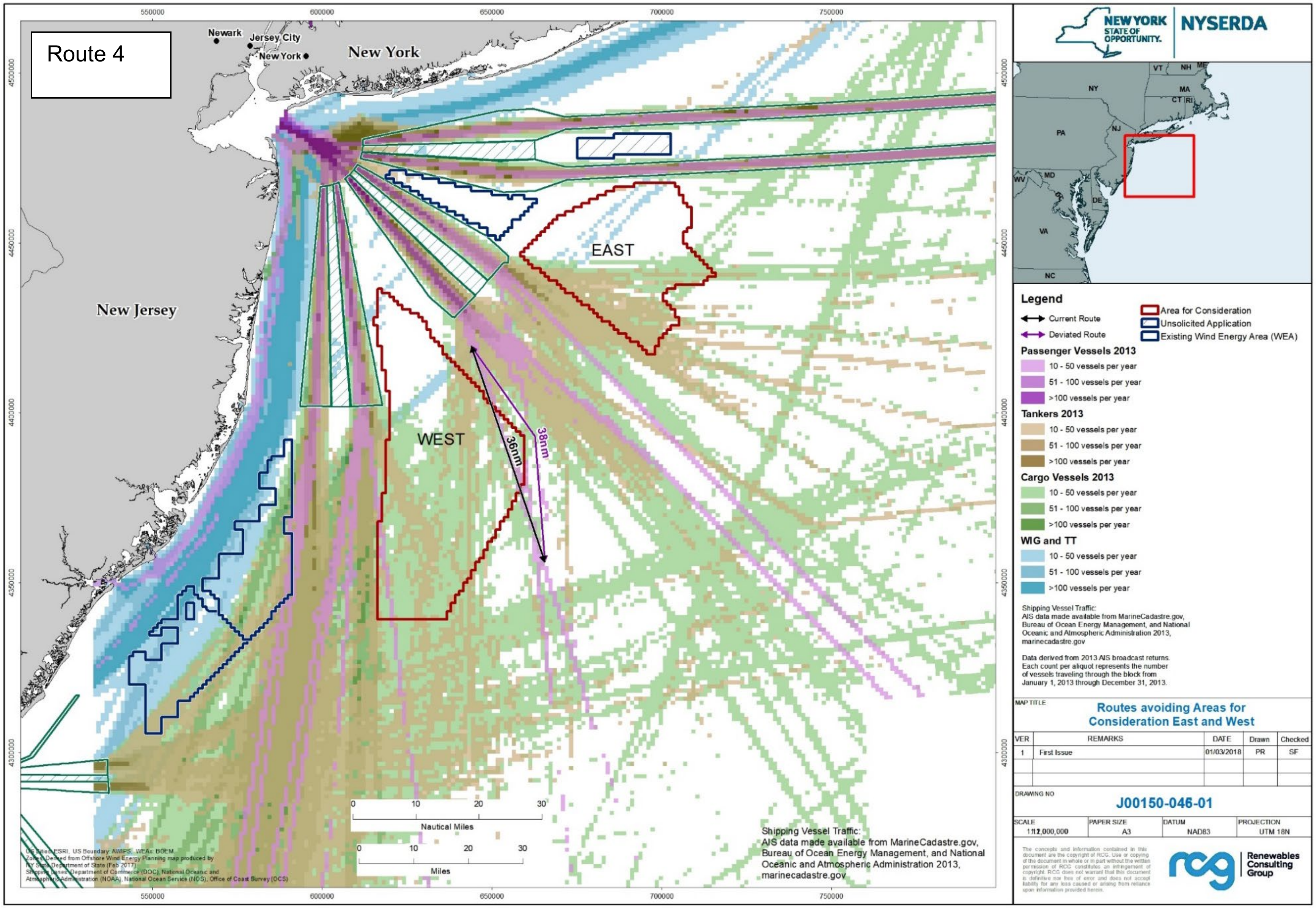
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Jersey City
New York
New York
New Jersey
EAST
WEST
36nm
38nm
10
20
30
Nautical Miles
0
10
20
30
Miles
US Cities: ESRI, US Boundary: AWIPS, WEAs: BOEM
Zones: Derived from Offshore Wind Energy Planning map produced by NY State Department of State (Feb 2017)
Shipping Lanes: Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office of Coast Survey (OCS)
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
550000
600000
650000
700000
750000
4500000
4450000
4400000
4350000
4300000
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
VT
NH
ME
NY
MA
CT
RI
PA
NJ
MD
WV
DE
VA
NC
Legend
Current Route
Deviated Route
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
MAP TITLE
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DATUM NAD83
PROJECTION UTM 18N
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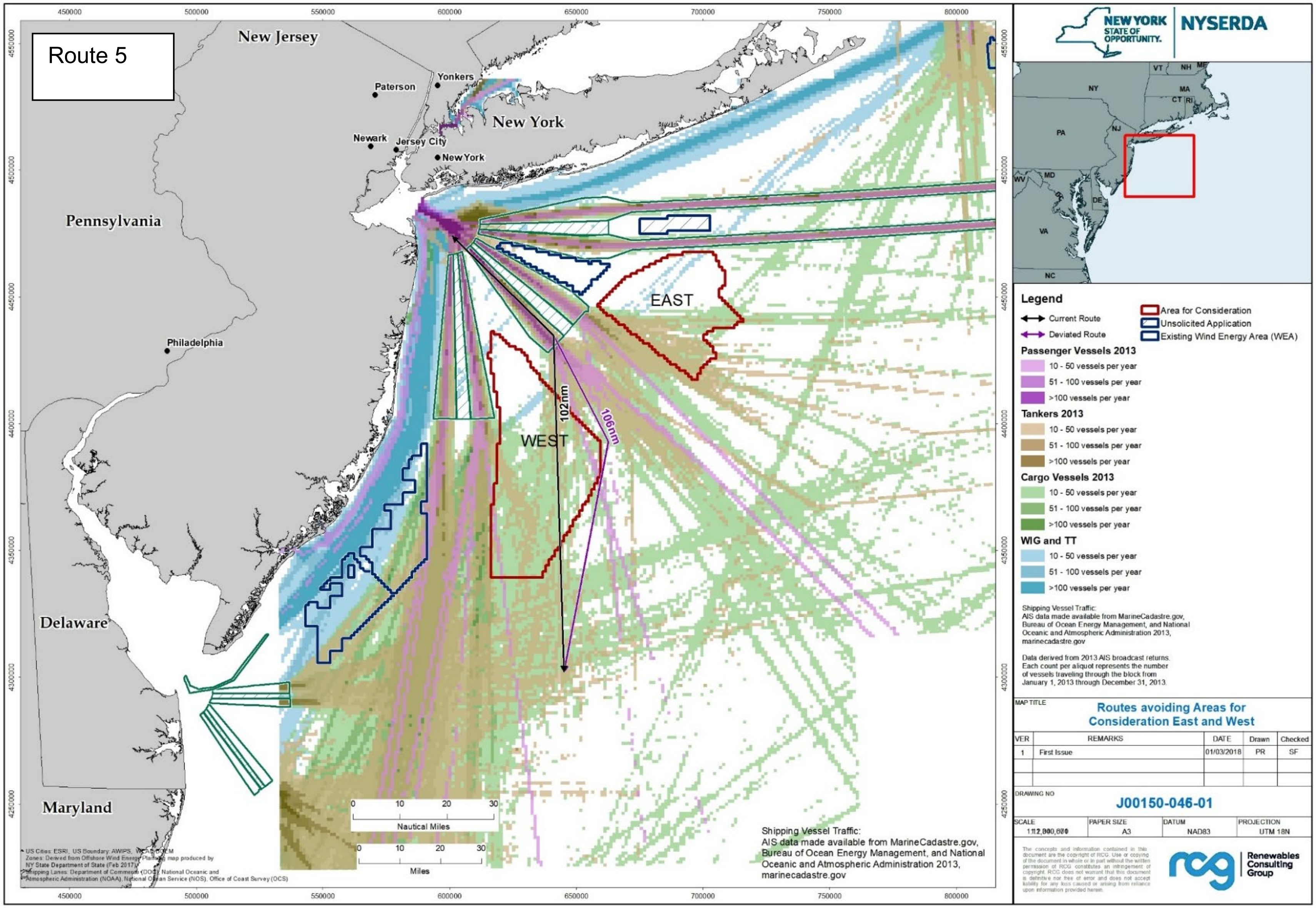

Route 5
New Jersey
New York
Pennsylvania
Delaware
Maryland
Paterson
Yonkers
Newark
Jersey City
New York
Philadelphia
EAST
WEST
102nm
106nm
0 10 20 30
Nautical Miles
0 10 20 30
Miles
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
US Cities: ESRI, US Boundary: AWIPS, WEAS: BOEM
Zones: Derived from Offshore Wind Energy Planning map produced by NY State Department of State (Feb 2017)
Shipping Lanes: Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office of Coast Survey (OCS)
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
NY
VT
NH
ME
MA
CT
RI
PA
NJ
MD
DE
WV
VA
NC
Legend
Current Route
Deviated Route
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
MAP TITLE
Routes avoiding Areas for Consideration East and West
VER | REMARKS | DATE | Drawn | Checked
1 | First Issue | 01/03/2018 | PR | SF
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J00150-046-01
SCALE | PAPER SIZE A3 | DATUM NAD83 | PROJECTION UTM 18N
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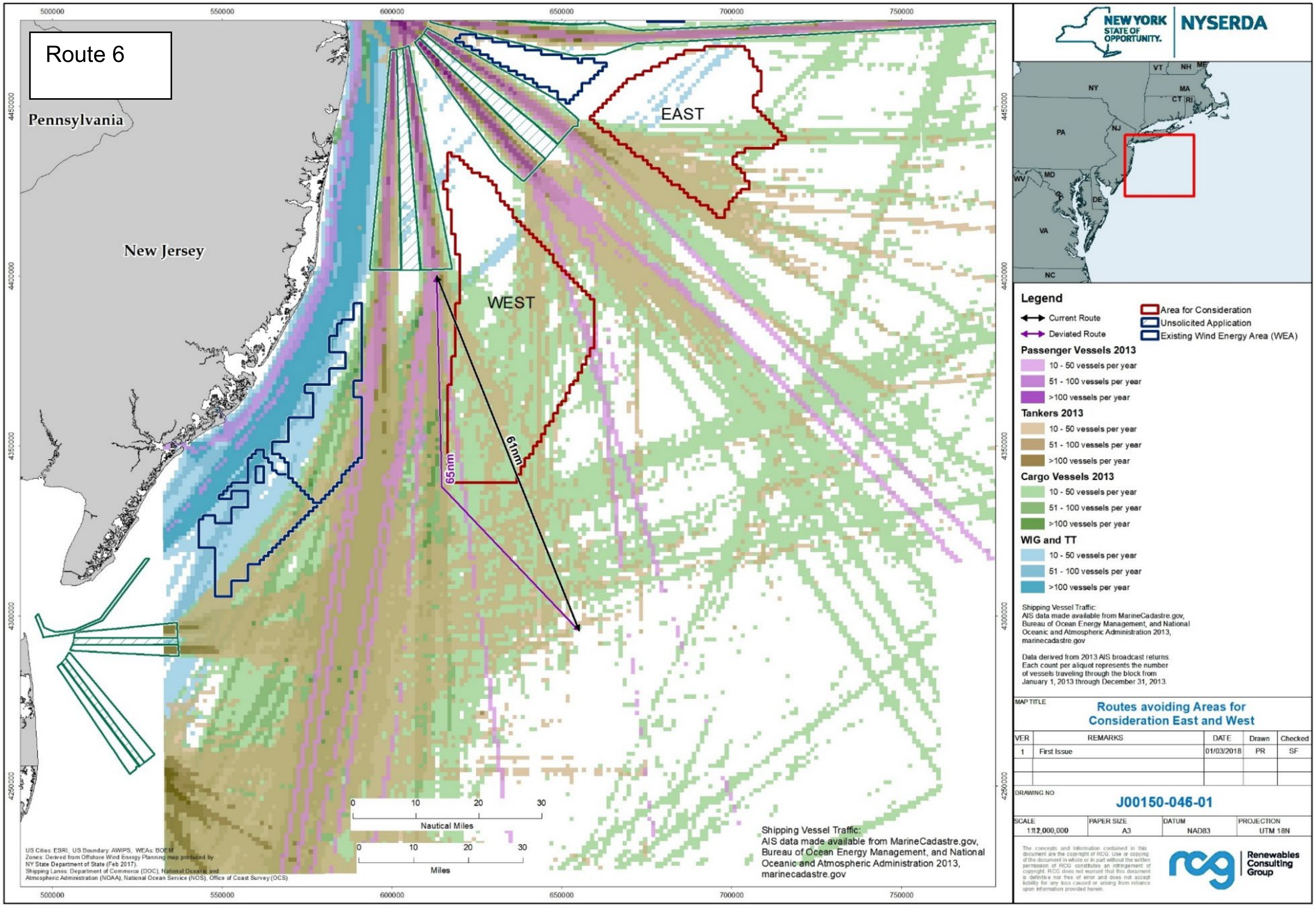
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Pennsylvania
New Jersey
EAST
WEST
65nm
61nm
Nautical Miles
Miles
US Cities: ESRI. US Boundary: AWIPS. WEAs: BOEM
Zones: Derived from Offshore Wind Energy Planning map produced by NY State Department of State (Feb 2017).
Shipping Lanes: Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office of Coast Survey (OCS)
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
Legend
Current Route
Deviated Route
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
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MAP TITLE
Routes avoiding Areas for Consideration East and West
VER | REMARKS | DATE | Drawn | Checked
1 | First Issue | 01/03/2018 | PR | SF
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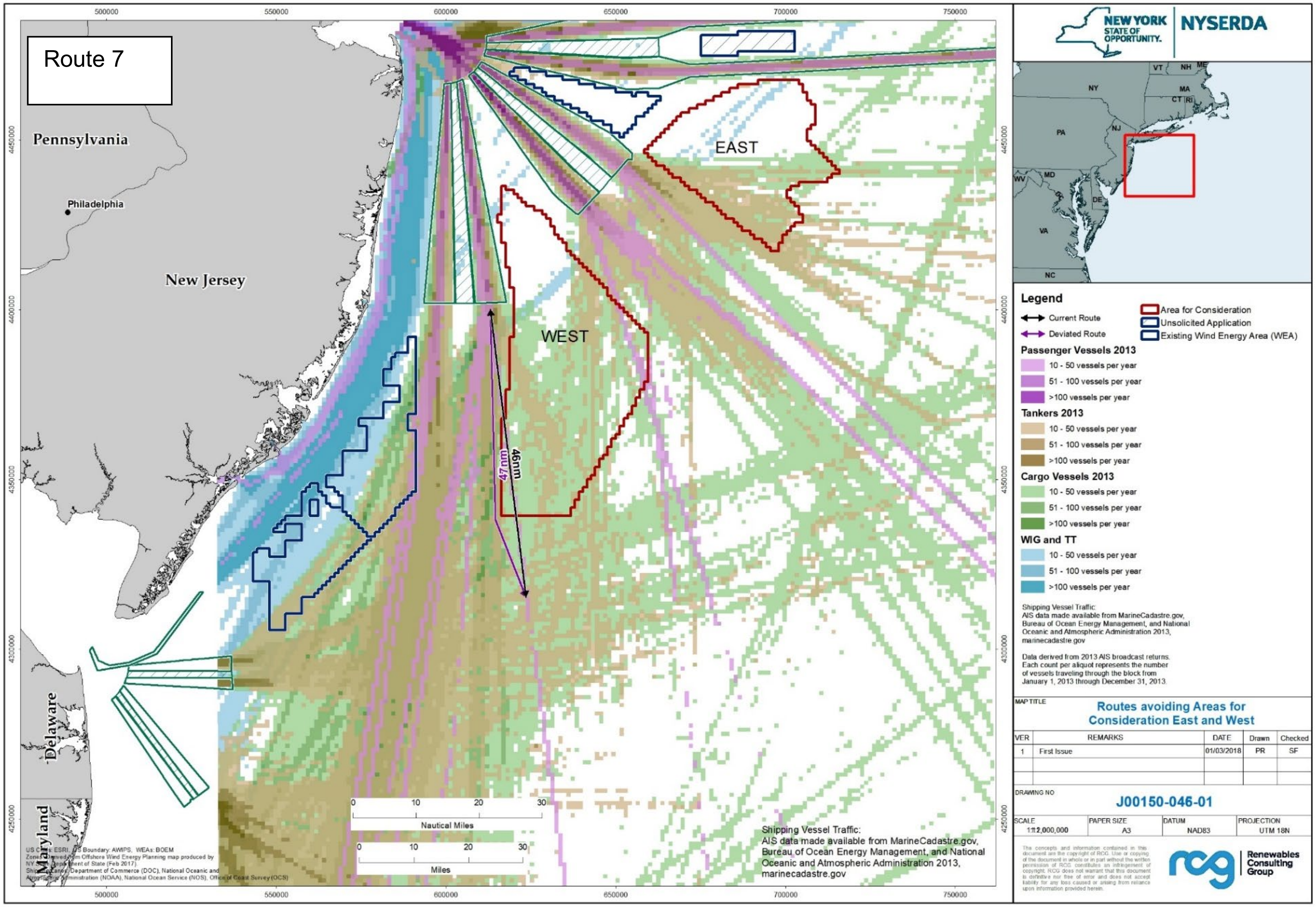
PROJECTION UTM 18N
Renewables Consulting Group


Route 7
Pennsylvania
Philadelphia
New Jersey
Delaware
Maryland
EAST
WEST
47nm
46nm
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
Legend
Current Route
Deviated Route
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Shipping Vessel Traffic: AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
MAP TITLE
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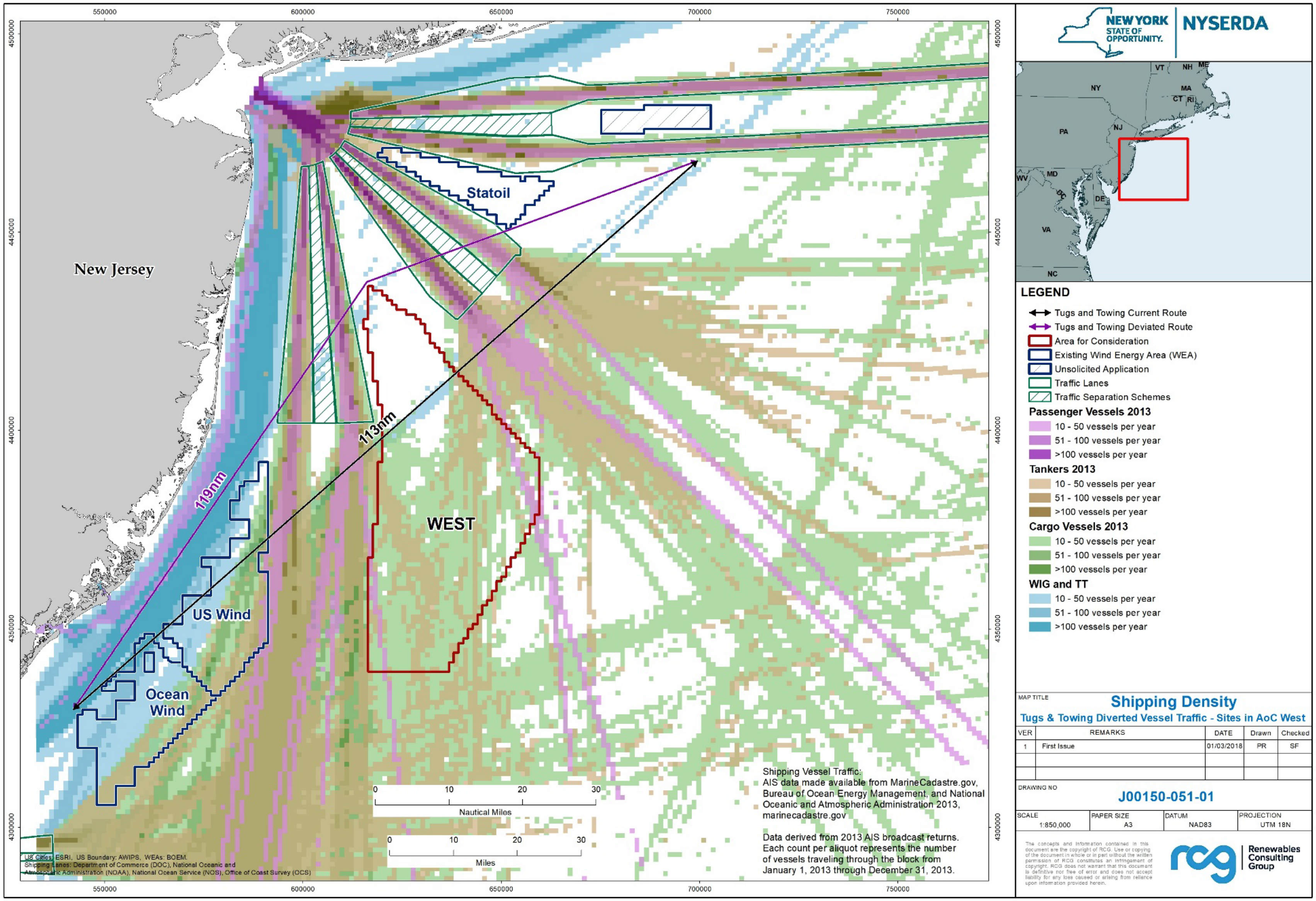
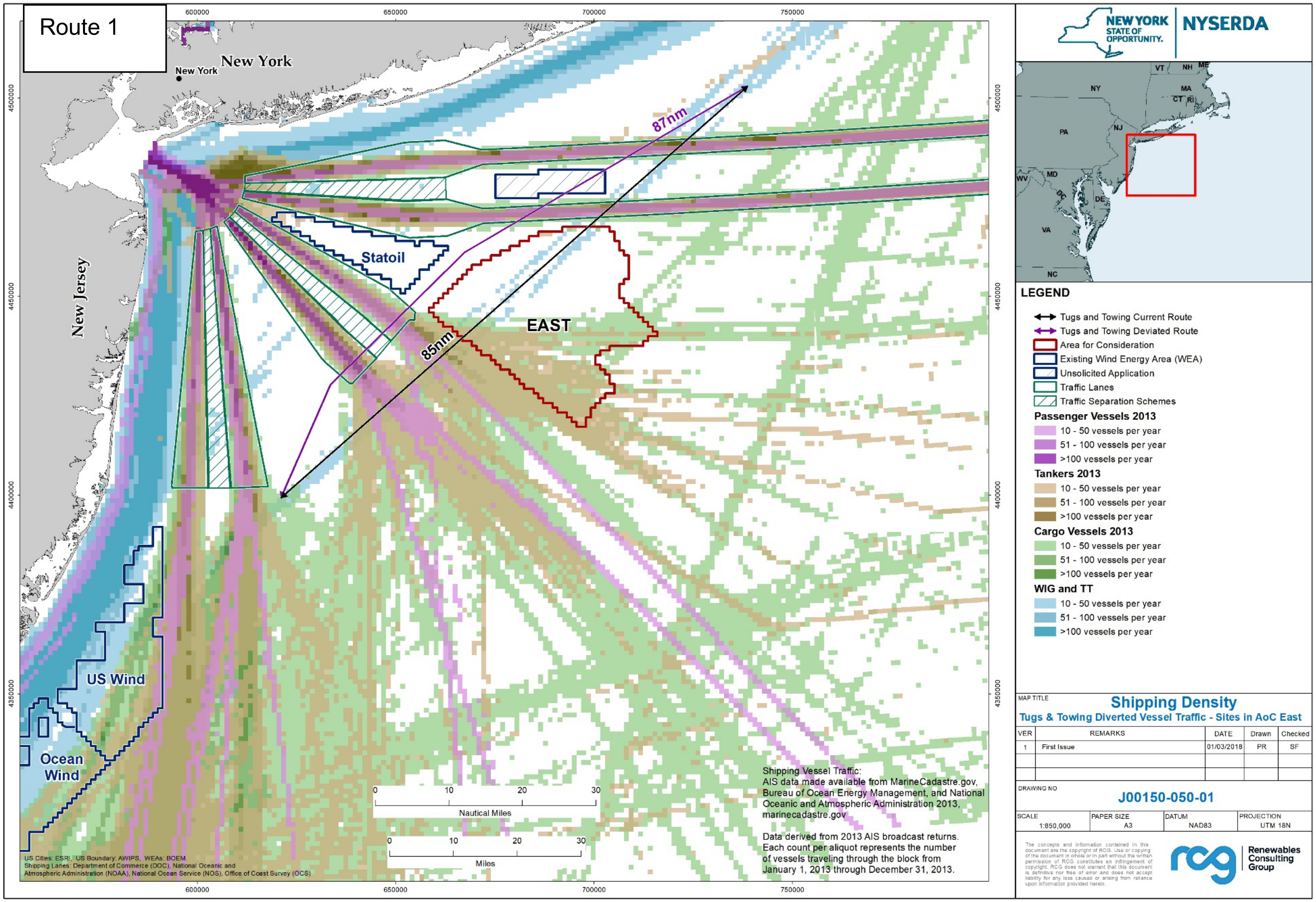
SCALE 1:1,2,000,000
PAPER SIZE A3
DATUM NAD83
PROJECTION UTM 18N
Renewables Consulting Group
Nautical Miles
Miles
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov

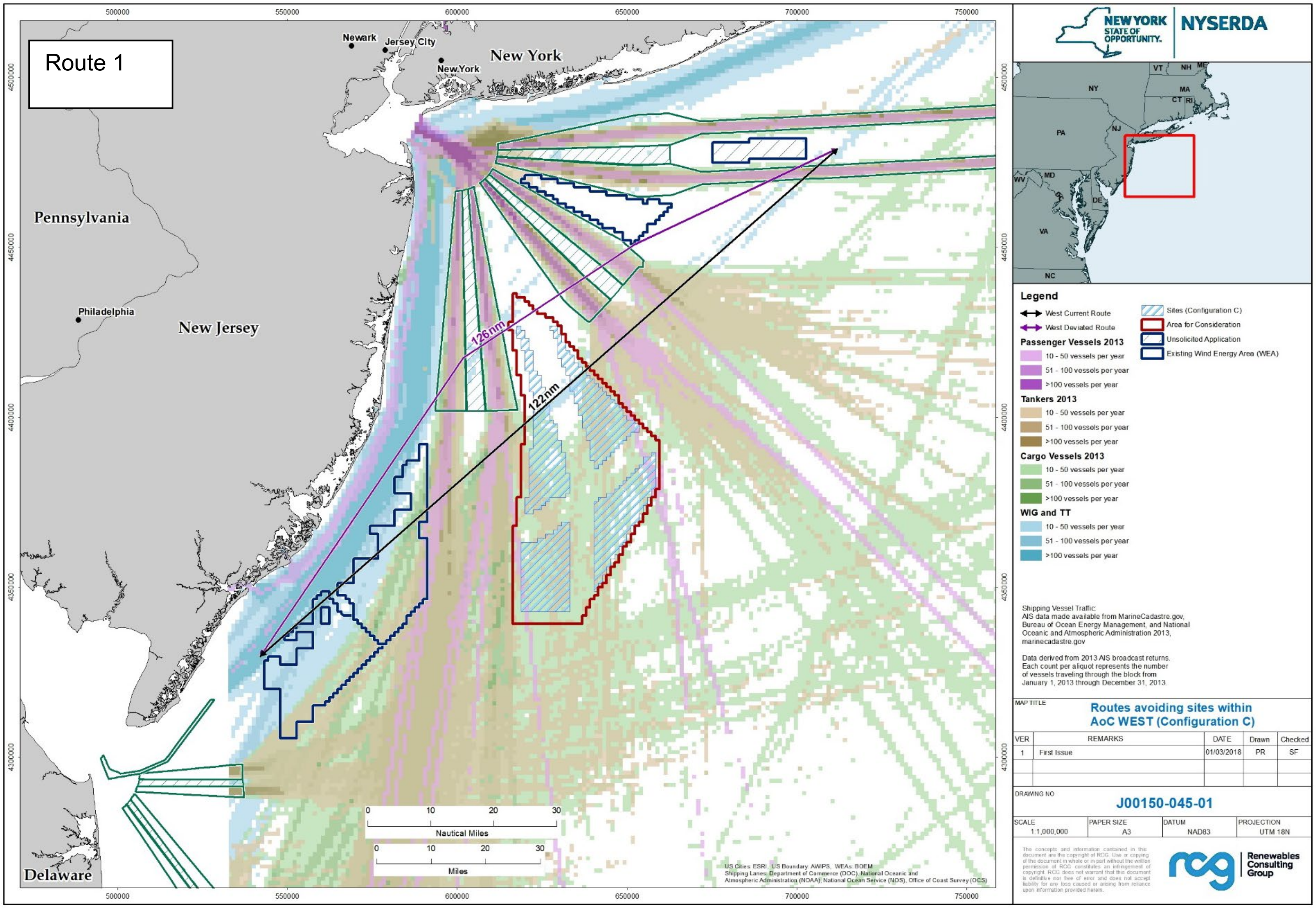
E.2 Scenario 2—Western Area for Consideration Only

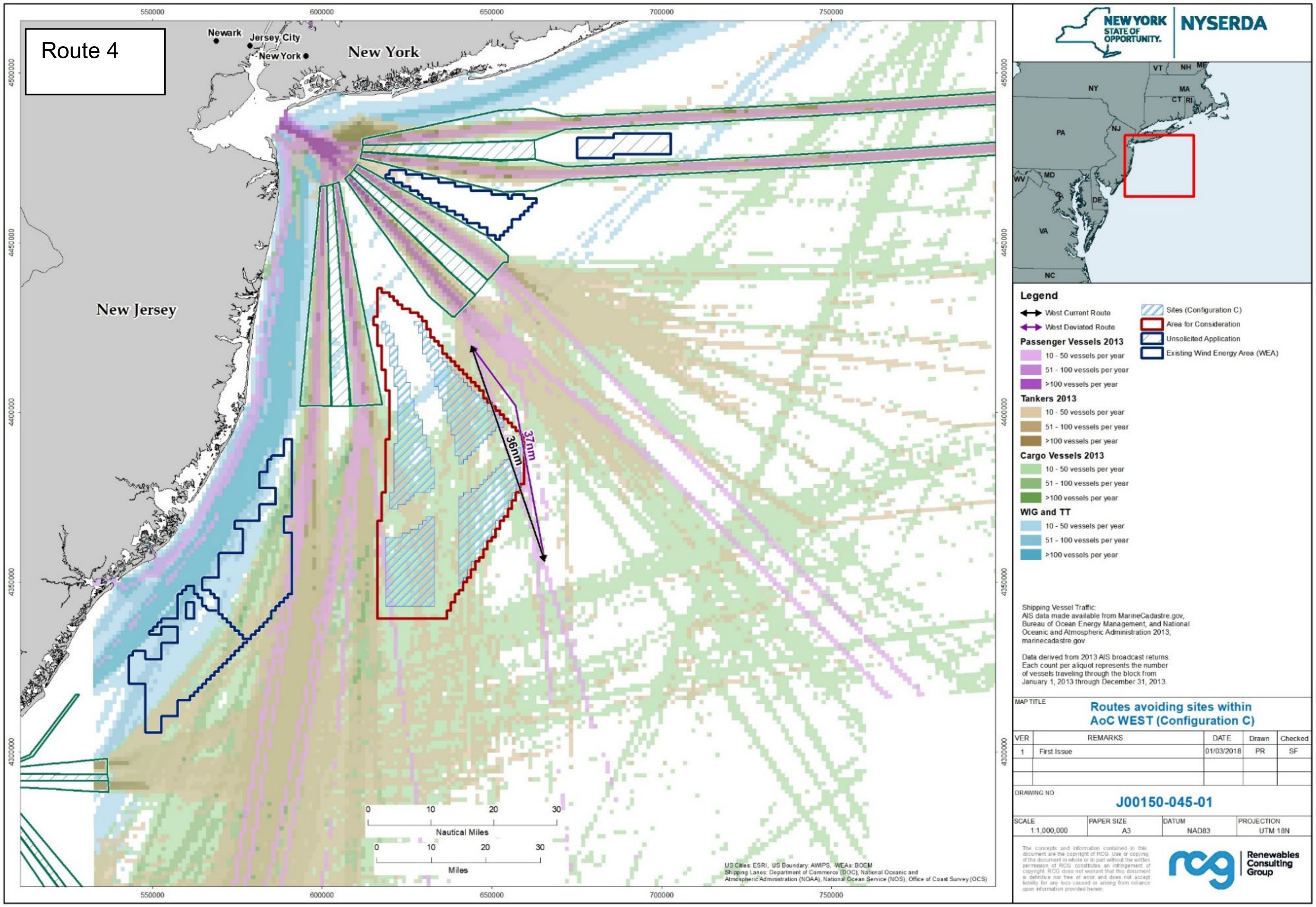


E.3 Scenario 3—Eastern Area for Consideration Only

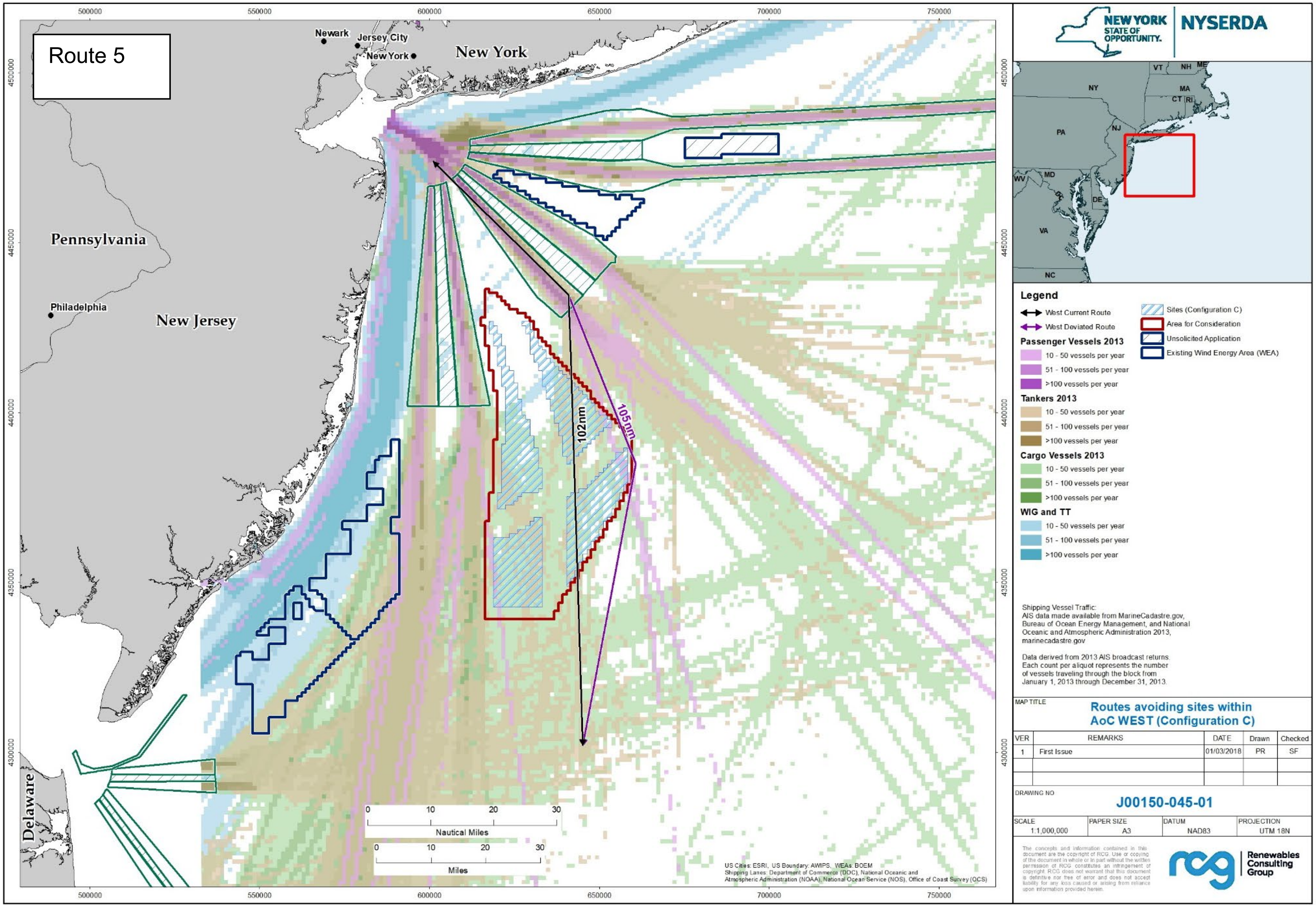


E.4 Scenario 4—Four Sites within Western Area for Consideration





Route 4
Newark
Jersey City
New York
New York
New Jersey
36nm
37nm
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
VT
NH
ME
NY
MA
CT
RI
PA
NJ
MD
WV
DE
VA
NC
Legend
West Current Route
West Deviated Route
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Sites (Configuration C)
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
Nautical Miles
Miles
0
10
20
30
US Cities: ESRI, US Boundary: AWIPS, WEAs: BOEM
Shipping Lanes: Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office of Coast Survey (OCS)
550000
600000
650000
700000
750000
4500000
4450000
4400000
4350000
4300000
MAP TITLE
Routes avoiding sites within AoC WEST (Configuration C)
VER
REMARKS
DATE
Drawn
Checked
1
First Issue
01/03/2018
PR
SF
DRAWING NO
J00150-045-01
SCALE
1:1,000,000
PAPER SIZE
A3
DATUM
NAD83
PROJECTION
UTM 18N
rcg
Renewables Consulting Group



Route 5
Newark
Jersey City
New York
New York
Pennsylvania
Philadelphia
New Jersey
Delaware
102nm
105nm
500000
550000
600000
650000
700000
750000
4300000
4350000
4400000
4450000
4500000
Nautical Miles
Miles
0 10 20 30
US Cities: ESRI, US Boundary: AWIPS, WEAs: BOEM
Shipping Lanes: Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office of Coast Survey (OCS)
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
VT
NH
ME
NY
MA
CT
RI
PA
NJ
MD
DE
WV
VA
NC
Legend
West Current Route
West Deviated Route
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Sites (Configuration C)
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
MAP TITLE
Routes avoiding sites within AoC WEST (Configuration C)
VER | REMARKS | DATE | Drawn | Checked
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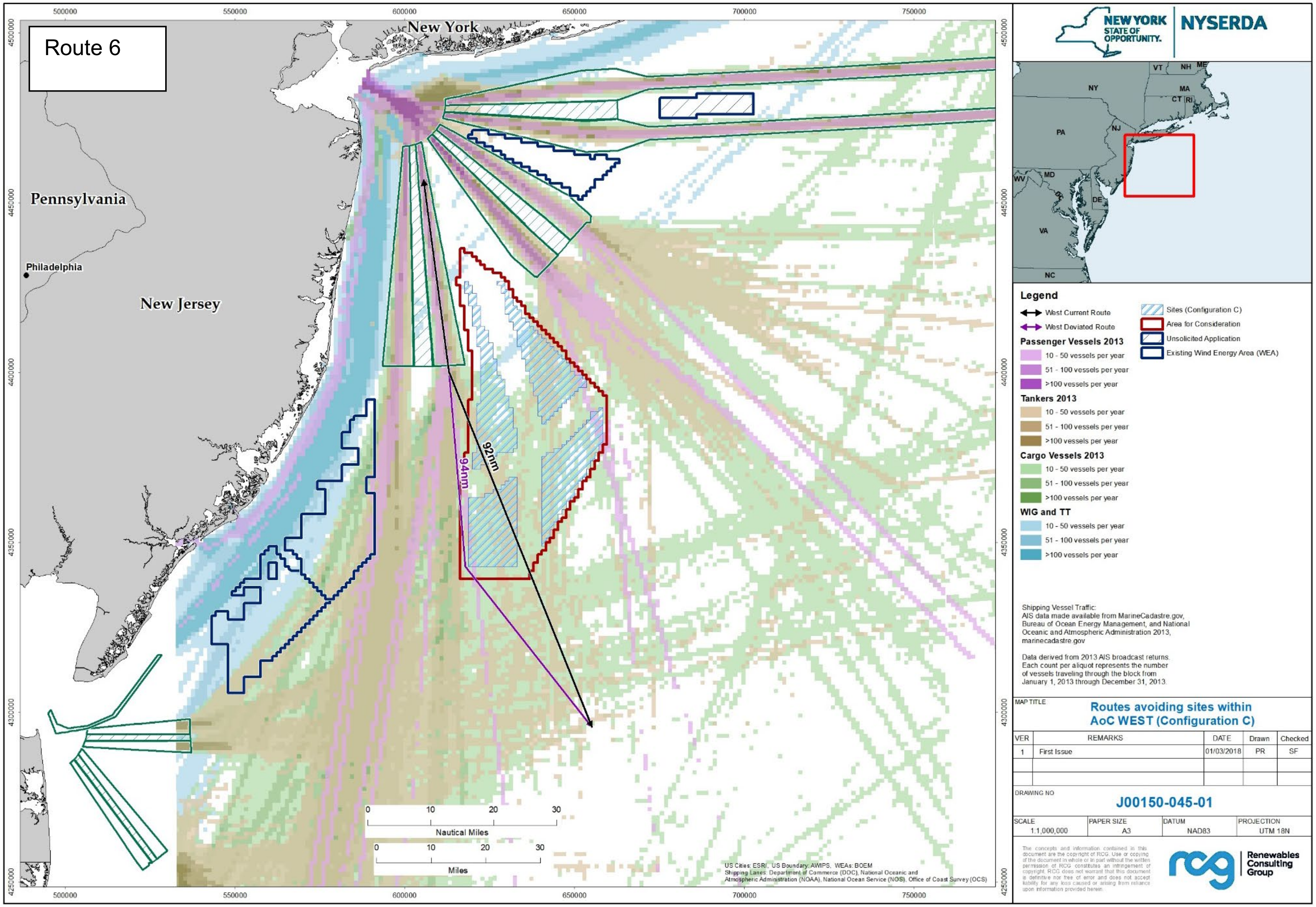
PROJECTION UTM 18N
rcg Renewables Consulting Group



Route 6
New York
Pennsylvania
Philadelphia
New Jersey
92nm
94nm
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
Legend
West Current Route
West Deviated Route
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Sites (Configuration C)
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
MAP TITLE
Routes avoiding sites within AoC WEST (Configuration C)
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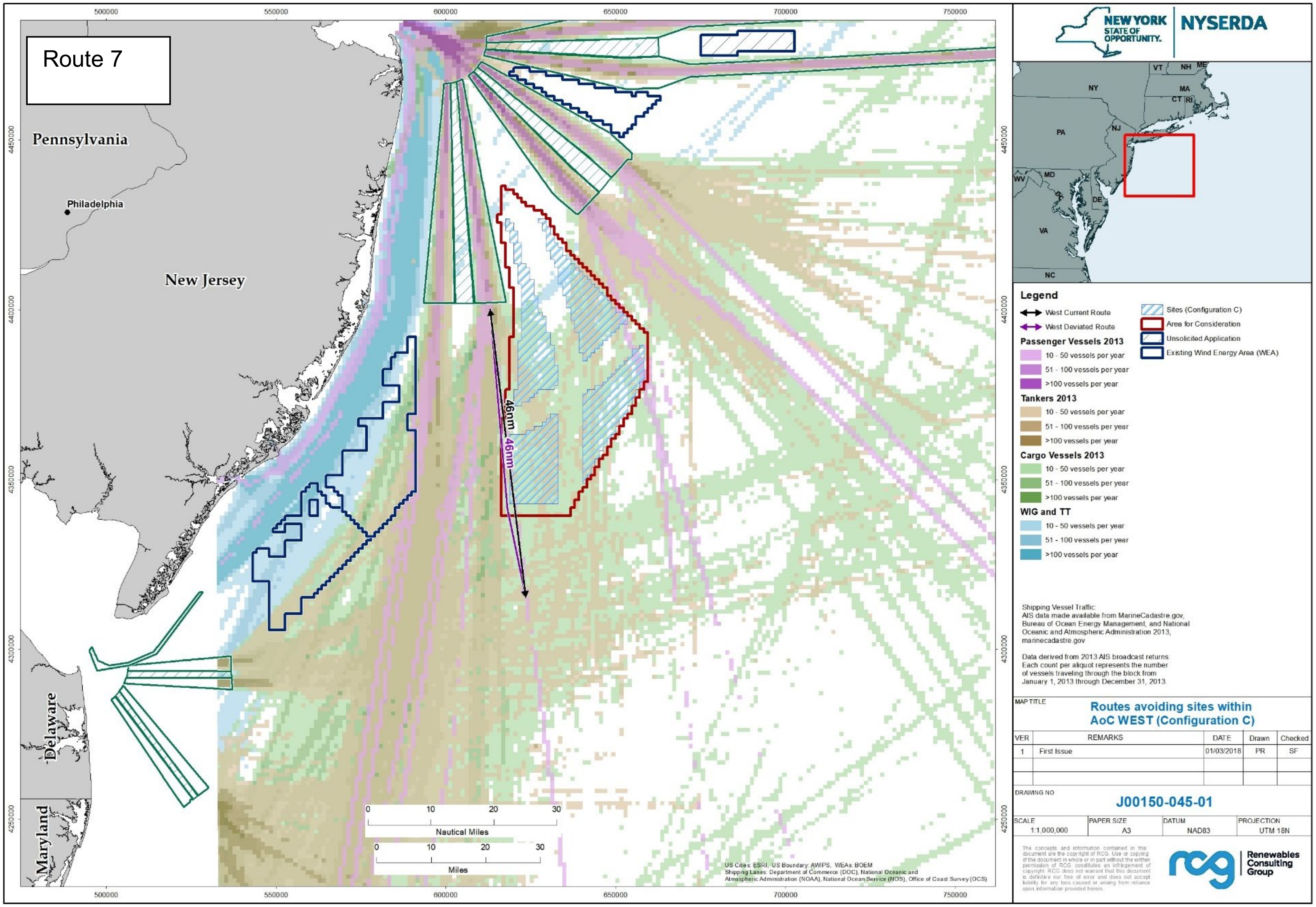
PROJECTION UTM 18N
Nautical Miles
Miles
Renewables Consulting Group


Route 7
Pennsylvania
Philadelphia
New Jersey
Delaware
Maryland
46nm
46nm
NEW YORK STATE OF OPPORTUNITY.
NYSERDA
NY
VT
NH
ME
MA
CT
RI
PA
NJ
WV
MD
DE
VA
NC
Legend
West Current Route
West Deviated Route
Passenger Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Tankers 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Cargo Vessels 2013
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
WIG and TT
10 - 50 vessels per year
51 - 100 vessels per year
>100 vessels per year
Sites (Configuration C)
Area for Consideration
Unsolicited Application
Existing Wind Energy Area (WEA)
Shipping Vessel Traffic:
AIS data made available from MarineCadastre.gov, Bureau of Ocean Energy Management, and National Oceanic and Atmospheric Administration 2013, marinecadastre.gov
Data derived from 2013 AIS broadcast returns. Each count per aliquot represents the number of vessels traveling through the block from January 1, 2013 through December 31, 2013.
MAP TITLE
Routes avoiding sites within AoC WEST (Configuration C)
VER | REMARKS | DATE | Drawn | Checked
1 | First Issue | 01/03/2018 | PR | SF
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PAPER SIZE A3
DATUM NAD83
PROJECTION UTM 18N
rcg Renewables Consulting Group
Nautical Miles
Miles
US Cities: ESRI, US Boundary: AWIPS, WEAs: BOEM
Shipping Lanes: Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Office of Coast Survey (OCS)

Appendix F. Results Tables

F.1 Scenario 1—Entire Area for Consideration

Table F-1. Fuel Costs ($/trip) Associated with the Reroutings for Each Vessel Type

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	183	2741	5574	274	1174	2842	2632	5109	5370	107	701	701
2	46	685	1393	69	294	710	658	1277	1342	27	175	175
3	8	114	232	11	49	118	110	213	224	4	29	29
4	15	228	464	23	98	237	219	426	447	9	58	58
5	30	457	929	46	196	474	439	851	895	18	117	117
6	30	457	929	46	196	474	439	851	895	18	117	117
7	8	114	232	11	49	118	110	213	224	4	29	29

Table F-2. Direct Economic Costs (2017$/trip) of Vessel Rerouting

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	664	3270	6638	823	1907	3575	14419	21731	21992	643	1673	1673
2	166	818	1659	206	477	894	3605	5433	5498	161	418	418
3	28	136	277	34	79	149	601	905	916	27	70	70
4	55	273	553	69	159	298	1202	1811	1833	54	139	139
5	111	545	1106	137	318	596	2403	3622	3665	107	279	279
6	111	545	1106	137	318	596	2403	3622	3665	107	279	279
7	28	136	277	34	79	149	601	905	916	27	70	70

Table F-3. Total Economic Costs ($/yr) per Vessel Type

Route	Cargo			Tanker			Passenger			Tugs and Towing		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0	0	0	0	0	0	0	0	0	18636	48504	48504
2	13278	65406	132760	11318	26221	49159	7209	10865	10996	1767	4599	4599
3	2988	14716	29871	2812	6515	12215	1802	2716	2749	27	70	70
4	3541	17442	35403	2607	6039	11322	55272	83302	84301	54	139	139
5	13721	67587	137185	11112	25744	48266	19225	28975	29322	1178	3066	3066
6	13499	66497	134972	7683	17798	33369	16822	25353	25657	428	1115	1115
7	3679	18123	36785	1406	3258	6108	15020	22636	22908	0	0	0

Table F-4. Total Social Costs ($/yr) per Vessel Type

Route	Cargo			Tanker			Passenger			Tugs and Towing		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0	0	0	0	0	0	0	0	0	4,529	93,374	156,987
2	5,354	251,983	861,426	5,522	74,204	301,941	1,928	11,740	20,746	429	8,854	14,887
3	1,205	56,696	193,821	1,372	18,438	75,028	482	2,935	5,187	7	134	226
4	1,428	67,195	229,714	1,272	17,089	69,538	14,778	90,007	159,053	13	268	451
5	5,533	260,382	890,141	5,421	72,854	296,451	5,140	31,307	55,323	286	5,903	9,924
6	5,443	256,182	875,784	3,748	50,369	204,954	4,498	27,394	48,407	104	2,147	3,609
7	1,484	69,820	238,687	686	9,219	37,514	4,016	24,459	43,221	0	0	0

Table F-5. Emissions Associated with Each Rerouting

Route	Additional NO_X Emissions (tons/yr)			Additional SO_2 Emissions (tons/yr)			Additional PM_{10} Emissions (tons/yr)			Additional CO_2 Emissions (tons/yr)		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	1	4	4	0	3	3	0	0	0	28	184	184
2	2	16	33	1	11	22	0	2	3	82	685	1409
3	0	4	8	0	2	5	0	0	1	19	154	322
4	3	17	13	2	5	8	0	1	1	108	345	539
5	2	17	34	2	12	23	0	2	3	102	732	1471
6	2	15	31	1	10	21	0	1	3	85	664	1331
7	1	5	9	1	3	6	0	0	1	38	204	375

F.2 Scenario 2—Western Area for Consideration Only

Table F-6. Fuel Costs ($/trip) Associated with the Reroutings for Each Vessel Type

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	46	685	1393	69	294	710	658	1277	1342	27	175	175
4	15	228	464	23	98	237	219	426	447	9	58	58
5	30	457	929	46	196	474	439	851	895	18	117	117
6	30	457	929	46	196	474	439	851	895	18	117	117
7	8	114	232	11	49	118	110	213	895	4	29	29

Table F-7. Direct Economic Costs (2017$/trip) of Vessel Rerouting

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	166	818	1659	206	477	894	3605	5433	5498	161	418	418
4	55	273	553	69	159	298	1202	1811	1833	54	139	139
5	111	545	1106	137	318	596	2403	3622	3665	107	279	279
6	111	545	1106	137	318	596	2403	3622	3665	107	279	279
7	28	136	277	34	79	149	601	905	3665	27	70	70

Table F-8. Total Economic Costs ($/yr) per Vessel Type

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0	0	0	0	0	0	0	0	0	4659	12136	12126
4	3541	17442	35403	2607	6039	11322	55272	83302	84301	54	139	139
5	13721	67587	137185	11112	25744	48266	19225	28975	29322	1178	3069	3066
6	13499	66497	134972	7683	17798	33369	16822	25353	25657	428	1116	1115
7	3679	18123	36785	1406	3258	6108	15020	22636	91632	0	0	0

Table F-9. Total Social Costs ($/yr) per Vessel Type

Route	Cargo			Tanker			Passenger			Tugs and Towing		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0	0	0	0	0	0	0	0	0	1,132	23,343	39,247
4	2,982	90,513	277,126	2,230	21,195	79,475	10,798	82,282	150,933	48	500	683
5	3,965	236,870	842,333	3,588	65,003	277,448	4,705	30,462	63,950	175	5,175	9,196
6	3,336	224,574	811,513	2,297	44,154	189,913	2,756	24,014	44,855	64	1,882	3,344
7	909	61,206	221,171	420	8,082	34,761	2,461	21,441	160,196	0	0	0

Table F-10. Emissions Associated with Each Rerouting

Route	Additional NO_X Emissions (tons/yr)			Additional SO_2 Emissions (tons/yr)			Additional PM_{10} Emissions (tons/yr)			Additional CO_2 Emissions (tons/yr)		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0.16	1.08	1.08	0.11	0.73	0.73	0.02	0.10	0.10	7.02	46.11	46.11
4	2.53	8.05	12.58	1.71	5.43	8.49	0.24	0.77	1.21	108.39	344.81	538.98
5	2.37	17.08	34.33	1.60	11.53	23.18	0.23	1.64	3.30	101.52	731.74	1470.76
6	2.00	15.50	31.07	1.35	10.46	20.98	0.19	1.49	2.99	85.48	663.88	1330.85
7	0.89	4.77	12.32	0.60	3.22	8.32	0.09	0.46	1.18	38.33	204.44	527.62

F.3 Scenario 3—Eastern Area for Consideration Only

Table F-11. Fuel Costs ($/trip) Associated with the Reroutings for Each Vessel Type

Route	Cargo			Tanker			Passenger			Tugs and Towing		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	15	228	464	23	98	237	219	426	447	9	58	58
2	46	685	1,393	69	294	710	658	1,277	1,342	27	175	175
3	8	114	232	11	49	118	110	213	224	4	29	29

Table F-12. Direct Economic Costs (2017$/trip) of Vessel Rerouting

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	55	273	553	69	159	298	1,202	1,811	1,833	54	139	139
2	166	818	1,659	206	477	894	3,605	5,433	5,498	161	418	418
3	28	136	277	34	79	149	601	905	916	27	70	70

Table F-13. Total Economic Costs ($/yr) per Vessel Type

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0	0	0	0	0	0	0	0	0	1,553	4,042	4,042
2	13,278	65,406	132,760	11,318	26,230	49,159	7,209	10,865	10,996	1,767	4,599	4,599
3	2,988	14,716	29,871	2,812	6,518	12,215	1,802	2,716	2,749	27	70	70

Table F-14. Total Social Costs ($/yr) per Vessel Type

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0	0	0	0	0	0	0	0	0	377	7,781	13,082
2	5,354	251,983	861,426	5,522	74,204	301,941	1,928	11,740	20,746	429	8,854	14,887
3	1,205	56,696	193,821	1,372	18,438	75,028	482	2,935	5,187	7	134	226

Table F-15. Emissions Associated with Each Rerouting

	Additional NO_X Emissions (tons/yr)			Additional SO_2 Emissions (tons/yr)			Additional PM_{10} Emissions (tons/yr)			Additional CO_2 Emissions (tons/yr)		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0.05	0.36	0.36	0.04	0.24	0.24	0.01	0.03	0.03	2.34	15.37	15.37
2	1.91	15.99	32.88	1.29	10.80	22.20	0.18	1.54	3.16	82.01	685.00	1408.68
3	0.44	3.61	7.52	0.30	2.43	5.08	0.04	0.35	0.72	19.00	154.48	322.22

F.4 Scenario 4—Four Sites within Western Area for Consideration

Table F-16. Fuel Costs ($/trip) Associated with the Reroutings for Each Vessel Type

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	30	457	929	46	196	474	439	851	895	18	117	117
4	8	114	232	11	49	118	110	213	224	4	29	29
5	23	343	697	34	147	355	329	639	671	13	88	88
6	15	228	464	23	98	237	219	426	447	9	58	58

Table F-17. Direct Economic Costs (2017$/trip) of Vessel Rerouting

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	111	545	1106	137	318	596	2403	3622	3665	107	279	279
4	28	136	277	34	79	149	601	905	916	27	70	70
5	83	409	830	103	238	447	1802	2716	2749	80	209	209
6	55	273	553	69	159	298	1202	1811	1833	54	139	139

Table F-18. Total Economic Costs ($/yr) per Vessel Type

	Cargo			Tanker			Passenger			Tugs and Towing		
Route	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0	0	0	0	0	0	0	0	0	3,106	8,084	8,084
4	1,770	8,721	17,701	1,303	3,019	5,661	27,636	41,651	42,151	27	70	70
5	10,291	50,690	102,889	8,334	19,308	36,199	14,419	21,731	21,992	884	2,300	2,300
6	6,750	33,248	67,486	3,841	8,899	16,684	8,411	12,676	12,828	214	558	558

Table F-19. Total Social Costs ($/yr) per Vessel Type

Route	Cargo Min	Cargo Typical	Cargo Max	Tanker Min	Tanker Typical	Tanker Max	Passenger Min	Passenger Typical	Passenger Max	Tugs and Towing Min	Tugs and Towing Typical	Tugs and Towing Max
1	0	0	0	0	0	0	0	0	0	755	15,562	26,164
4	714	33,598	114,857	636	8,545	34,769	7,389	45,004	79,526	7	134	226
5	4,149	195,286	667,605	4,066	54,641	222,338	3,855	23,480	41,492	215	4,427	7,443
6	2,722	128,091	437,892	1,874	25,184	102,477	2,249	13,697	24,204	52	1,073	1,804

Table F-20. Emissions Associated with Each Rerouting

Route	Additional NO_X Emissions (tons/yr)			Additional SO_2 Emissions (tons/yr)			Additional PM_{10} Emissions (tons/yr)			Additional CO_2 Emissions (tons/yr)		
	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max	Min	Typical	Max
1	0.11	0.72	0.72	0.07	0.48	0.48	0.01	0.07	0.07	4.68	30.74	30.74
4	1.27	4.02	6.29	0.85	2.72	4.25	0.12	0.39	0.60	54.20	172.40	269.49
5	1.78	12.81	25.75	1.20	8.65	17.39	0.17	1.23	2.48	76.14	548.81	1103.07
6	1.00	7.75	15.53	0.67	5.23	10.49	0.10	0.75	1.49	42.74	331.94	665.43

Appendix G. Societal benefits

G.1 Scenario 1—Entire Area for Consideration

Table G-1. Net CO_2 Savings

Year	Total Generation (MWh)	Total CO_2 saved (tons/yr)	Lifecycle emissions (ton CO_2/yr)	Net CO_2 saved (tons/yr)		
				Min	Typical	Max
2024	1,539,671	828,343	20,477.62	807,736.25	806,841.41	805,949.97
2025	3,109,327	1,672,818	41,354.05	1,631,334.77	1,630,439.93	1,629,548.50
2026	3,109,327	1,672,818	41,354.05	1,631,334.77	1,630,439.93	1,629,548.50
2027	4,736,440	2,548,205	62,994.66	2,485,081.18	2,484,186.34	2,483,294.90
2028	6,352,229	3,417,499	84,484.65	3,332,885.55	3,331,990.71	3,331,099.27
2029	7,981,388	4,293,987	106,152.46	4,187,705.39	4,186,810.55	4,185,919.11
2030	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2031	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2032	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2033	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2034	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2035	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2036	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2037	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2038	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2039	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2040	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2041	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2042	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2043	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53

Table G-1 continued

Year	Total Generation (MWh)	Total CO_2 saved (tons/yr)	Lifecycle emissions (ton CO_2/yr)	Net CO_2 saved (tons/yr)		
				Min	Typical	Max
2044	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2045	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2046	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2047	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2048	9,649,914	5,191,654	128,343.86	5,063,180.81	5,062,285.97	5,061,394.53
2049	8,110,243	4,363,311	107,866.23	4,255,315.49	4,254,420.65	4,253,529.21
2050	6,540,587	3,518,836	86,989.81	3,431,716.97	3,430,822.13	3,429,930.69
2051	6,540,587	3,518,836	86,989.81	3,431,716.97	3,430,822.13	3,429,930.69
2052	4,913,474	2,643,449	65,349.20	2,577,970.56	2,577,075.72	2,576,184.28
2053	3,297,685	1,774,154	43,859.21	1,730,166.19	1,729,271.35	1,728,379.91
2054	1,668,526	897,667	22,191.39	875,346.35	874,451.51	873,560.07
Total	**241,247,850**	**129,791,343**	**3,208,596.41**	**126,578,745.82**	**126,551,005.75**	**126,523,371.26**
Average per year	**7,782,189**	**4,186,818**				

Table G-2. Scenario 1. Summary Table—All Routes Yearly Basis

	Min	Typical	Max
Total direct cost of rerouting ($/yr)	22,5084	566,686	900,841
Total social cost of rerouting ($/yr)	74,674	1,502,953	4,793,015
Total socioeconomic cost ($/yr)	299,758	2,069,640	5,693,857
Net socioeconomic benefit ($/yr)	262,652,896	260,883,015	257,258,798

Table G-3. Scenario 1. Summary table—All Routes Lifetime Basis

	Min	Typical	Max
Net socioeconomic benefit ($)	**8,142,239,804**	**8,087,372,053**	**7,975,022,756**

G.2 Scenario 2—Western Area for Consideration Only

Table G-4. Net CO_2 Savings

Year	Total Generation (MWh)	Total CO2 saved (tons/yr)	Lifecycle emissions (ton CO2/yr)	Net CO2 saved (tons/yr)		
				Min	Typical	Max
2024	1,539,671	828,343	20,477.62	807,648.40	806,742.66	805,809.47
2025	3,109,327	1,672,818	41,354.05	1,631,246.92	1,630,341.18	1,629,407.99
2026	3,109,327	1,672,818	41,354.05	1,631,246.92	1,630,341.18	1,629,407.99
2027	4,736,440	2,548,205	62,994.66	2,484,993.32	2,484,087.59	2,483,154.40
2028	6,352,229	3,417,499	84,484.65	3,332,797.69	3,331,891.96	3,330,958.76
2029	7,981,388	4,293,987	106,152.46	4,187,617.53	4,186,711.80	4,185,778.60
2030	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2031	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2032	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2033	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2034	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2035	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2036	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2037	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2038	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2039	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2040	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2041	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2042	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2043	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2044	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2045	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03

Table G-4. (continued)

Year	Total Generation (MWh)	Total CO_2 saved (tons/yr)	Lifecycle emissions (ton CO_2/yr)	Net CO_2 saved (tons/yr)		
				Min		
2046	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2047	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2048	9,649,914	5,191,654	128,343.86	5,063,092.96	5,062,187.22	5,061,254.03
2049	8,110,243	4,363,311	107,866.23	4,255,227.63	4,254,321.90	4,253,388.70
2050	6,540,587	3,518,836	86,989.81	3,431,629.11	3,430,723.38	3,429,790.18
2051	6,540,587	3,518,836	86,989.81	3,431,629.11	3,430,723.38	3,429,790.18
2052	4,913,474	2,643,449	65,349.20	2,577,882.70	2,576,976.97	2,576,043.77
2053	3,297,685	1,774,154	43,859.21	1,730,078.33	1,729,172.60	1,728,239.40
2054	1,668,526	897,667	22,191.39	875,258.50	874,352.76	873,419.57
Total	**241,247,850**	**129,791,343**	**3,208,596.41**	**126,576,022.32**	**126,547,944.52**	**126,519,015.50**
Average per year	**7,782,189**	**4,186,818**				

Table G-5. Scenario 2. Summary Table—All Routes Yearly Basis

	Min	Typical	Max
Total direct cost of rerouting ($/yr)	169,905	399,212	690,768
Total social cost of rerouting ($/yr)	41,868	940,694	3,206,144
Total socioeconomic cost ($/yr)	211,774	1,339,907	3,896,912
Net socioeconomic benefit ($/yr)	262,740,881	261,612,748	259,055,742

Table G-6. Scenario 2. Summary Table—All Routes Lifetime Basis

	Min	Typical	Max
Net socioeconomic benefit ($)	8,144,967,316	8,109,995,212	8,030,728,029

G.3 Scenario 3—Eastern Area for Consideration Only

Table G-7. Net CO_2 Savings

Year	Total Generation (MWh)	Total CO_2 saved (tons/yr)	Lifecycle emissions (ton CO_2/yr)	Net CO_2 saved (tons/yr)		
				Min	Typical	Max
2024	1,539,671	828,343	20,477.62	807,761.98	807,010.48	806,119.05
2025	3,109,327	1,672,818	41,354.05	1,631,360.50	1,630,609.00	1,629,717.57
2026	3,109,327	1,672,818	41,354.05	1,631,360.50	1,630,609.00	1,629,717.57
2027	4,736,440	2,548,205	62,994.66	2,485,106.91	2,484,355.41	2,483,463.97
2028	6,352,229	3,417,499	84,484.65	3,332,911.28	3,332,159.78	3,331,268.34
2029	7,981,388	4,293,987	106,152.46	4,187,731.11	4,186,979.62	4,186,088.18
2030	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2031	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2032	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2033	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2034	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2035	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2036	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2037	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2038	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2039	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2040	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2041	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2042	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2043	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2044	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2045	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61

TableG-7 continued

Year	Total Generation (MWh)	Total CO_2 saved (tons/yr)	Lifecycle emissions (ton CO_2/yr)	Net CO_2 saved (tons/yr)		
				Min	Typical	Max
2046	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2047	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2048	9,649,914	5,191,654	128,343.86	5,063,206.54	5,062,455.04	5,061,563.61
2049	8,110,243	4,363,311	107,866.23	4,255,341.21	4,254,589.72	4,253,698.28
2050	6,540,587	3,518,836	86,989.81	3,431,742.69	3,430,991.20	3,430,099.76
2051	6,540,587	3,518,836	86,989.81	3,431,742.69	3,430,991.20	3,430,099.76
2052	4,913,474	2,643,449	65,349.20	2,577,996.29	2,577,244.79	2,576,353.35
2053	3,297,685	1,774,154	43,859.21	1,730,191.92	1,729,440.42	1,728,548.98
2054	1,668,526	897,667	22,191.39	875,372.08	874,620.58	873,729.15
Total	**241,247,850**	**129,791,343**	**3,208,596.41**	**126,579,543.39**	**126,556,246.95**	**126,528,612.46**
Average per year	**7,782,189**	**4,186,818**				

Table G-8. Scenario 3. Summary Table—All Routes Yearly Basis

	Min	Typical	Max
Total direct cost of rerouting ($/yr)	42754.72	135163.66	246461.26
Total social cost of rerouting ($/yr)	16675.14	432765.55	1486342.54
Total socioeconomic cost ($/yr)	59,429.85	567,929.21	1,732,803.80
Net socioeconomic benefit ($/yr)	262,893,225.97	262,384,726.61	261,219,852.02

Table G-9. Scenario 3. Summary Table—All Routes Lifetime Basis

	Min	Typical	Max
Net socioeconomic benefit ($)	8,149,690,004.97	8,133,926,524.87	8,097,815,412.61

G.4 Scenario 4—Four Sites within Western Area for Consideration

Table G-10. Net CO_2 Savings

Year	Total Generation (MWh)	Total CO_2 saved (tons/yr)	Lifecycle emissions (ton CO_2/yr)	Net CO_2 saved (tons/yr)		
				Min	Typical	Max
2024	1,539,671	828,343	20,477.62	807,730.31	807,113.37	806,462.02
2025	3,109,327	1,672,818	41,354.05	1,631,328.83	1,630,711.89	1,630,060.54
2026	3,109,327	1,672,818	41,354.05	1,631,328.83	1,630,711.89	1,630,060.54
2027	4,736,440	2,548,205	62,994.66	2,485,075.24	2,484,458.30	2,483,806.95
2028	6,352,229	3,417,499	84,484.65	3,332,879.61	3,332,262.67	3,331,611.32
2029	7,981,388	4,293,987	106,152.46	4,187,699.45	4,187,082.51	4,186,431.15
2030	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2031	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2032	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2033	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2034	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2035	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2036	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2037	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2038	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2039	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2040	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2041	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2042	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2043	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2044	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2045	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58

Table G-11. (continued)

2046	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2047	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2048	9,649,914	5,191,654	128,343.86	5,063,174.87	5,062,557.93	5,061,906.58
2049	8,110,243	4,363,311	107,866.23	4,255,309.55	4,254,692.61	4,254,041.26
2050	6,540,587	3,518,836	86,989.81	3,431,711.03	3,431,094.09	3,430,442.73
2051	6,540,587	3,518,836	86,989.81	3,431,711.03	3,431,094.09	3,430,442.73
2052	4,913,474	2,643,449	65,349.20	2,577,964.62	2,577,347.68	2,576,696.33
2053	3,297,685	1,774,154	43,859.21	1,730,160.25	1,729,543.31	1,728,891.96
2054	1,668,526	897,667	22,191.39	875,340.41	874,723.47	874,072.12
Total	**241,247,850**	**129,791,343**	**3,208,596.41**	**126,578,561.69**	**126,559,436.55**	**126,539,244.64**
Average per year	**7,782,189**	**4,186,818**				

Table G-12. Scenario 4. Summary Table—All Routes Yearly Basis

	Min	Typical	Max
Total direct cost of rerouting ($/yr)	86,985	210,954	334,602
Total social cost of rerouting ($/yr)	28,681	548,722	1,760,797
Total socioeconomic cost ($/yr)	115,667	759,677	2,095,400
Net socioeconomic benefit ($/yr)	**262,836,988**	**262,192,978**	**260,857,255**

Table G-13. Scenario 4. Summary Table—All Routes Lifetime Basis

	Min	Typical	Max
Net socioeconomic benefit ($)	8,147,946,645	8,127,982,329	8,086,574,930

Endnotes

[1] Vessel rerouting was modeled using Marico Marine Ltd proprietary vessel traffic analysis software based on 2013 AIS data.

[2] Vessel rerouting was modeled using Marico Marine Ltd proprietary vessel traffic analysis software based on 2013 AIS data.

[3] Equivalent to the mass of fuel oil consumed per average shaft power generated by the engine at the same point in time.

[4] In the future, it is anticipated that less polluting, but more expensive fuels will be used worldwide as the International Maritime Organization ("IMO") enforces a rule requiring fuel to have 0.5% Sulphur content by 2020 (International Maritime Organization, n.d.).

[5] Because the typical daily operational hours for each vessel type were not available, operational costs were evenly spread throughout the day by dividing $/day by 24 hours.

[6] Having a particle size less than or equal to 10 microns in diameter.

[7] As physical and economic systems become more stressed in response to greater climatic change.

[8] No consultation was carried out with the relevant vessel operators to determine the actual routes that would be taken.

[9] ESs require a full navigational safety risk assessment.

[10] NYSERDA estimate that the development of 2.4 GW of offshore wind energy would annually reduce GHG emissions in New York State by more than five million short tons.

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[12] The carbon payback period is defined as the time taken for the carbon savings from the wind power produced to equal the life cycle carbon emissions of the wind farm development including emissions from vessels rerouting.

[13] Figure 3 in this report shows the location of vessel traffic routes identified for analysis in this study.

[14] NYSERDA estimate that the development of 2.4 GW of offshore wind energy would annually reduce GHG emissions in New York State by more than five million short tons.

[15] The carbon payback period is defined as the time taken for the carbon savings from the wind power produced to equal the life cycle carbon emissions of the wind farm development including emissions from vessels rerouting.

[16] Figure 3 in this report shows the location of vessel traffic routes identified for analysis in this study.

[17] This is considered in line with rule 10 of the International Regulations for Preventing Collisions at Sea (COLREGS).

[18] NYSERDA estimates that the development of 2.4 GW of offshore wind energy would annually reduce GHG emissions in New York State by more than five million short tons.

[19] The carbon payback period is defined as the time taken for the carbon savings from the wind power produced to equal the life cycle carbon emissions of the wind farm development including emissions from vessels rerouting.

[20] Vessel speeds were obtained in knots and converted to km/hr (1knot = 1.852 km/hr)

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