VINEYARD MID-ATLANTIC

CONSTRUCTION AND OPERATIONS PLAN
VOLUME II APPENDIX

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Vineyard Mid-Atlantic

Vineyard Offshore

PUBLIC VERSION

Vineyard Mid-Atlantic COP

Appendix II-A Air Emissions Calculations and Methodology

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Revision	Date	Description
0	January 2024	Initial submission.
1	September 2024	Updated to address Bureau of Ocean Energy Management Round 1 Comments and to incorporate revisions to the Project Design Envelope.
1	January 2025	Resubmitted without revisions.

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List of Acronyms

AHTS	anchor handling tug supply
AIS	Automatic Identification System
BOEM	Bureau of Ocean Energy Management
BSFC	brake specific fuel consumption
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalents
COP	Construction and Operations Plan
CTV	crew transfer vessel
DP	dynamic positioning
eGRID	Emissions & Generation Resource Integrated Database
EPA	Environmental Protection Agency
ESP	electrical service platform
ft	feet
ft^2	square feet
g	gram
gal	gallon
GHG	greenhouse gas
GWP	global warming potential
HAP	hazardous air pollutant
HC	hydrocarbons
HDD	horizontal directional drilling
HHV	higher heating value
HLV	heavy lift vessel
hr	hour
HTV	heavy transport vessel
HVAC	high voltage alternating current
HVDC	high voltage direct current
IPCC	Intergovernmental Panel on Climate Change
IWG	Interagency Working Group on Social Cost of Greenhouse Gases
km	kilometers
km^2	square kilometers
kV	kilovolt
kW	kilowatt
lb	pound
MDO	marine diesel oil
MGO	marine gas oil
m	meters
m^2	square meters
mi	miles

List of Acronyms (Continued)

MMBtu	metric million British thermal unit
MOVES	MOtor Vehicle Emission Simulator
MT	metric tonne
MW	megawatt
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NM	nautical miles
NMHC	non-methane hydrocarbon
NOx	nitrogen oxides
N_2O	nitrous oxide
NPCC	Northeast Power Coordinating Council
OCS	Outer Continental Shelf
OECC	offshore export cable corridor
OGV	ocean-going vessel
O&M	operations and maintenance
Pb	lead
PDE	Project Design Envelope
PM	particulate matter
$PM_{2.5}$	particulate matter smaller than 2.5 microns
PM_{10}	particulate matter smaller than 10 microns
ppm	parts per million
RCS	reactive compensation station
RORO	roll-on/roll-off
RSZ	reduced speed zone
SATV	service accommodation and transfer vessel
SC-GHG	social cost of greenhouse gases
SF_6	sulfur hexafluoride
SOV	service operation vessel
SO_2	sulfur dioxide
TSS	traffic separation schemes
tpy	tons per year
ULSD	ultra-low sulfur diesel
US	United States
VOCs	volatile organic compounds
WTG	wind turbine generator
XLPE	cross-linked polyethylene

1 Introduction

Vineyard Mid-Atlantic LLC (the "Proponent") proposes to develop, construct, and operate offshore renewable wind energy facilities in Bureau of Ocean Energy Management (BOEM) Lease Area OCS-A 0544 (the "Lease Area") along with associated offshore and onshore transmission systems. This proposed development is referred to as "Vineyard Mid-Atlantic." Vineyard Mid-Atlantic includes 118 total wind turbine generator (WTG) and electrical service platform (ESP) positions within the Lease Area. One or two of those positions will be occupied by ESPs and the remaining positions will be occupied by WTGs. At its closest point, the 174 square kilometer (km^2) (43,056 acre) Lease Area is approximately 38 km (33 nautical miles [NM]) south of Fire Island, New York. Offshore export cables installed within an Offshore Export Cable Corridor (OECC) will transmit power from the renewable wind energy facilities to onshore transmission systems on Long Island, New York.

Electricity generated by the WTGs will displace electricity produced by fossil fuel power plants and significantly reduce emissions from the regional electric grid over the lifespan of Vineyard Mid-Atlantic. However, there will be air emissions from vessels, construction equipment, generators, helicopters, on-road vehicles, and some fugitive emissions during the construction and operation of Vineyard Mid-Atlantic.

This document details the methods used to estimate all air emissions from Vineyard Mid-Atlantic within the United States (US) (onshore and ~200 NM [~370 kilometers] out to sea) in order to assess regional impacts to air quality as part of the Vineyard Mid-Atlantic Construction and Operations Plan (COP) and for BOEM's National Environmental Policy Act (NEPA) process. This document also describes the methods used to quantify emissions from the electric grid (and the associated social costs) that are expected to be avoided as a result of the clean, renewable energy provided by Vineyard Mid-Atlantic.

Section 2 describes the types of air emissions sources that may be used during the construction and operation of Vineyard Mid-Atlantic and discusses the methods used to calculate air emissions from those sources. Section 3 provides the preliminary estimate of air emissions from construction and operation of Vineyard Mid-Atlantic. Section 4 describes the methods used to quantify emissions from fossil fuel power plants and the associated social costs of greenhouse gases (GHGs) that will be avoided as a result of Vineyard Mid-Atlantic. Section 5 lists the references used to develop this analysis.

All anticipated air emission sources associated with Vineyard Mid-Atlantic are itemized in Attachment A. Attachment B contains parameters of the Project Design Envelope (PDE) used to develop the emissions estimates. Attachment C contains emission factors, load factors, and other supporting calculations used to calculate potential emissions. Attachment D contains avoided emission and avoided social cost of GHG calculations.

1.1 Maximum Design Scenario for the Air Emissions Estimates

Vineyard Mid-Atlantic is being developed and permitted using a PDE based on expected commercial and technological advancements. The PDE outlines a reasonable range of project design parameters (e.g., multiple foundation types) and installation techniques (e.g., use of various cable installation tools). The use of a PDE allows analysis of the maximum impacts that could occur from Vineyard Mid-Atlantic based on the "maximum design scenario" for each resource while providing the Proponent with the flexibility to optimize its project(s) within the approved PDE during later stages of the development process. The maximum design scenario used to assess potential impacts and benefits to air quality is described below:

- Offshore emissions were estimated assuming that 118 WTG/ESP positions would be occupied by one or two ESPs and the remainder would be occupied by WTGs (i.e., 116–117 WTGs).[1] The estimates also assume the maximum length of offshore cables, the maximum area of scour protection, and the maximum area of cable protection included in the PDE.

- Onshore emissions were estimated assuming the construction of two landfall sites, two onshore cable routes, two onshore reactive compensation stations (RCSs), and two new onshore substations.

- Avoided emissions and avoided social costs were estimated based on the approximate nameplate capacity for the entire Lease Area.

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1 For each emission source, the assumed combination of WTGs and ESP(s) (i.e., 117 WTGs/one ESP or 116 WTGs/two ESPs) varies depending on which combination yields the maximum air emissions estimates.

2 Air Emissions Methodology

In general, air emissions are estimated by calculating the duration and intensity of emission-generating activities and multiplying those estimates by appropriate emission factors. The pollutants included in the air emissions analysis are nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO), particulate matter (PM) 10 microns and smaller (PM_{10}), particulate matter 2.5 microns and smaller ($PM_{2.5}$, a subset of PM_{10}), sulfur dioxide (SO_2), lead (Pb),[2] total hazardous air pollutants (HAPs, individual compounds are either VOC or PM), and GHG emissions, reported as carbon dioxide equivalent (CO_2e).

Typically, ozone is not emitted directly into the air; instead, ground-level ozone primarily forms from the reaction of VOCs and NOx in sunlight. VOCs and NOx, which are often emitted directly into the air, are commonly referred to as ozone precursors. Emissions of these precursors to ozone are quantified instead of ozone itself.

Emissions were calculated for the following categories of emission sources:

1. Commercial marine vessels
2. Helicopters
3. Offshore generators
4. Other offshore construction equipment
5. Onshore non-road engines
6. On-road vehicles
7. Construction dust
8. Fugitive emissions

These emission sources are described in Section 2.1. The types of emission sources, engine sizes, and durations of activities used in this air emissions analysis reflect Vineyard Mid-Atlantic's logistical and operational plans to the best of the Proponent's knowledge at the time of submission, but because the Proponent is still selecting contractors and finalizing the design of the facilities, the actual emissions associated with individual activities may differ from the estimates provided in the COP.

[2] Because Pb is a type of HAP, Pb emissions are not presented separately in the emissions summary tables in Section 3.

2.1 Description of Air Emission Sources

Offshore air emissions will primarily come from the main engines and auxiliary engines on commercial marine vessels used during construction and operations and maintenance (O&M) activities.[3] There may also be emissions from other construction equipment used aboard vessels including, but not limited to, engines used to power pile driving hammers, motion compensation system engines, and engines used for noise mitigation devices during pile driving (e.g., air compressors used to supply air to bubble curtains). Additional offshore emissions are expected to come from diesel generators used to temporarily supply power to the WTGs and ESP(s) as well as helicopters. Anticipated emission sources for offshore construction and O&M activities are described in the following table.

Table 2.1-1 Description of Offshore Emissions Sources

Emission Source[1]	Description
Anchor handling tug supply (AHTS) vessels	Vessels that primarily handle and reposition the anchors of other vessels (e.g., cable laying vessels), but may also be used to transport equipment or for other services.
Barges	Vessels with or without propulsion that may be used for transporting components (e.g., foundations, WTGs, etc.) or installation activities.
Bunkering vessels	Vessels used to supply fuel and other provisions to other vessels offshore.
Cable laying vessels	Specialized vessels/barges that lay and bury offshore cables into the seafloor.
Crew transfer vessels (CTVs)	Smaller vessels that transport crew, protected species observers, parts, and/or equipment.
Heavy lift vessels (HLVs)	Vessels that may be used to lift, support, and orient the WTGs, ESP(s), and foundations during installation.
Heavy transport vessels (HTVs)/modified cargo vessels	Ocean-going vessels (OGVs) that may transport components to staging ports or directly to the Lease Area.
Jack-up vessels	Vessels that extend legs to the seafloor to provide a safe, stable working platform. Jack-up vessels may be used to install foundations, ESP topside(s), and/or WTGs, to transport components to the Lease Area, for offshore accommodations, for cable splicing activities, and/or for cable pull-in at the landfall site(s).
Safety vessels	Vessels that are used to address other mariners and fishing vessels entering active work sites. The safety vessels would provide guidance to mariners and fishing vessels, explain the ongoing activities, and request that they give a wide berth to the work site or construction vessel(s), if necessary.
Scour/cable protection installation vessels	Vessels (e.g., fallpipe vessels) that may be used to deposit a layer of rock around the foundations or over limited sections of the offshore cable system.

3 A vessel's main engines, also referred to as propulsion engines, supply power to move the vessel. A vessel's auxiliary engines supply power for non-propulsion (e.g., electrical) loads.

Table 2.1-1 Description of Offshore Emissions Sources (Continued)

Emission Source[1]	Description
Service operation vessels (SOVs)/service accommodation and transfer vessels (SATVs)	Larger vessels that provide offshore living accommodations and workspace as well as transport crew to and from the Lease Area.
Support vessels	Multipurpose vessels (e.g., work boats, supply boats, accommodation vessels, diving support vessels) that may be used for a variety of activities, such as the pre-lay grapnel runs, supporting cable installation, commissioning WTGs, or transporting equipment.
Survey vessels	Specialized vessels used to perform geophysical, geotechnical, and environmental surveys.
Tugboats	OGVs or smaller harbor craft used to transport equipment and barges.
Offshore generators	Diesel engines that temporarily supply power to the WTGs and ESP(s).
Other construction equipment	Non-road construction equipment used aboard vessels, on the WTGs, and/or ESP(s) (e.g., pile driving hammer engines, air compressors, motion compensation platform engines, forklifts, winches, etc.).
Helicopters	Helicopters capable of transporting crew to vessels or the ESP(s).
Fugitive emissions	Emissions from solvents, paints, coatings, diesel fuel storage/transfer, and sulfur hexafluoride (SF_6).

Note:

1. Fishing vessels may be used for crew transfer, safety vessels, or other miscellaneous activities described above.

Emission sources during onshore construction and O&M activities will include construction equipment and vehicles used during the unloading and loading of components at the port facilities, during construction at the landfall site(s) (e.g., horizontal directional drilling [HDD]), during installation of the onshore cables, and during construction of the onshore RCSs and onshore substations. Onshore emission sources include:

- Non-road construction equipment (e.g., cranes, excavators, backhoes, trenchers, drilling tools, front end loaders, forklifts, generators, pumps, welders, air conditioning units, and aerial lifts)
- Worker vehicles, delivery vehicles, and heavy-duty vehicles (e.g., concrete delivery trucks, dump trucks)
- Fugitive emissions from incidental solvent release and sulfur hexafluoride (SF_6)
- Particulate emissions from construction dust

The number and types of vessels, equipment, helicopters, and vehicles along with anticipated hours of operation and number of round trips for each emission source was provided by the Proponent's engineers. A complete description of all anticipated emission points associated with Vineyard Mid-Atlantic can be found in Attachment A.

2.2 Emissions Calculation Methods

2.2.1 Commercial Marine Vessels

Emissions from commercial marine vessels were calculated according to the methodology described in BOEM's *Offshore Wind Energy Facilities Emission Estimating Tool Technical Documentation,* referred to as the "BOEM Wind Tool" (Chang et al. 2017).[4] The BOEM Wind Tool was developed to provide a consistent approach for estimating emissions associated with proposed offshore wind projects and to ensure consistency in BOEM's environmental review process. When necessary, the BOEM Wind Tool calculation methodology was supplemented with guidance from:

- Environmental Protection Agency's (EPA's) (2009) *Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories*, referred to as "EPA's Port-Related Emission Guidance;"

- EPA's *2014 National Emissions Inventory Technical Support Document* and supporting documentation, referred to as the "2014 NEI" (EPA 2015, 2018a);

- EPA's *2017 National Emissions Inventory Technical Support Document* and supporting commercial marine vessel documentation, referred to as the "2017 NEI" (ERG 2019a, 2019b); and

- EPA's (2022) *Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions*.

Consistent with the BOEM Wind Tool, vessel air emissions were calculated based on vessels' assumed hours of operation, distance traveled, speed, total number of round trips, engine size, load factor, and emission factor. For each vessel, the following calculations were made:[5]

- Emissions from the main engines while in transit

- Emissions from the main engines while maneuvering

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4 An updated version (Version 2.0) of the BOEM Wind Tool was released in 2021 (Chang et al. 2021). Version 2.0 of the BOEM Wind Tool applies the same emission factors to all marine vessel types and engines, which assumes that all vessel engines are Category 2 EPA Tier 1 marine engines. The Proponent believes that the use of marine engine emission factors based on fleet-weighted averages, as presented in Version 1 of the BOEM Wind Tool, is more appropriate given the range of vessel types and sizes expected to be employed during Vineyard Mid-Atlantic. BOEM indicated that it was acceptable to use Version 1 of the BOEM Wind Tool for Vineyard Mid-Atlantic during a call on June 15, 2023.

5 Per EPA's (2018a) 2014 NEI methodology, the emission estimates do not include activity or emissions associated with boilers used to generate steam. Any thermal energy needs (e.g., hot water) on vessels will typically be met using excess heat from the vessel's engines or electric heaters.

- Emissions from the auxiliary engines while in transit
- Emissions from the auxiliary engines while maneuvering
- Emission from the auxiliary engines while hoteling in port

The basic equation used for each of the calculations above is:

$$E = kW * hours * LF * EF * 1.10231 \times 10^{-6}$$

Where:

- *E* = total emissions (US tons)
- *kW* = total engine size (kilowatt [kW])
- *hours* = duration of each activity (hours [hr])
- *LF* = engine load factor (unitless)
- *EF* = emission factor (gram [g]/kW-hr)
- 1.10231×10^{-6} = g to ton conversion factor

The methods used to determine vessels' engine sizes, hours of operation, load factors, emission factors, and fuel use are described in the following sections.

2.2.1.1 Engine Size

Vessel engine sizes were determined from specification sheets for actual vessels that may be used during Vineyard Mid-Atlantic or are closely representative of the types of vessels that are expected to be used. Some vessel specification sheets do not specify the size of auxiliary engines or differentiate between auxiliary engines and main engines. In some instances, it was assumed that the smallest engine(s) supplied auxiliary power (EPA 2022). For example, the scour protection installation vessel has three 4,500 kW engines, one 1,200 kW engine, and one 429 kW engine. It was assumed that the 1,200 kW and 429 kW engines provide auxiliary power. For other vessels, thruster power was assumed as a surrogate for auxiliary engine power. In diesel-electric vessels, the main engines are used to provide both auxiliary and propulsion power. In these vessels, at low loads, some engines can be shut down to allow others to operate more efficiently (EPA 2009). Consequently, for diesel-electric vessels, it was assumed that one or more of the main engines provides auxiliary power.

2.2.1.2 Hours of Operation

Hours of operation for a vessel's engines while in transit were calculated from the vessel's assumed speed and distance traveled. Vessel speeds were obtained from specification sheets for each representative vessel or based on the Proponent's expected operational speed. The Proponent's engineering team provided the number of vessel trips required for each activity based on the anticipated schedule and prior experience. The distance traveled during each trip was determined from preliminary vessel routes; these distances are provided in

Attachment B. The preliminary vessel routes were developed based on regions of concentrated vessel traffic (using vessels' Automatic Identification System [AIS] data), taking into consideration traffic separation schemes (TSS), recommended vessel routes, coastal maintained channels, and anchorage areas.[6] To account for the envelope of possible ports used during construction and operations, the emissions estimates generally assume the use of the port with the longest transit distances to and from the Offshore Development Area[7] (within US waters) that is likely to be used for each individual activity, within reason.

For several vessels, additional round trips were included in the total number of round trips to/from the Offshore Development Area to account for the vessel's initial trip to a Vineyard Mid-Atlantic staging port from another port (i.e., mobilization) and final departure from a Vineyard Mid-Atlantic staging port to another port (i.e., demobilization). This is a conservative approach since the ports in the PDE will likely be the homeports of several harbor craft (e.g., tugs and crew transfer vessels) used for Vineyard Mid-Atlantic.

Hours of operation for a vessel's engines while maneuvering at the Lease Area or OECC were based on the expected durations to install each component, which were provided by the Proponent's engineering team. It was assumed that a vessel's engines will provide power for maneuvering activities anytime the vessel is within the Offshore Development Area and not in transit (except for jack-up vessels' main engines, which will not provide propulsion power while the vessel is jacked-up). Additional hours spent maneuvering in port were based on typical maneuvering times by vessel type provided in the 2014 NEI[8] (shown in Table 2.2-1 below) and the number of round trips.

Table 2.2-1 In-Port Maneuvering Time by Vessel

Vessel Type	Maneuvering Time (hr)
Bulk Carrier	1
Bulk Carrier, Laker	1
Buoy Tender	1.7
Container	1
Crude Oil Tanker	1.5
General Cargo	1
Liquified Natural Gas Tanker	1

6 For each trip, individual vessel captains will need to consider weather, water depths, tides, loading conditions, and visibility before selecting their route to port. Therefore, vessel captains may opt for different routes than those used in this analysis. It is expected that vessel traffic routes will continue to be developed throughout the construction planning process and that potentially significant refinements to the preliminary routes will occur.

7 The Offshore Development Area is comprised of the Lease Area, the OECC, and the broader region surrounding the offshore facilities that could be affected by Vineyard Mid-Atlantic activities.

8 From EPA's (2018a) *2014 National Emissions Inventory, Version 2 Technical Support Document*, Table 4-111: Estimated Maneuvering Time by Vessel Type. The maneuvering time includes time spent approaching the port and time spent departing from the port.

Table 2.2-1 In-Port Maneuvering Time by Vessel (Continued)

Vessel Type	Maneuvering Time (hr)
Liquified Petroleum Gas Tanker	1
Miscellaneous	1
Passenger (cruise ship)	0.8
Reefer	1
Roll-on/roll-off (RORO)	1
Tanker	1
Tug	1.7
Vehicle Carrier	1

For all vessels, it was assumed that all main engines used for propulsion would not operate while the vessel is dockside per 2014 NEI guidance (EPA 2018a). For vessels equipped with Category 1 and 2 main engines (except for some larger Category 2 vessels), it was assumed that neither the propulsion nor the auxiliary engines would operate while the vessel was dockside to conserve fuel (EPA 2018a). For vessels equipped with Category 3 main engines (and some larger Category 2 vessels), auxiliary engines were assumed to be hoteling any time the vessel is within the US and not in transit or maneuvering.[9]

2.2.1.3 Load Factors

Load factors are expressed as a percent of the vessel's total propulsion or auxiliary power that is used for a given operational mode (EPA 2009). Load factors for propulsion power can be calculated from the Propeller Law, which is the theory that propulsion power varies by the cube of speed as illustrated by the following equation:

$$LF = (AS/MS)^3$$

Where:

- *LF* = load factor
- *AS* = actual speed (knots)
- *MS* = maximum speed (knots)

[9] For EPA Tier 1 and 2 engines, Category 1 marine compression-ignition engines are defined as engines with a gross engine power ≥ 37 kW and a displacement <5 liters per cylinder (L/cyl) and Category 2 marine compression-ignition engines have a displacement greater ≥5 L/cyl and <30 L/cyl. For EPA Tier 3 and 4 engines, Category 1 marine compression-ignition engines are defined as engines with a displacement of <7 L/cyl and Category 2 engines are those with displacement ≥7 L/cyl and <30 L/cyl. For all Tiers, Category 3 engines are marine engines with a displacement at or above 30 L/cyl.

Vessels in transit were assumed to operate at or below cruise speed, which is defined as approximately 94% of maximum speed (EPA 2009). Based on the Propeller Law, for the main (propulsion) engines of vessels operating at 94% of maximum speed, the load factor is 0.83. Consistent with EPA guidance, a load factor of 0.83 was used in the emission estimates for main engines while in transit.

Consistent with the 2014 NEI and the BOEM Wind Tool, a load factor of 0.20 was used for most main (propulsion) engines while maneuvering onsite (EPA 2018a; Chang et al. 2017).[10] However, based on discussions with the Proponent's engineers and vessel suppliers, a load factor of 0.2 underestimates the power required by many vessels that use dynamic positioning (DP) to maintain a precise location within the Offshore Development Area. Fuel consumption rates during DP from vessel specification sheets were used to derive a more conservative load factor for vessel's main engines during DP. See the following example DP load factor calculation for a typical vessel:

Maximum speed: 13 knots
Fuel consumption at 12 knots: 14.5 metric tonne (MT)/day
Fuel consumption in DP mode: 7 MT/day

Using the Propeller Law to calculate the load factor at 12 knots:

$$LF = (AS/MS)^3 = (12/13)^3 = 0.79$$

Using the ratio of fuel consumption at different speeds to determine the load factor during DP:

$$LF \text{ during DP} = 0.79 * (7 \text{ MT per day during DP}/14.5 \text{ MT per day at 12 knots})$$

$$LF \text{ during DP} = 0.38$$

This calculation was repeated for several vessels to determine an approximate load factor of 0.4 for the main engines during DP operations. This load factor was used for most vessels whose specification sheets suggested that the vessel had a DP system.

According to BOEM, although it is appropriate to use the default vessel profiles provided in the BOEM Wind Tool (which are based on national fleet data), some factors within the BOEM Wind Tool are defaults that serve as placeholders for more accurate information. For example, the auxiliary engine load factor in the BOEM Wind Tool is defaulted to 1. Consequently, the default auxiliary engine load factor was not used. Auxiliary engine load factors for OGVs (typically vessels whose main engines are Category 3 engines) were taken from *Table 2-7: Auxiliary Engine Load Factor Assumptions* of EPA's (2009) Port-Related Emission Guidance,

10 According to the 2014 NEI, the propulsion engine load factor of 0.20 is from Entec's European emission inventory (Entec UK Limited. 2002. *Quantification of emissions from ships associated with ship movements between ports in the European Community, European Commission Final Report*). EPA recommends that future National Emissions Inventories consider reviewing port inventory data to derive more accurate maneuvering load factors.

which is shown in Table 2.2-2 below. For auxiliary engines in transit, the more conservative reduced speed zone (RSZ) load factor was used, since vessels may operate at speeds slower than cruise speeds. RSZ speed is the maximum safe speed the vessel uses to traverse distances within a waterway leading to a port (less than cruise speed and greater than maneuvering speed). For auxiliary engines maneuvering onsite or in port, the "maneuver" load factor was selected. For vessels equipped with Category 3 engines (and some large Category 2 vessels), the "hotel" load factor was used for the auxiliary engines while hoteling in port.

Table 2.2-2 EPA Auxiliary Engine Load Factors for Ocean-Going Vessels

Ship Type	Cruise	RSZ	Maneuver	Hotel
Auto Carrier	0.15	0.30	0.45	0.26
Bulk Carrier	0.17	0.27	0.45	0.10
Container Ship	0.13	0.25	0.48	0.19
Cruise Ship	0.80	0.80	0.80	0.64
General Cargo	0.17	0.27	0.45	0.22
Miscellaneous	0.17	0.27	0.45	0.22
Ocean-going Tug	0.17	0.27	0.45	0.22
RORO	0.15	0.30	0.45	0.26
Reefer	0.20	0.34	0.67	0.32
Tanker	0.24	0.28	0.33	0.26

Auxiliary engine load factors for harbor craft (typically vessels whose main engines are Category 1 or 2 engines) are from *Table 4 Auxiliary and Boiler Power Surrogates* of the 2017 NEI supporting documentation for vessels with Category 1 and 2 main engines (ERG 2019a). The auxiliary engine load factors are shown in Table 2.2-3 below.

Table 2.2-3 2017 NEI Auxiliary Engine Load Factors for Harbor Craft

Vessel Group	Auxiliary Operating Load Factor
Bulk Carrier	0.10
Commercial Fishing	0.43
Container Ship	0.19
Ferry Excursion	0.43
General Cargo	0.22
Government	0.43
Miscellaneous	0.43
Offshore support	0.56
Reefer	0.32
RORO	0.26
Tanker	0.26
Tug	0.43
Work Boat	0.43

Specific to the service operation vessels (SOVs) used for site services and during O&M, load factors were based on historical operational data provided directly from potential SOV suppliers. The assumed load factors are conservatively high compared to records of actual operations for similar projects.

2.2.1.4 Emission Factors

The BOEM Wind Tool contains default vessel characteristics for a variety of vessel types commonly used in offshore wind projects. For each vessel type, the BOEM Wind Tool provides default emission factors for main and auxiliary engines. These default emission factors were developed using Information Handling Service vessel population data, which takes into account typical vessels' country of registration, engine categories, and regulatory tiers (Chang et al. 2017). These vessel profiles were then combined with tier level emission factors from EPA's *2014 National Emissions Inventory, Version 1 Technical Support Document* to create weighted emission factors for each vessel type (Chang et al. 2017). The BOEM default emission factors for main and auxiliary engines of each vessel type are listed in Tables 2.2-4 and 2.2-5 below.

Table 2.2-4 BOEM Default Emission Factors for Vessel Main Engines

Vessel Type	Vessel Main Engine Emission Factors (g/kW*hr)									
	NOx	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2	CO_2	CH_4	N_2O	Pb
AHTS	9.26	0.24	2.16	0.34	0.33	0.08	636.09	0.004	0.03	4.0E-05
Barge	13.61	0.63	1.40	0.45	0.42	0.36	588.90	0.004	0.03	1.2E-05
Cable Laying	9.49	0.25	2.20	0.34	0.33	0.09	635.02	0.004	0.03	3.9E-05
Crew	9.15	0.14	2.30	0.31	0.30	0.01	648.16	0.004	0.03	4.6E-05
Dredging	9.60	0.28	2.13	0.36	0.34	0.11	630.62	0.004	0.03	3.7E-05
Ice Breaker	9.92	0.45	1.78	0.40	0.38	0.23	610.83	0.004	0.03	2.5E-05
Jack-up	10.03	0.14	2.30	0.31	0.30	0.01	647.08	0.004	0.03	4.5E-05
Research/ Survey	9.86	0.22	2.25	0.34	0.33	0.07	638.26	0.004	0.03	4.2E-05
Shuttle Tanker	9.05	0.63	1.40	0.45	0.42	0.36	588.90	0.004	0.03	1.2E-05
Supply Ship	9.44	0.17	2.29	0.32	0.31	0.03	644.58	0.004	0.03	4.5E-05
Tug	9.52	0.18	2.29	0.33	0.32	0.03	643.66	0.004	0.03	4.5E-05

Table 2.2-5 BOEM Default Emission Factors for Vessel Auxiliary Engines

Vessel Type	Vessel Main Engine Emission Factors (g/kW*hr)									
	NOx	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2	CO_2	CH_4	N_2O	Pb
AHTS	9.88	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Barge	12.57	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Cable Laying	9.89	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Crew	10.37	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Dredging	9.85	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Ice Breaker	10.09	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Jack-up	11.55	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Research/ Survey	10.21	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Shuttle Tanker	9.80	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Supply Ship	10.43	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05
Tug	10.10	0.14	2.48	0.32	0.31	0.01	648.2	0.004	0.03	4.8E-05

As shown in the following table, each representative vessel used for Vineyard Mid-Atlantic was assigned to one of the eleven vessel types listed above and the corresponding emissions factors were used.

Table 2.2-6 Assigned Vessel Types

Vineyard Mid-Atlantic Vessel Type	BOEM Category
AHTS vessel	AHTS
Barge	Barge
Bunkering vessel	Shuttle tanker
Cable laying vessel	Cable laying
CTV	Crew
HLV	Barge (the most conservative emission factors)
HTV/modified cargo vessel	Supply ship
Jack-up vessel	Jack-up
Safety vessel	Crew
Scour/cable protection installation vessel	Cable laying (most similar in size and function)
SOV/SATV	Cable laying (most similar in size and function)
Support vessel	Cable laying (most similar in size and function)
Survey vessel	Research/Survey
Tugboats	Tug

Emissions of GHGs from commercial marine vessels, which include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), were estimated using the GHG emission factors provided in Tables 2.2-4 and 2.2-5. GHG emissions as CO_2e were then calculated using global warming potential (GWP) factors from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (2021), which provides a GWP of 27.9 for CH_4 (for fossil fuels) and 273 for N_2O. Total CO_2e emissions were calculated using the following equation:

$$E = CH_4 * GWP_{CH4} + N_2O * GWP_{N20} + CO_2$$

Where:

- E = total CO_2e emissions, tons
- CH_4 = total CH_4 emissions, tons
- N_2O = total N_2O emissions, tons
- CO_2 = total CO_2 emissions, tons
- GWP_{CH4} = GWP for CH_4
- GWP_{N20} = GWP for N_2O

The BOEM Wind Tool does not provide emission factors for HAPs emitted from commercial marine vessels. Consequently, HAP emissions were estimated according to the methodology provided in the 2017 NEI supporting documentation for commercial marine vessels (ERG 2019a, 2019b). HAP emissions were estimated by applying speciation profiles to VOC estimates for organic HAPs and PM estimates for metal HAPs. HAPs were calculated as percentages of the $PM_{2.5}$ and VOC emissions from the vessels using the following equation:

$$E = VOC * SF_{VOC} + PM_{2.5} * SF_{PM2.5}$$

Where:

- E = total HAP emissions, tons
- VOC = total VOC emissions, tons
- $PM_{2.5}$ = total $PM_{2.5}$ emissions, tons
- SF_{VOC} = speciation factor for VOC
- $SF_{PM2.5}$ = speciation factor for $PM_{2.5}$

The HAPs speciation profiles were obtained from the 2017 NEI supporting documentation for commercial marine vessels (ERG 2019a, 2019b).

2.2.1.5 Fuel Use

EPA's (2022) Ports Emissions Inventory Guidance provides brake specific fuel consumption (BSFC) rates for the main and auxiliary engines of marine vessels for various engine types and fuels. According to the 2014 NEI (EPA 2018a) and EPA's (2022) Ports Emissions Inventory Guidance, the dominant propulsion engine configuration for large Category 3 vessels is the slow-speed diesel engine. Accordingly, a BSFC of 185 g/kw-hr for slow-speed diesel OGV main engines was used for Category 3 propulsion engines.[11] For Category 3 auxiliary engines, a BSFC of 217 g/kw-hr was used, assuming that these auxiliary engines will primarily fire marine diesel oil (MDO) or marine gas oil (MGO).[12] For Category 1 and 2 propulsion and auxiliary engines, a BSFC of 248 g/kw-hr was used for engines smaller than 37 kW whereas a BSFC of 213 g/kw-hr was used for engines 37 kW or larger.[13]

Fuel use was calculated using the following equation:

*Fuel use = BSFC/(7.10 lb/gal) * 0.00220462 * kW * hours * LF*

Where:

- *Fuel use* = total fuel used (gallons [gals])
- *BSFC* = BSFC rate (g/kW-hr)
- *7.10 pounds [lb]/gal* = diesel fuel density
- 0.00220462 = g to lb conversion factor
- *kW* = total engine size (kW)
- *hours* = duration of each activity (hr)
- *LF* = engine load factor (unitless)

Total fuel use was calculated separately for emissions from the main engines while in transit, the main engines while maneuvering, the auxiliary engines while maneuvering, the auxiliary engines while in transit, and the auxiliary engines while hoteling.

11 From EPA's (2022) Ports Emissions Inventory Guidance "Table 3.6. Category 3 Vessel BSFC Rates (g/kWh)."

12 From EPA's (2022) Ports Emissions Inventory Guidance "Table 3.6. Category 3 Vessel BSFC Rates (g/kWh)."

13 From EPA's (2022) Ports Emissions Inventory Guidance "Table 4.3. Category 1 and 2 BSFC Rates (g/kWh)."

2.2.2 Offshore Generators

It was assumed that a portable, temporary ~250 kW diesel generator would be used for 10 days (24 hours per day) on each WTG at 100% load during construction and commissioning. The WTGs will include backup systems utilizing batteries or other zero emission technologies to provide standby/emergency power in order to maintain yaw control and communication at all times.[14]

It was assumed that the ESP(s) will collectively require six ~500 kW diesel generators to provide backup power to critical systems. These backup generators would operate for emergencies and reliability testing during O&M. Emergencies include unplanned loss of grid power or a failure of the offshore cable system that requires an ESP to be disconnected from external power (either from onshore or the WTGs). It was assumed that the backup generators would operate for approximately 500 hours per year during O&M (for reliability testing and emergency usage). However, given the unplanned and unpredictable nature of an emergency, it is impossible to predict with accuracy how long these backup generators would need to operate in an emergency.

In addition, the backup generators on the ESP(s) will likely be used to provide power for installation and commissioning activities until the ESP(s) can be connected to the electric grid (although this power could come from other generators of similar size). It was assumed that during construction, the generators will operate for about four months, approximately 50% of the time.

It is anticipated that the generators located on the WTGs and ESP(s) will be required to meet or exceed EPA's highest applicable marine engine emission standards at 40 CFR Part 1042 and use ultra-low sulfur diesel (ULSD) with a maximum sulfur content of 15 parts per million (ppm). Thus, emissions from the generators located on the WTGs and ESP(s) were estimated based on the most stringent EPA marine engine emission standards applicable for each engine size (i.e., EPA Tier 3 marine engine emission standards for engines less than 600 kW and EPA Tier 4 marine engine emission standards for engines greater than or equal to 600 kW). It was assumed that the engines would fire ULSD with a maximum sulfur content of 15 ppm. The fuel usage rate for each generator was determined from equipment specification sheets for diesel generators that are representative of the type of generators that will be used for Vineyard Mid-Atlantic.

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[14] In the unlikely event of a failure of the WTG's backup power system or some other unforeseen issue (e.g., loss of connection to the grid for an extended period), portable diesel generators may be temporarily placed on a WTG (or alternatively on a support vessel) during O&M to supply backup power. These generators would be necessary to maintain safety systems (e.g., aviation obstruction lights, marine navigation lights, electrical cooling and dehumidification systems) and to yaw the WTG's rotor nacelle assembly during adverse weather. Given the unplanned and unpredictable nature of an emergency, it is impossible to predict with accuracy how long these backup generators would need to operate in an emergency.

The following hydrocarbon (HC) + NOx, CO, and PM emission factors were used to estimate emissions from the generators.

Table 2.2-7 Assumed EPA Marine Engine Emission Standards

Generator	EPA Marine Engine Standard	Emission Factors (g/kW*hr)		
		HC + NOx	CO	PM
Temporary Generator on WTG (~250 kW)	EPA Tier 3 (for Category 1 Engines with 0.9 ≤ disp. < 1.2 and power density ≤ 35 kW/L)	5.4	5.0	0.12
Permanent Generator on ESP (~500 kW)	EPA Tier 3 (for Category 1 Engines <600 kW with 2.5 ≤ disp. < 3.5 and power density ≤ 35 kW/L)	5.6	5.0	0.10

Note:
1. "Disp." = Displacement in liters per cylinder.

Based on the Revolution Wind Outer Continental Shelf (OCS) Air Permit, it was assumed that NOx is 97.6% of HC + NOx, HC is 2.4% of HC + NOx, and VOC is 1.053 times the HC emission factor (EPA 2023b). For all generators, based on guidance from EPA's (2010a) *Exhaust and Crankcase Emission Factor for Nonroad Engine Modeling – Compression Ignition Report*, it was assumed that 100% of PM is PM_{10} and 97% of PM is $PM_{2.5}$.

SO_2 emissions from the generators were calculated using the following mass balance equation based on the consumption of diesel fuel containing 15 ppm sulfur with a fuel density of 7.1 lb/gal and assuming 100% conversion of sulfur to SO_2 (a 2:1 mass ratio of SO_2 to sulfur):

$$SO_2\ (tons) = fuel\ use\ (gal) * 7.1\ lb/gal\ diesel\ fuel * (0.000015\ lb\ S/lb\ diesel\ fuel) * 64\ lb\ SO_2/32\ lb\ S * 0.0005\ ton/lb$$

CO_2 emission factors were based on the default Distillate Fuel No. 2 CO_2 emission factor (73.96 kg CO_2/metric million British thermal unit [MMBtu]) and higher heating value (HHV) of 0.138 MMBtu/gal from 40 CFR Part 98 Table C-1.[15] CH_4 and N_2O emission factors were based on default CH_4 and N_2O emission factors for petroleum from 40 CFR Part 98 Table C-2[16] and the default Distillate Fuel No. 2 HHV from 40 CFR Part 98.

GHG emissions (as CO_2e) from the generators were calculated using GWP emission factors provided in IPCC's Sixth Assessment Report (2021) using the same equation and methodology described for commercial marine vessels (see Section 2.2.1.4).

15 From 40 CFR Part 98 Table C-1: Default CO_2 Emission Factors and High Heat Values for Various Types of Fuel.

16 From 40 CFR Part 98 Table C-2: Default CH_4 and N_2O Emission Factors for Various Types of Fuel.

HAP emission factors for generators smaller than 447 kW (600 horsepower [hp]) were based on the HAP emission factors for small uncontrolled stationary diesel engines from AP-42.[17] For generators larger than 447 kW (600 hp), the HAP emission factors were based on the emission factors for large uncontrolled stationary diesel engines from AP-42.[18] For all generators, the HAP emission factors in lb/MMBtu were converted to lb/gal using the default HHV for Distillate No. 2 Fuel Oil from 40 CFR Part 98 Table C-1. These lb/gal emission factors were multiplied by the total fuel use of each generator to determine total emissions of HAPs. Pb emissions from engines firing ULSD were assumed to be negligible.

2.2.3 Other Offshore Construction Equipment

Various construction equipment may be used aboard vessels as well as on the WTGs and ESP(s) during construction and operation of Vineyard Mid-Atlantic. The assumptions used to estimate emissions from major offshore construction equipment (e.g., pile driving hammer engines, air compressors, motion compensation platform engines, winches, etc.) are described in Section 2.2.3.1, followed by a discussion of the emission factors used for the construction equipment in Section 2.2.3.2.

2.2.3.1 Assumptions for Offshore Construction Equipment

Pile Driving Hammer Engines

It was conservatively assumed that two ESPs will have 12 jacket piles each and that 116 WTGs will be installed on monopiles, which provides the maximum number of piles that may be driven for Vineyard Mid-Atlantic. For each pile, it was conservatively assumed that pile driving would take approximately six hours to achieve the target penetration depth (including time to power up and power down the hammer engines). It was conservatively assumed that the pile driving hammer engines would operate at 100% load.

Engine size and fuel usage were determined from the equipment specification sheet of a diesel engine that is representative of the type of engine used for pile driving. Based on the specification sheet, it was assumed that three ~747 kW engines will power the pile driving

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17 The HAP emission factor for small uncontrolled stationary diesel engines is the sum of emission factors listed in AP-42 from Table 3.3-2: Speciated Organic Compound Emission Factors for Uncontrolled Diesel Engines; Table 1.3-10: Emission Factors for Trace Elements from Distillate Fuel Oil Combustion Sources; and Table 3.1-5: Emission Factors for Metallic Hazardous Air Pollutants from Distillate Oil-Fired Stationary Gas Turbines.

18 The HAP emission factor for large uncontrolled stationary diesel engines is the sum of emission factors listed in AP-42 from Table 1.3-10: Emission Factors for Trace Elements from Distillate Fuel Oil Combustion Sources; Table 3.4-3: Speciated Organic Compound Emission Factors for Large Uncontrolled Stationary Diesel Engines; Table 3.4-4: PAH Emission Factors for Large Uncontrolled Stationary Diesel Engines; and Table 3.1-5: Emission Factors for Metallic Hazardous Air Pollutants from Distillate Oil-Fired Stationary Gas Turbines.

hammer. As described in Section 2.2.3.2, emissions from the engines used to power the pile driving hammer were estimated based on a Tier 2 marine engine burning fuel with a sulfur content of 1,000 ppm.

Air Compressors

The air compressors that may be used for noise mitigation devices (e.g., bubble curtains) were assumed to operate for eight hours per pile driven. Engine size and fuel usage were determined from the equipment specification sheet of a diesel air compressor that is representative of the type of compressor typically used for noise mitigation in offshore wind projects. As discussed further in Section 2.2.3.2, emissions from the air compressors were estimated based on a Tier 2 marine engine burning fuel with a sulfur content of 1,000 ppm.

Motion Compensation Platform Engines

Depending on the type of transport vessel used, the WTGs or foundation components may need to be held by a motion compensation platform during lifting operations. During the lift of the foundation or WTG, the motion compensation platform compensates for the vessel's roll, pitch, and heave motions.

For the air emissions estimates, it was assumed that the transition pieces will be delivered to the Lease Area using vessels that employ a motion compensation platform. For each transition piece, it was conservatively estimated that the motion compensation platform's engines would operate for two hours at 100% load to hold the transition piece steady for lifting operations.

Engine size and fuel usage were determined from the equipment specification sheet of a typical diesel engine that could be used to power a motion compensation platform. It was assumed that three ~510 kW engines will power the motion compensation platform. Emissions from the engines used to power the motion compensation platform were estimated based on a Tier 2 marine engine burning fuel with a sulfur content of 1,000 ppm (see Section 2.2.3.2).

Winches

Winches will likely be used to pull offshore cables into the ESP(s) and WTGs. For winching operations, it was assumed that an ~4 kW generator would operate at 100% load for eight hours at each WTG/ESP position. Engine size and fuel usage were determined from the equipment specification sheet of a typical diesel engine that could be used to power a winch. As described further in Section 2.2.3.2, emissions were estimated based on a Tier 2 marine engine burning fuel with a sulfur content of 1,000 ppm.

Cable Landing Tensioner

A cable tensioner may be used aboard a vessel to pull the offshore export cables through conduits installed at the landfall site(s). It was assumed that a cable tensioner would operate for 45 hours at 100% load for each cable pull-in operation. Engine size and fuel usage were determined from the equipment specification sheet of a typical diesel engine that could be used to power a cable tensioner. As discussed in Section 2.2.3.2, emissions from the ~90 kW engine used to power the tensioner were estimated based on a Tier 2 marine engine burning fuel with a sulfur content of 1,000 ppm.

Cable Landing Excavator

Assuming HDD is used at the landfall site(s), to facilitate offshore export cable pull-in, an offshore exit pit will be excavated possibly using an offshore excavator aboard a vessel (other methods that may be used include controlled flow excavation, etc.). It was conservatively assumed that an ~258 kW excavator would operate at 100% load for 27 hours per cable. Engine size and fuel usage were determined from the equipment specification sheet of a typical excavator. As discussed in Section 2.2.3.2, emissions from the excavator's engines were estimated based on a Tier 2 marine engine burning fuel with a sulfur content of 1,000 ppm.

Cable Landing Generator

In addition to a tensioner and excavator, a generator may be used to perform cable pull-in operations at the landfall site(s). It was assumed that an ~283 kW generator would operate for 72 hours at 100% load for each offshore export cable. Fuel usage was determined from the equipment specification sheet of a representative diesel generator. As discussed in Section 2.2.3.2, emissions from the generator's engines were estimated based on a Tier 2 marine engine burning fuel with a sulfur content of 1,000 ppm.

2.2.3.2 Emission Factors for Offshore Construction Equipment

Emission factors assumed for offshore construction equipment are provided in Table 2.2-8.

Table 2.2-8 Assumed EPA Emission Standards

Engine	EPA Engine Standard[1]	Emission Factors (g/kW*hr)		
		HC + NOx	CO	PM
Pile Driving Hammer Engine (~747 kW)	EPA Tier 2 Marine Engine (for Category 1 Engines with 1.2 ≤ disp. < 5.0)	7.2	5.0	0.20
Air Compressor (~399 kW)	EPA Tier 2 Marine Engine (for Category 1 Engines with 1.2 ≤ disp. < 5.0)	7.2	5.0	0.20
Motion Compensation System Platform Engine (~510 kW)	EPA Tier 2 Marine Engine (for Category 1 Engines with 1.2 ≤ disp. < 5.0)	7.2	5.0	0.20
Winch Engine (~4 kW)	EPA Tier 2 Marine Engine (for kW < 8)	7.5[2]	8.0	0.80
Tensioner Engine (~90 kW)	EPA Tier 2 Marine Engine (for Category 1 Engines with 0.9 ≤ disp. < 1.2)	7.2	5.0	0.30

Table 2.2-8 Assumed EPA Emission Standards (Continued)

Engine	EPA Engine Standard[1]	Emission Factors (g/kW*hr)		
		HC + NOx	CO	PM
Excavator Engine (~258 kW)	EPA Tier 2 Marine Engine (for Category 1 Engines with 1.2 ≤ disp. < 5.0)	7.2	5.0	0.20
Cable Landing Generator (~283 kW)	EPA Tier 2 Marine Engine (for Category 1 Engines with 1.2 ≤ disp. < 5.0)	7.2	5.0	0.20

Notes:
1. "Disp." = Displacement in liters per cylinder.
2. Non-methane hydrocarbon (NMHC) + NOx emission standard.

Based on the Revolution Wind OCS Air Permit, it was assumed that NOx is 97.6% of HC + NOx (or non-methane hydrocarbon [NMHC] + NOx), HC is 2.4% of HC + NOx (or NMHC + NOx), and VOC is 1.053 times the HC (or NMHC) emission factor (EPA 2023b). Based on guidance from EPA's (2010a) *Exhaust and Crankcase Emission Factor for Nonroad Engine Modeling – Compression Ignition Report*, it was assumed that 100% of PM is PM_{10} and 97% of PM is $PM_{2.5}$.

SO_2 emission factors were developed using a mass balance based on the consumption of diesel fuel containing 1,000 ppm sulfur, a fuel density of 7.1 lb/gal, and a 2:1 mass ratio of SO_2 to sulfur. Total tons of SO_2 were calculated using the same equation as described for the offshore generators (see Section 2.2.2).

CO_2 emission factors were based on the default Distillate Fuel No. 2 CO_2 emission factor (73.96 kg CO_2/MMBtu) and HHV (0.138 MMBtu/gal) from 40 CFR Part 98 Table C-1.[19] CH_4 and N_2O emission factors were based on default CH_4 and N_2O emission factors for petroleum from 40 CFR Part 98 Table C-2[20] and the default Distillate Fuel No. 2 HHV from 40 CFR Part 98. GHG emissions as CO_2e were calculated using GWP emission factors using the same methodology as described for commercial marine vessels (see Section 2.2.1.4).

The Pb and HAP emission factors for the pile driving hammer engines and motion compensation platform engines were based on the Pb and HAP emission factors for large (greater than 600 hp) uncontrolled stationary diesel engines from AP-42.[21] The Pb and HAP

[19] Distillate Fuel Oil No. 2 HHV and CO_2 emission factor are from 40 CFR Part 98 Table C-1: Default CO_2 Emission Factors and High Heat Values for Various Types of Fuel.

[20] Default CH_4 and N_2O emission factors are from 40 CFR Part 98 Table C-2: Default CH_4 and N_2O Emission Factors for Various Types of Fuel

[21] The HAP emission factor for large uncontrolled stationary diesel engines is the sum of emission factors listed in AP-42 from Table 1.3-10: Emission Factors for Trace Elements from Distillate Fuel Oil Combustion Sources; Table 3.4-3: Speciated Organic Compound Emission Factors for Large Uncontrolled Stationary Diesel Engines; Table 3.4-4: PAH Emission Factors for Large Uncontrolled Stationary Diesel Engines; and Table 3.1-5: Emission Factors for Metallic Hazardous Air Pollutants from Distillate Oil-Fired Stationary Gas Turbines. The Pb emission factor is from Table 3.1-5:

emission factors for the remaining construction equipment were based on the Pb and HAP emission factors for small (less than 600 hp) uncontrolled stationary diesel engines from AP-42.[22] The Pb and HAP emission factors in lb/MMBtu were converted to lb/gal using the default HHV for Distillate No. 2 Fuel Oil from 40 CFR Part 98 Table C-1. These lb/gal emission factors were multiplied by the total fuel use of the offshore construction equipment to determine total emissions of Pb and HAPs.

2.2.4 Helicopters

Air emissions from helicopters were calculated using the BOEM Wind Tool methodology. All helicopters for Vineyard Mid-Atlantic were assumed to be medium-sized twin-engine helicopters. Emissions from helicopters were calculated based on the following equation:

$$E = hours * EF * 0.0005$$

Where:

- *E* = total emissions (US tons)
- *hours* = total hours in flight
- *EF* = emission factor (lb/hr)
- *0.005* = pounds to ton conversion factor

Total hours in flight were based on the total distance each helicopter is expected to travel and the BOEM Wind Tool default speed (183 miles [mi] per hr) for twin medium helicopters. The approximate distance traveled by the helicopters is provided in Attachment B. The emission estimates used the following emission factors for twin-medium helicopters from the BOEM Wind Tool.

Table 2.2-9 BOEM Default Emission Factors for Twin-Medium Helicopters

Helicopter Type	Helicopter Emission Factors (lb/hr)									
	NOx	VOC	CO	PM_{10}	$PM_{2.5}$	SO_2	CO_2	CH_4	N_2O	PB
Twin Medium	7.22	3.02	3.48	0.2031	0.1982	0.78	2459.9	0.07	0.08	0

Emission Factors for Metallic Hazardous Air Pollutants from Distillate Oil-Fired Stationary Gas Turbines.

22 The HAP emission factor for small uncontrolled stationary diesel engines is the sum of emission factors listed in AP-42 from Table 3.3-2: Speciated Organic Compound Emission Factors for Uncontrolled Diesel Engines; Table 1.3-10: Emission Factors for Trace Elements from Distillate Fuel Oil Combustion Sources; and Table 3.1-5: Emission Factors for Metallic Hazardous Air Pollutants from Distillate Oil-Fired Stationary Gas Turbines. The Pb emission factor is from Table 3.1-5: Emission Factors for Metallic Hazardous Air Pollutants from Distillate Oil-Fired Stationary Gas Turbines.

Since the BOEM Wind Tool does not provide emission factors for HAPs, HAP emissions from helicopters were estimated using a similar methodology used to estimate HAP emissions from vessels (see Section 2.2.1.4). HAP emissions were estimated by applying speciation profiles to the VOC estimates for organic HAPs and PM_{10} estimates for metal HAPs using the following equation:

$$E = VOC * SF_{VOC} + PM_{10} * SF_{PM10}$$

Where:

- E = total HAP emissions, tons
- VOC = total VOC emissions, tons
- PM_{10} = total PM_{10} emissions, tons
- SF_{VOC} = speciation factor for VOC
- SF_{PM10} = speciation factor for PM_{10}

The HAP speciation profile for helicopters was created using HAPs, VOC, and PM emission factors for distillate oil-fired stationary gas turbines found in AP-42 Chapter 3.1 Tables 3.1-2a, 3.1-4, and 3.1-5.

GHG emissions as CO_2e from helicopters were calculated based on the total tons of CH_4, N_2O, and CO_2 using the same equation and methodology described for commercial marine vessels (see Section 2.2.1.4).

Fuel use from helicopters was calculated using the default fuel consumption rate for twin medium helicopters provided in the BOEM Wind Tool. The default fuel usage rate (117 gal/hr) was multiplied by the total hours in flight to determine the total quantity of fuel used.

2.2.5 Onshore Non-Road Engines

Emissions from non-road engines in onshore construction equipment (e.g., cranes, excavators, drilling rigs, etc.) were calculated using EPA's (2018b) Motor Vehicle Emission Simulator, MOVES2014b. Emission factors from MOVES2014b were used to calculate emissions for each pollutant (NOx, VOC, CO, PM_{10}, $PM_{2.5}$, SO_2, CO_2, CH_4, and HAPs[23]). To calculate emission factors and fuel consumption rates for onshore activities, a run was completed for a weekday in August 2022. Air emissions from non-road equipment were primarily calculated based on each equipment's hours of operation and emission factor using the following equation:

$$E = hours * EF * 1.10231 \times 10^{-6}$$

23 MOVES2014b provides emission factors for individual HAPs, which were summed together.

Where:

- *E* = total emissions (US tons)
- *hours* = duration of each activity (hr)
- *EF* = emission factor (g/hr)
- 1.10231×10^{-6} = g to ton conversion factor

For some equipment, air emissions from non-road equipment were calculated based on hours of operation, engine size, load factor, and emission factor using the following equation:

$$E = kW * hours * LF * EF * 1.10231 \times 10^{-6}$$

Where:

- *E* = total emissions (US tons)
- *kW* = total engine size (kW)
- *hours* = duration of each activity (hr)
- *LF* = engine load factor (unitless)
- *EF* = emission factor (g/kW-hr)
- 1.10231×10^{-6}= g to ton conversion factor

GHG emissions (as CO_2e) were calculated using GWP emission factors provided in IPCC's Sixth Assessment Report (2021) using the same equation and methodology described for commercial marine vessels (see Section 2.2.1.4).

Load factors were from EPA's (2010b) *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling*. Activity types and hours of operation were largely based on inputs from the Proponent's engineers. Key assumptions used to estimate non-road emissions for Vineyard Mid-Atlantic are listed in the table below for each onshore activity. These calculations can be found in Attachment B.

Table 2.2-10 Key Assumptions for Non-Road Engine Onshore Activities

Onshore Activity	Assumptions
Onshore port activities	• During construction: o Each foundation will take approximately six hours of crane operations to offload and load onto a vessel. o Each WTG will take approximately 14 hours of crane operations to offload and load onto a vessel. o Offloading and loading offshore cables onto vessels will take approximately two 24-hour days per vessel round trip. • During O&M: o A crane will be used for approximately one 24-hour day each time the WTG repair support vessel transits to port.

Table 2.2-10 Key Assumptions for Non-Road Engine Onshore Activities (Continued)

Onshore Activity	Assumptions
All onshore construction	• Typical work hours for installation of the onshore cables will be 7:00 AM to 6:00 PM (11-hr days). Typical work hours at the landfall site(s) will be 7:00 AM to 7:00 PM (12-hr days). • All equipment will use ULSD. • Concrete trucks have a capacity of 7 m^3 (9.5 cubic yards) and take two hours per load, including travel.
Trench, conduit, duct bank, and splice vault installation	• The maximum total length of the onshore cable routes is ~70 kilometers (km) (43 mi). • The maximum cross-sectional area of the duct bank trench is approximately 14 square meters (m^2) (149 square feet [ft^2]). • The maximum duct bank cross sectional area is ~4.6 m^2 (~50 ft^2). • The maximum cross-sectional area of the pit excavated for splice vaults is ~80 m^2 (~860 ft^2). The maximum length is ~15 meters (m) (~50 feet [ft]). • On average, onshore construction (trenching, duct bank installation, concrete pouring, etc.) will occur a rate of ~35 m (~115 ft) per day.[1] • There will be splice vaults every ~152 m (~500 ft).[2] • Each splice vault will take approximately one hour to place by crane.
Cable delivery, pulling, splicing, and termination	• Cable pulling will take approximately 530 days. • Cable splicing and termination will take approximately 980 days.
Construction at the landfall sites and other trenchless crossings	• Set up of the drilling rigs will take approximately two weeks (six 12-hr workdays per week) per landfall site/trenchless crossing. • Drilling at the landfall site/trenchless crossing will require approximately six weeks (six 12-hr workdays per week) per cable conduit. • Dismantling the drilling rigs will take approximately one week (six 12-hr workdays per week) per landfall site/trenchless crossing.
Onshore substation construction	• Clearing/grading each onshore substation site will take approximately two months and clearing/grading each onshore RCS site will take approximately eight days. • Overall, construction and commissioning of each onshore substation and onshore RCS will take up to approximately 44 months. • Each onshore substation will include concrete pad(s) ~2,787 m^2 (30,000 ft^2) in size and ~0.2 m (0.7 ft) thick and have ~4,000 m^2 (1.0 acre) of internal gravel roadways of the same thickness. • Each onshore RCS site will include concrete pad(s) ~372 m^2 (4,000 ft^2) in size and 0.2 m (0.7 ft) thick and have ~540 m^2 (0.13 acre) of internal gravel roadways of the same thickness.

Notes:

1. Onshore construction is typically expected to proceed at an average rate of approximately 24 to 61 m (80 to 200 ft) per day depending on a number of factors including existing utility density.
2. Onshore cables typically require splices approximately every 152–457 m (500–1,500 ft) or more.

2.2.6 On-Road Vehicles

NOx, VOC, CO, and $PM_{2.5}$ emissions from on-road vehicles (passenger cars, light-duty trucks, and heavy-duty trucks) were calculated using emission factors for the year 2024 from the Bureau of Transportation Statistics' (2021) "Table 4-43 Estimated U.S. Average Vehicle emissions Rates per Vehicle by Vehicle Type Using Gasoline and Diesel." These emission factors are generated from EPA's MOtor Vehicle Emission Simulator (MOVES3). PM_{10} was estimated from $PM_{2.5}$, assuming a PM_{10} to $PM_{2.5}$ ratio of 1.130 for gasoline and 1.087 for diesel based on the MOVES Speciation Report (EPA 2020).

SO_2 emission factors were calculated using the following mass balance equation based on fuel sulfur content, fuel density, and fuel economy, and assuming 100% conversion of sulfur to SO_2 (a 2:1 mass ratio of SO_2 to sulfur):

$$EF_{SO2} = fuel\ sulfur/1{,}000{,}000 * fuel\ density/MPG * 64\ lb\ SO_2/32\ lb\ S * 453.592$$

Where:

- EF_{SO2} = SO_2 emission factor (g/mile)
- *fuel sulfur* = fuel sulfur content (15 ppm for diesel and 10 ppm for gasoline)
- *fuel density* = 7.1 lb/gal for diesel and 6.2 lb/gal for gasoline
- *MPG* = fuel economy (mi/gal)
- 453.592 = lb to g conversion factor

CO_2 emission factors for diesel-fired vehicles were based on the default Distillate Fuel No. 2 CO_2 emission factor (73.96 kg CO_2/MMBtu) and HHV (0.138 MMBtu/gal) from 40 CFR Part 98 Table C-1.[24] CO_2 emission factors for gas-fired vehicles were based on the default motor gasoline CO_2 emission factor (70.22 kg CO_2/MMBtu) and HHV (0.125 MMBtu/gal) from 40 CFR Part 98 Table C-1. For both diesel and gas-fired vehicles, CH_4 and N_2O emission factors were based on default CH_4 and N_2O emission factors for petroleum from 40 CFR Part 98 Table C-2[25] and the default HHV from 40 CFR Part 98. Pb and HAP emissions were assumed to be negligible.

GHG emissions (as CO_2e) from vehicles were calculated using GWP emission factors provided in IPCC's Sixth Assessment Report (2021) using the same equation and methodology described for commercial marine vessels (see Section 2.2.1.4).

[24] From 40 CFR Part 98 Table C-1: Default CO_2 Emission Factors and High Heat Values for Various Types of Fuel.

[25] From 40 CFR Part 98 Table C-2: Default CH_4 and N_2O Emission Factors for Various Types of Fuel.

Air emissions from on-road vehicles were then calculated based on the above emission factors and the distance each vehicle is expected to travel using the following equation:

$$E = miles * EF * 1.10231 \times 10^{-6}$$

Where:

- E = total emissions (US tons)
- *miles* = total distance traveled (mi)
- EF = emission factor (g/mile)
- 1.10231×10^{-6} = g to ton conversion factor

The number of round trips taken by workers' personal vehicles was based on the duration of each activity. The number of round trips taken by delivery vehicles and dump trucks was based on the quantity of materials requiring transport. These calculations can be found in Attachment B. Key assumptions used to generate on-road emission estimates are listed in the table below for each onshore construction and O&M activity.

Table 2.2-11 Key Assumptions for On-Road Vehicles

Onshore Activity	Assumptions
Onshore port activities	• During construction and O&M, there will be 25 port workers who will commute on average 24 km (15 mi) each way.[1]
All onshore construction	• Workers will commute on average 24 km (15 mi) each way.[1] • Vehicles will not idle. • Dump trucks have a capacity of 15 m^3 (20 cubic yards) and travel 48 km (30 mi) each way.
Trench, conduit, duct bank, and splice vault installation	• All dirt and pavement will be hauled away as it is excavated. • All backfill will be delivered by dump truck. • Conduits will be delivered on one flatbed truck per day. • Installation of the onshore cables will require a 20-man crew.
Cable delivery, pulling, splicing, and termination	• Cable pulling will take approximately 530 days. • Cable splicing and termination will take approximately 980 days. • Cable delivery, pulling, splicing, and termination will require two heavy-duty support trucks and two crew trucks.
Construction at the landfall sites and other trenchless crossings	• Construction at the landfall sites and at other trenchless crossings will require a 20-person crew.
Onshore substation construction	• Onshore substation and onshore RCS construction will require one truck delivery per day while equipment is being installed. • Onshore substation and onshore RCS construction will require a 20-person crew.

Table 2.2-11 Key Assumptions for On-Road Vehicles (Continued)

Onshore Activity	Assumptions
Onshore O&M	• Each day, 20 O&M workers will commute on average 24 km (15 mi) each way.[1] • Onshore substation and onshore RCS inspections will be carried out weekly.

Note:

1. Bureau of Transportation Statistics (2003).

2.2.7 Construction Dust

Particulate emissions from onshore construction activities were estimated according to the methodology provided in EPA's *AP-42, Chapter 13.2.3: Heavy Construction Operation*. Particulate emissions are proportional to the size of the construction area and level of construction activity. PM_{10} emissions from onshore cable installation, landfall site activities, and onshore substation and onshore RCS construction were estimated using the following equation:

$$E = 1.2 * months * acres$$

Where:

- E = total PM_{10} emissions (US tons)
- *months* = duration of activity (months)
- *acres* = area of construction (acres)
- 1.2 = emission factor (tons PM/acre*month)

To estimate onshore construction dust emissions, it was assumed that each 35 m (115 ft) section of trench will be an active construction site for two days, each onshore substation construction area will be ~0.06 square kilometers (km^2) (~15 acres), each onshore RCS construction area will be 0.008 km^2 (2 acres), and each landfall site or trenchless crossing construction staging area will be approximately 0.008 km^2 (2 acres).

According to AP-42 Section 13.2.3.3, the emission factor of 1.2 tons/acre*month will result in conservatively high estimates of PM_{10} and "may result in too high an estimate for PM_{10} to be of much use for a specific site under consideration." While AP-42 Chapter 13.2.3 recommends estimating construction particulate emissions by breaking down the construction process into component operations using *Table 13.2.3-1: Recommended Emission Factors for Construction Operations* instead, the emission factors and equations provided in the table require specific information beyond what is currently available for Vineyard Mid-Atlantic. It was conservatively estimated that 100% of PM_{10} from construction dust is $PM_{2.5}$.

PM emissions from miscellaneous operations offshore, such as sanding or grinding, are expected to be trivial.

2.2.8 Fugitive Emissions

During construction, it was conservatively estimated that 1 ton per year of VOCs would be emitted from fugitive emissions of solvents, paints, coatings, and diesel fuel storage/transfer. During O&M, it was assumed that there would be fugitive emissions from the use of 303 liters (80 gals) of marine paint for touch-ups each year. The VOC emission rate was based on the product information sheet for White Ketamine Marine Primer,[26] which had the highest VOC content from a selection of several marine coatings material sheets. Fugitive emissions from kitchen and sanitary facilities on vessels are expected to be trivial.

SF_6 may be used to insulate electrical equipment offshore and onshore. The Proponent's engineers indicated that there would be up to approximately 25 kg (55 lb) of SF_6 on each WTG and 10,300 kg (22,708 lb) on each ESP. Emissions of SF_6 used to insulate electrical equipment on the WTGs and ESP(s) were estimated based on an annual leak rate of 0.5%. It was assumed that the onshore substations and onshore RCSs would contain a total of 118,252 kg (260,700 lb) of SF_6 and would have an annual leak rate of 0.5%. GHG emissions of SF_6 as CO_2e were calculated using a GWP of 25,200 from IPCC's Sixth Assessment Report (2021). SF_6 calculations are provided in Attachment C.

[26] Cardinal White Ketamine Marine Primer from http://www.cardinalpaint.com/assets/TDS/7M90-10-tds.pdf.

3 Summary of Potential Emissions

Table 3-1 provides an estimate of emissions within the US (offshore and onshore) from the construction of Vineyard Mid-Atlantic. These construction emissions were conservatively assumed to be distributed over a three-year period.

Table 3-1 Estimated Air Emissions from the Construction of Vineyard Mid-Atlantic

	NOx	VOCs	CO	PM_{10}	$PM_{2.5}$	SO_2	HAPs	CO_2e
Offshore Emissions								
Year 1 construction emissions (US tons)	5,220	118	1,173	173	166	38	16	335,602
Year 2 construction emissions (US tons)	6,800	154	1,528	225	216	50	21	437,204
Year 3 construction emissions (US tons)	4,045	92	909	134	129	30	13	260,083
Onshore Emissions								
Year 1 construction emissions (US tons)	1	0.1	1	24	24	0.0	0.0	17,243
Year 2 construction emissions (US tons)	103	6	45	54	54	0.2	3	53,484
Year 3 construction emissions (US tons)	74	4	33	30	30	0.2	2	45,788
Total Emissions								
Year 1 construction emissions (US tons)	5,221	118	1,174	197	190	38	16	352,845
Year 2 construction emissions (US tons)	6,903	160	1,573	279	270	50	24	490,688
Year 3 construction emissions (US tons)	4,119	96	941	164	159	30	14	305,872

Table 3-2 provides an estimate of potential emissions from the O&M of Vineyard Mid-Atlantic, including an estimate of air emissions for a typical year of operation (for planned, routine O&M activities) as well as an estimate of the maximum annual operational air emissions (assuming several repair activities occur all within the same year).

Table 3-2 Estimated Air Emissions from the Operation of Vineyard Mid-Atlantic

	NOx	VOCs	CO	PM_{10}	$PM_{2.5}$	SO_2	HAPs	CO_2e
Offshore Emissions								
Operational emissions, typical year (US tons per year)	453	8	118	15	15	1	1	34,664
Operational emissions, maximum year (US tons per year)	750	13	184	24	23	2	2	53,091
Onshore Emissions								
Operational emissions (US tons per year)	0.1	0.1	0.9	0.0	0.0	0.0	0.0	16,546
Total Emissions								
Operational emissions, typical year (US tons per year)	453	8	118	15	15	1	1	51,210
Operational emissions, maximum year (US tons per year)	750	13	185	24	23	2	2	69,637

Most of the air emissions from the construction and operation of Vineyard Mid-Atlantic will occur offshore within the Lease Area, OECC, and surrounding waters. Only a limited proportion of the emissions reported in Tables 3-1 and 3-2 will occur at ports. Table 3-3 quantifies the subset of emissions that could occur within 5.6 kilometers (km) (3 NM) of the ports used during the construction and operation of Vineyard Mid-Atlantic. Due to the uncertainty regarding the combination of ports that may be used for Vineyard Mid-Atlantic, it is conservatively assumed that these estimated construction and operational emissions could all occur at one port (in a maximum case scenario) or be spread amongst several of the ports identified in Sections 3.10.1 and 4.4.1 of COP Volume I.

Table 3-3 Estimated Air Emissions from Activities in Port

	NOx	VOCs	CO	PM_{10}	$PM_{2.5}$	SO_2	HAPs	CO_2e
Total port-related construction emissions (US tons)[1]	323	5	80	11	10	0.6	0.8	21,248
Total port-related operational emissions, maximum year (US tpy)[1]	85	1	21	3	3	0.1	0.2	5,492

Note:

1. Includes emissions from onshore equipment and vehicles at a port as well as emissions from vessels hoteling, maneuvering, and transiting within 5.6 km (3 NM) of a port.

4 Avoided Emissions and Avoided Social Cost of GHGs

Vineyard Mid-Atlantic will produce clean, renewable offshore wind energy that is expected to displace electricity generated by fossil fuel power plants. To quantify the NOx, SO_2, CO_2, CH_4, N_2O, and total GHG (reported as CO_2e) emissions associated with conventional power generation that would be avoided due to Vineyard Mid-Atlantic, the following equation was used:

$$AE_i = EF_i * PG * 8{,}760\ hr/year * CF * (1- TLF) * 0.0005\ ton/lb$$

Where:

- AE_i = annual avoided emissions for pollutant i (tons)
- EF_i = eGRID avoided emission factor for pollutant i (lb/megawatt [MW]-hr)
- *PG* = total rated peak power generation (MW)
- *CF* = capacity factor
- *TLF* = transmission loss factor

The avoided emissions analysis uses the Northeast Power Coordinating Council (NPCC) Long Island annual non-baseload output emission rates from EPA's (2023a) Emissions & Generation Resource Integrated Database (eGRID2021)[27,28] shown in Table 4-1.

Table 4-1 eGRID Avoided Emission Factors (lb/MW-hr)

	NOx	SO_2	CO_2	CH_4	N_2O	CO_2e
eGRID avoided emission factor (lb/MW-hr)	0.893	0.324	1,317	0.040	0.005	1,320

The analysis is based on the approximate nameplate capacity for the entire Lease Area of 2,000 MW and assumes an annual capacity factor[29] of 43%. The export cables may be 220–345 kilovolt (kV) high voltage alternating current (HVAC) cables and/or 320–525 high voltage direct

[27] The avoided emissions analysis is based on NPCC Long Island subregion annual non-baseload output emission rates from EPA's Emissions & Generation Resource Integrated Database (eGRID2021) released 1/30/2023 https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

[28] An updated version (Version 2.0) of the BOEM Wind Tool was released in 2021 (Chang et al. 2021), which recommends the use of EPA's AVoided Emissions and geneRation Tool (AVERT) data to estimate avoided emissions. However, inputting the approximate nameplate capacity of Vineyard Mid-Atlantic into AVERT results in an error message because the power from Vineyard Mid-Atlantic would displace more than 30% of regional fossil generation in New York State for at least one hour of the year and the recommended limit for AVERT is 15%. As such, the Proponent used EPA's eGRID data, as recommended by Version 1 of the BOEM Wind Tool. BOEM has accepted this approach for past projects and indicated that it was acceptable to use eGRID for Vineyard Mid-Atlantic during a call on June 15, 2023.

[29] Capacity factor refers to the ratio of an offshore wind project's annual power production to the nameplate production potential.

current (HVDC) cables. Given that HVAC export cables are expected to have greater transmission losses than HVDC export cables, the avoided emissions analysis conservatively assumed a transmission loss factor based on the use of 220 kV HVAC cables for all export cables. The transmission loss factor was determined from Lazaridis's (2005) *Economic Comparison of HVAC and HVDC Solutions for Large Offshore Wind Farms under Special Consideration of Reliability*.[30] The study gives average transmission loss factors for 400 to 1,000 MW offshore wind projects using 123 kV, 220 kV, and 400 kV three-core HVAC cables with cross-linked polyethylene (XLPE) insulation for various distances and windspeeds. These values were interpolated to determine an average transmission loss factor of 4.9% (see Attachment D).

Table 4-2 quantifies the air emissions associated with fossil fuel power plants that could be avoided by using electricity generated from Vineyard Mid-Atlantic. Additional avoided emission calculation details can be found in Attachment D.

Table 4-2 Avoided Air Emissions Resulting from Vineyard Mid-Atlantic

	NOx	**SO_2**	**CO_2**	**CH_4**	**N_2O**	**CO_2e**
Emissions Avoided Annually (US tons/year)	3,198	1,160	4,717,722	143	18	4,726,614

The "social cost of greenhouse gases" (SC-GHG) is the monetary value of the net harm to society associated with adding an incremental amount of GHGs to the atmosphere in a given year (IWG 2021). The SC-GHG can be used to indicate the societal value (i.e., savings or avoided social costs) of reducing GHG emissions. In principle, the SC-GHG includes the value of all climate change impacts, including changes in net agricultural productivity, human health effects, property damage from increased flood risk and natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services (IWG 2021). However, according to EPA (2023c), "In practice, because of data and modeling limitations, which prevent full representation of harmful climate impacts, estimates of the SC-GHG…are a partial accounting of climate change impacts and, as such, lead to underestimates of the marginal benefits of abatement." The estimate of social costs differs by the type of GHG (e.g., CO_2, CH_4, and N_2O), the year in which the emissions change occurs, and the discount rate applied (i.e., how future damages are converted into present-day values).

Table 4-3 presents estimates of the avoided social costs resulting from Vineyard Mid-Atlantic based on the avoided emission estimates presented in Table 4-2 and interim estimates of SC-GHG released by the US Government's Interagency Working Group (IWG) on Social Cost of Greenhouse Gases in 2021 (IWG 2021). The annual estimates of avoided social costs are

[30] The BOEM Wind Tool only provides a default transmission loss factor for HVDC export cables, which is 3%.

presented for the years 2030, 2040, and 2050[31] for discount rates ranging from 2.5 % to 5%.[32] IWG (2021) indicates its interim estimates of SC-GHG factors should be used by agencies until a comprehensive review and update is developed in line with the requirements of Presidential Executive Order 13990 (Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis).

In late 2023, EPA published estimates of SC-GHG that reflect recent advances in scientific literature on climate change and its economic impacts (EPA 2023c). Table 4-4 presents estimates of the avoided social costs resulting from Vineyard Mid-Atlantic based on the avoided emission estimates presented in Table 4-2 and EPA's SC-GHG estimates for the years 2030, 2040, and 2050 with a discount rate ranging from 1.5% to 2.5%.

As shown in Tables 4-3 and 4-4, there is considerable variability in the estimates of social costs avoided by Vineyard Mid-Atlantic depending on the source of the SC-GHG estimates, the year of the emission reduction, and the assumed discount rate. Based on IWG's estimates, the total avoided social costs (for CO_2, CH_4, and N_2O combined) from Vineyard Mid-Atlantic range from $82 million to $498 million annually between 2030 and 2050.[33] Based on EPA's estimates, the total avoided social costs range from $600 million to $2.06 billion annually between 2030 and 2050.[34] Avoided social costs for additional years (other than 2030, 2040, and 2050) and detailed calculations are provided in Attachment D.

[31] A sampling of years during which Vineyard Mid-Atlantic could be operational.

[32] Estimates of avoided social costs based on a discount rate of 5%, 3%, 2.5%, and the 95th percentile of estimates based on a 3% discount rate are provided in Attachment D.

[33] For discount rates of 5% to 2.5%. Avoided social costs using the 95th percentile of estimates based on a 3% discount rate are even greater (see Attachment D).

[34] For discount rates of 2.5% to 1.5%.

Table 4-3 Estimated Social Costs Avoided by Vineyard Mid-Atlantic (IWG 2021)

	Annual Avoided Social Costs (2020 dollars) Based on IWG 2021 Estimates[1,2]							
	CO_2		CH_4		N_2O		Total	
Year[3]	5% Rate	2.5% Rate	5% Rate	2.5% Rate	5% Rate	2.5% Rate	5% Rate	2.5% Rate
2030	$81,317,000	$380,906,000	$122,000	$325,000	$127,000	$536,000	$81,566,000	$381,767,000
2040	$106,996,000	$440,824,000	$169,000	$403,000	$162,000	$634,000	$107,327,000	$441,861,000
2050	$136,955,000	$496,462,000	$221,000	$494,000	$211,000	$731,000	$137,387,000	$497,687,000

Notes:

1. The avoided social costs are calculated from the avoided emission estimates presented in Table 4-2. The avoided emission estimates are based on the approximate nameplate capacity of Vineyard Mid-Atlantic and 2021 air emissions data for Long Island's electric grid, not future projections of emissions from the electric grid.
2. Avoided social costs using the 95th percentile of estimates based on a 3% discount rate are even greater (see Attachment D).
3. A sampling of years during which Vineyard Mid-Atlantic could be operational. Avoided social costs for other years are provided in Attachment D.

Table 4-4 Estimated Social Costs Avoided by Vineyard Mid-Atlantic (EPA 2023c)

	Annual Avoided Social Costs (2020 dollars) Based on EPA 2023 Estimates[1]							
	CO_2		CH_4		N_2O		Total	
Year[2]	2.5% Rate	1.5% Rate	2.5% Rate	1.5% Rate	2.5% Rate	1.5% Rate	2.5% Rate	1.5% Rate
2030	$599,178,000	$1,626,342,000	$247,000	$416,000	$731,000	$1,624,000	$600,156,000	$1,628,382,000
2040	$727,574,000	$1,840,334,000	$351,000	$546,000	$893,000	$1,949,000	$728,818,000	$1,842,829,000
2050	$855,969,000	$2,054,326,000	$455,000	$689,000	$1,072,000	$2,274,000	$857,496,000	$2,057,289,000

Notes:

1. The avoided social costs are calculated from the avoided emission estimates presented in Table 4-2. The avoided emission estimates are based on the approximate nameplate capacity of Vineyard Mid-Atlantic and 2021 air emissions data for Long Island's electric grid, not future projections of emissions from the electric grid.
2. A sampling of years during which Vineyard Mid-Atlantic could be operational. Avoided social costs for other years are provided in Attachment D.

5 References

Bureau of Transportation Statistics. 2003. From home to work, the average commute is 26.4 minutes. Omnistats, Vol. 3 (Issue 4). https://www.nrc.gov/docs/ML1006/ML100621425.pdf.

Bureau of Transportation Statistics. 2021. Estimated U.S. average vehicle emissions rates per vehicle by vehicle type using gasoline and diesel. [accessed 2022 June 7]. https://www.bts.gov/content/estimated-national-average-vehicle-emissions-rates-vehicle-vehicle-type-using-gasoline-and

Chang R, Do B, Billings R. 2017. Technical documentation for the offshore wind energy facilities emission estimating tool. US Dept. of the Interior, Bureau of Ocean Energy Management, Sterling, VA. OCS Study BOEM 2017-079. 51 pp. https://www.boem.gov/sites/default/files/renewable-energy-program/BOEM-Wind-Power-Technical-Documentation_2017_079-%281%29.pdf

Chang R, Mendenhall S, Lamie C, Perez H, Billings R. 2021. User's guide for the offshore wind energy facilities emission estimating tool, version 2.0. US Department of the Interior, Bureau of Ocean Energy Management, Sterling, VA. OCS Study BOEM 2021-046. 32 pp. https://www.boem.gov/sites/default/files/documents/about-boem/BOEM-Wind-Power-User-Guide-V2.pdf

[EPA] Environmental Protection Agency. 2009. Current methodologies in preparing mobile source port-related emission inventories: final report. https://archive.epa.gov/sectors/web/pdf/ports-emission-inv-april09.pdf

[EPA] Environmental Protection Agency. 2010a. Exhaust and crankcase emission factor for nonroad engine modeling –compression ignition report. https://nepis.epa.gov

[EPA] Environmental Protection Agency. 2010b. Median life, annual activity, and load factor values for nonroad engine emissions modeling. https://permanent.fdlp.gov/gpo48248/420r10016.pdf

[EPA] Environmental Protection Agency. 2015. commercial marine vessels – 2014 NEI commercial marine vessels final. https://www.epa.gov/sites/production/files/2015-12/documents/2014_nei_commercial_marine_vessels_reviewdraft20151217_cleaned.pdf

[EPA] Environmental Protection Agency. 2018a. 2014 national emissions inventory, version 2 technical support document (July 2018). https://www.epa.gov/sites/production/files/2018-07/documents/nei2014v2_tsd_05jul2018.pdf

[EPA] Environmental Protection Agency. 2018b. EPA releases MOVES2014b mobile source emissions model: questions and answers. [accessed 2020 May 1]. https://www.epa.gov/sites/production/files/2018-07/documents/nei2014v2_tsd_05jul2018.pdf

[EPA] Environmental Protection Agency. 2020. Speciation of total organic gas and particulate matter emissions from onroad vehicles in MOVES3. EPA-420-R-20-021. Office of Transportation and Air Quality. US Environmental Protection Agency. AnnArbor, MI. November 2020. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1010THD.pdf

[EPA] Environmental Protection Agency. 2022. Ports emissions inventory guidance: methodologies for estimating port-related and good movement mobile source emissions. EPA-420-B-22-011. Transportation and Climate Division, Office of Transportation and Air Quality. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf

[EPA] Environmental Protection Agency. 2023a. Emissions & generation resource integrated database (eGRID) (eGRID2021). Released January 30, 2023. https://www.epa.gov/egrid/download-data

[EPA] Environmental Protection Agency. 2023b. Outer Continental Shelf air permit: Revolution Wind, LLC offshore renewable wind energy development project. EPA Permit Number: OCS-R1-05. [accessed 2024 Jan 18]. https://www.epa.gov/system/files/documents/2023-09/rw-ocs-air-permit-ocs-r1-05-final-permit.pdf

[EPA] Environmental Protection Agency. 2023c. Report on the social cost of greenhouse gases: estimates incorporating recent scientific advances. November 2023. National Center for Environmental Economics Office of Policy, Climate Change Division, Office of Air and Radiation. [accessed 2024 Jan 2]. https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf

[ERG] Eastern Research Group. 2019a. Category 1 and 2 commercial marine vessel 2017 emissions inventory (2019). https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

[ERG] Eastern Research Group. 2019b. Category 3 commercial marine vessel 2017 emissions inventory. https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

[IPCC] Intergovernmental Panel on Climate Change. 2021. Climate change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Berger S, Caud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews JBR, Maycock TK, Waterfield T, Yelekçi O, Yu R, Zhou B (eds.)]. Cambridge University Press. InPress.

[IWG] Interagency Working Group on Social Cost of Greenhouse Gases. 2021. Technical support document: Social Cost of carbon, methane, and nitrous oxide interim estimates under Executive Order 13990. https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

Lazaridis LP. 2005. Economic comparison of HVAC and HVDC solutions for large offshore wind farms under special consideration of reliability. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.66.4595&rep=rep1&type=pdf

Attachment A

Detailed Emissions Estimates for Vineyard Mid-Atlantic

The detailed emission spreadsheets in this Attachment are redacted.

Vineyard Mid-Atlantic Emissions Summary

Construction Emissions	Year	Total Fuel Consumption (gal)	Vineyard Mid-Atlantic Total Emissions in US (US Tons)							
			NOX	VOC	CO	PM10	PM2.5	SO2	HAPs	CO2e
Offshore Emissions	Year 1	29,163,192	5,220	118	1,173	173	166	38	16	335,602
	Year 2	37,992,161	6,800	154	1,528	225	216	50	21	437,204
	Year 3	22,600,726	4,045	92	909	134	129	30	13	260,083
Onshore Emissions	Year 1	73,164	1	0.1	1	24	24	0.0	0.0	17,243
	Year 2	3,295,023	103	6	45	54	54	0.2	3	53,484
	Year 3	2,612,319	74	4	33	30	30	0.2	2	45,788
Total Emissions	Year 1	29,236,356	5,221	118	1,174	197	190	38	16	352,845
	Year 2	41,287,183	6,903	160	1,573	279	270	50	24	490,688
	Year 3	25,213,045	4,119	96	941	164	159	30	14	305,872

Annual O&M Emissions	Fuel Consumption per Year (gal)	Vineyard Mid-Atlantic Total Emissions in US (US Tons per Year)							
		NOX	VOC	CO	PM10	PM2.5	SO2	HAPs	CO2e
Offshore Emissions, Routine O&M	2,892,912	453	8	118	15	15	1	1	34,664
Onshore Emissions, Routine O&M	12,070	0.1	0.1	0.9	0.0	0.0	0.0	0.0	16,546
Total Emissions, Routine O&M	2,904,983	453	8	118	15	15	1	1	51,210
Offshore Emissions, Maximum	4,534,521	750	13	184	24	23	2	2	53,091
Onshore Emissions, Maximum	12,070	0.1	0.1	0.9	0.0	0.0	0.0	0.0	16,546
Total Emissions, Maximum	4,546,592	750	13	185	24	23	2	2	69,637

	Vineyard Mid-Atlantic Total US Port Emissions							
	NOX	VOC	CO	PM10	PM2.5	SO2	HAPs	CO2e
Total port-related construction emissions (US tons)	323	5	80	11	10	0.6	0.8	21,248
Total port-related operational emissions, maximum year (US tpy)	85	1	21	3	3	0.1	0.2	5,492

Attachment B

Vineyard Mid-Atlantic Parameters

This Attachment is redacted in its entirety.

Attachment C
Supporting Tables

This Attachment is redacted in its entirety.

Attachment D

Avoided Emissions and Social Cost of GHGs

Avoided Emissions for Vineyard Mid-Atlantic

Inputs	
Approximate Nameplate Capacity (MW)	2,000
Capacity Factor	43%
Transmission Loss Factor[1,2]	4.9%
Hours per year	8,760
Annual Power Generated (MW-hr)	7,162,638

1) Conservatively assumes that all export cables will be 220 kV HVAC cables.

2) From Lazaridis' (2005) Economic Comparison of HVAC and HVDC Solutions for Large Offshore Wind Farms under Special Consideration of Reliability. Tables 4.3 - 4.5: Average power losses in percent of the windfarm's average output power for different windfarm rated power, average wind speed, transmission distances and transmission voltage levels.

Pollutant	Avoided Emission Factor (lb/MWH)[1]	Displaced Emissions from Conventional Power Generation (US tons/year)	Fraction of 2021 NPCC Long Island Region Emissions (%)[2]
Avoided Emissions			
NOx	0.893	3,198	59%
SO2	0.324	1,160	74%
CO2e	1,320	4,726,614	65%
CO2	1,317	4,717,722	
CH4	0.040	143	
N2O	0.005	18	

1) Avoided emission factors use NPCC Long Island annual non-baseload output emission rates from EPA's eGRID2021 released 1/30/2023 https://www.epa.gov/egrid/download-data

2) Based on eGRID2021 (released 1/30/2023) subregion annual emissions.

Cars Removed Equivalency	
Avoided CO2e (US tons/year)	4,726,614
Avoided CO2e (metric tons/year)	4,287,913
EPA Metric tons CO2e per car per year[1]	4.6
Cars Removed from Road for the Duration of the Operational Period	932,155

1) Based on EPA Office of Transportation and Air Quality Report EPA-420-F-18-008 "Greenhouse Gas Emissions from a Typical Passenger Vehicle" (March 2018) - update

eGRID 2021 Emission Rates and Emissions										
		Non-baseload output emission rates						eGRID Subregion Annual Emissions		
eGRID subregion acronym	eGRID subregion name	annual NOx (lb/MWh)	SO2 (lb/MWh)	annual CO2e (lb/MWh)	annual CO2 (lb/MWh)	annual CH4 (lb/MWh)	annual N2O (lb/MWh)	annual NOx emissions (tons)	annual SO2 emissions (tons)	annual CO2 equivalent emissions
NEWE	NPCC New England	0.411	0.130	905	900	0.073	0.009	16,865	4,825	28,034,172
NWPP	WECC Northwest	1.526	0.758	1,555	1,546	0.139	0.020	78,145	48,492	90,292,281
NYCW	NPCC NYC/Westchester	0.309	0.011	932	931	0.020	0.002	3,674	173	13,290,453
NYLI	NPCC Long Island	0.893	0.324	1,320	1,317	0.040	0.005	5,444	1,576	7,275,719
NYUP	NPCC Upstate NY	0.439	0.062	884	881	0.047	0.006	4,291	628	10,005,339

Avoided Emissions for Vineyard Mid-Atlantic

Parameter	HVAC
Length per offshore export cable (km)	100
Length per onshore export cable (km)	28
Maximum total export cable length per cable (km)	128
Average transmission loss factor @ 100 km (assumed 220 kV HVAC)[1]	3.7
Average transmission loss factor @ 150 km (assumed 220 kV HVAC)[1]	5.9
Average transmission loss factor[1]	4.9

1) Given that HVAC export cables are expected to have greater transmission losses than HVDC export cables, the avoided emissions analysis conservatively assumed the use of 220 kV HVAC cables to transmit the Lease Area's entire capacity. The transmission loss factors are based on the highest windfarm rated power provided in the table

Transmission Loss Factors (%) for HVAC Cables for Different Windfarm Rated Power, Average Wind Speed, Transmission Distances and Transmission Voltage Levels												
400 MW Windfarm Rated Power												
	132 kV Cable Voltage				**220 kV Cable Voltage**				**400 kV Cable Voltage**			
Cable Length	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**
50 km	2.67	2.73	2.78	2.81	1.63	1.61	1.59	1.57	1.19	1.13	1.1	1.07
100 km	5.13	5.26	5.36	5.43	2.92	2.87	2.83	2.81	2.85	2.64	2.51	2.43
150 km	8.13	8.3	8.44	8.54	4.97	4.85	4.77	4.71	5.93	5.4	5.07	4.84
200 km	11.98	12.17	12.32	12.45	7.86	7.62	7.47	7.38	18.47	17.54	16.93	16.52
250 km	14.28	14.12	14.03	13.97	13.55	13.08	12.78	12.59	-	-	-	-
300 km	20.39	20.11	19.95	19.85	-	-	-	-	-	-	-	-
500 MW Windfarm Rated Power												
	132 kV Cable Voltage				**220 kV Cable Voltage**				**400 kV Cable Voltage**			
Cable Length	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**
50 km	2.81	2.78	2.76	2.74	1.62	1.63	1.64	1.65	1.18	1.14	1.12	1.11
100 km	4.74	4.77	4.79	4.81	3.07	3.07	3.07	3.07	2.68	2.54	2.46	2.4
150 km	7.5	7.53	7.56	7.57	5.1	5.05	5.02	5.01	5.36	4.98	4.74	4.58
200 km	11.08	11.09	11.1	11.1	7.87	7.76	7.69	7.65	18.29	17.59	17.15	16.85
250 km	15.28	15.3	15.33	15.37	12.48	12.12	11.89	11.74	-	-	-	-
300 km	19.96	19.74	19.61	19.53	-	-	-	-	-	-	-	-
600 MW Windfarm Rated Power												
	132 kV Cable Voltage				**220 kV Cable Voltage**				**400 kV Cable Voltage**			
Cable Length	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**
50 km	2.83	2.86	2.89	2.91	1.89	1.9	1.91	1.92	1.23	1.21	1.2	1.19
100 km	5.39	5.47	5.53	5.58	3.31	3.35	3.39	3.42	2.68	2.58	2.52	2.49
150 km	8.45	8.57	8.66	8.73	5.38	5.41	5.44	5.47	5.14	4.85	4.68	4.57
200 km	12.31	12.45	12.55	12.64	7.64	7.49	7.51	7.44	17.17	16.8	16.6	16.49
250 km	14.6	14.57	14.55	14.55	12.53	12.23	12.04	11.92	-	-	-	-
300 km	19.79	19.58	19.57	19.47	-	-	-	-	-	-	-	-
700 MW Windfarm Rated Power												
	132 kV				**220 kV**				**400 kV**			
Cable Length	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**
50 km	3.32	3.37	3.42	3.45	1.94	1.98	2.02	2.04	1.26	1.25	1.25	1.26
100 km	5.54	5.69	5.48	5.45	3.67	3.74	3.8	3.85	2.7	2.65	2.62	2.61
150 km	7.96	7.99	8	8.01	5.19	5.12	5.06	5.02	4.85	4.62	4.48	4.39
200 km	11.2	11.25	11.3	11.34	7.66	7.57	7.51	7.48	16.64	16.03	15.63	15.35
250 km	15.53	15.61	15.69	15.76	11.93	11.69	11.53	11.43	-	-	-	-
300 km	20.04	19.94	19.9	19.88	-	-	-	-	-	-	-	-
800 MW Windfarm Rated Power												
	132 kV Cable Voltage				**220 kV Cable Voltage**				**400 kV Cable Voltage**			
Cable Length	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**
50 km	2.88	2.9	2.92	2.94	1.85	1.84	1.83	1.9	1.31	1.33	1.34	1.36
100 km	5.52	5.59	5.63	5.67	**3.17**	**3.34**	**3.33**	**3.32**	2.55	2.47	2.4	2.36
150 km	8.66	8.75	8.82	8.87	**5.16**	**5.15**	**5.15**	**5.15**	4.63	4.43	4.31	4.23
200 km	12.15	12.31	12.44	12.54	7.79	7.75	7.74	7.74	16.23	15.85	15.61	15.45
250 km	15.13	15.12	15.11	15.11	11.84	11.66	11.55	11.48	-	-	-	-
300 km	19.78	19.68	19.63	19.6	-	-	-	-	-	-	-	-
900 MW Windfarm Rated Power												
	132 kV Cable Voltage				**220 kV Cable Voltage**				**400 kV Cable Voltage**			
Cable Length	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**
50 km	3.16	3.22	3.26	3.3	1.86	1.88	1.89	1.9	1.17	1.15	1.13	1.17
100 km	6.07	6.2	6.29	6.37	3.48	3.5	3.52	3.53	2.4	2.33	2.29	2.26
150 km	8.5	8.46	8.43	8.4	5.37	5.4	5.44	5.47	4.5	4.33	4.23	4.17
200 km	11.62	11.66	11.69	11.71	7.52	7.47	7.43	7.4	15.8	15.56	15.43	15.36
250 km	14.67	14.65	14.64	14.82	11.71	11.52	11.4	11.32	-	-	-	-
300 km	19.67	19.49	19.45	19.42	-	-	-	-	-	-	-	-
1,000 MW Windfarm Rated Power												
	132 kV Cable Voltage				**220 kV Cable Voltage**				**400 kV Cable Voltage**			
Cable Length	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**	**8 m/s Wind Speed**	**9 m/s Wind Speed**	**10 m/s Wind Speed**	**11m/s Wind Speed**
50 km	3.17	3.15	3.14	3.12	1.93	1.96	1.98	2	1.17	1.14	1.13	1.12
100 km	**5.66**	**5.7**	**5.89**	**5.89**	**3.63**	**3.67**	**3.71**	**3.74**	**2.37**	**2.32**	**2.36**	**2.33**
150 km	**8.65**	**8.75**	**8.82**	**8.87**	**5.79**	**5.85**	**5.89**	**5.93**	**4.44**	**4.3**	**4.21**	**4.16**
200 km	12.18	12.36	12.49	12.59	7.62	7.58	7.57	7.56	15.51	15.14	14.89	14.72
250 km	15.36	15.38	15.41	15.44	11.62	11.48	11.39	11.3	-	-	-	-
300 km	19.54	19.53	19.47	19.43	-	-	-	-	-	-	-	-

Source: Lazaridis, L., P. (2005). Economic Comparison of HVAC and HVDC Solutions for Large Offshore Wind Farms under Special Consideration of Reliability. Tables 4.3 - 4.5: Average power losses in percent of the windfarm's average output power for different windfarm rated power, average wind speed, transmission distances and transmission voltage levels.

Note: loss calculations were performed for 3 three-core HVAC cables with XPLE insulation (the type of HVAC cable expected to be used for Vineyard Mid-Atlantic)

Avoided Social Costs for Vineyard Mid-Atlantic

Vineyard Mid-Alantic Avoided Emissions (metric ton per year)		
CO2	CH4	N2O
4,279,846	130	16

EPA (2023) Social Cost of Carbon ($ Per Metric Ton)

	SC-CO2 (2020 dollars per metric ton of CO2)			SC-CH4 (2020 dollars per metric ton of CH4)			SC-N2O (2020 dollars per metric ton of N2O)		
	2.50%	2.00%	1.50%	2.50%	2.00%	1.50%	2.50%	2.00%	1.50%
2020	$ 120	$ 190	$ 340	$ 1,300	$ 1,600	$ 2,300	$ 35,000	$ 54,000	$ 87,000
2030	$ 140	$ 230	$ 380	$ 1,900	$ 2,400	$ 3,200	$ 45,000	$ 66,000	$ 100,000
2040	$ 170	$ 270	$ 430	$ 2,700	$ 3,300	$ 4,200	$ 55,000	$ 79,000	$ 120,000
2050	$ 200	$ 310	$ 480	$ 3,500	$ 4,200	$ 5,300	$ 66,000	$ 93,000	$ 140,000
2060	$ 230	$ 350	$ 530	$ 4,300	$ 5,100	$ 6,300	$ 76,000	$ 110,000	$ 150,000
2070	$ 260	$ 380	$ 570	$ 5,000	$ 5,900	$ 7,200	$ 85,000	$ 120,000	$ 170,000
2080	$ 280	$ 410	$ 600	$ 5,800	$ 6,800	$ 8,200	$ 95,000	$ 130,000	$ 180,000

From: Table ES.1: TEstimates of the Social Cost of Greenhouse Gases (SC-GHG), 2020-2080 (2020 dollars) https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf

EPA (2023) Social Cost of Carbon (Total Dollars)

	SC-CO2 (2020 dollars)			SC-CH4 (2020 dollars)			SC-N2O (2020 dollars)		
	2.50%	2.00%	1.50%	2.50%	2.00%	1.50%	2.50%	2.00%	1.50%
2020	$ 513,581,547	$ 813,170,782	$ 1,455,147,715	$ 168,944	$ 207,931	$ 298,901	$ 568,561	$ 877,208	$ 1,413,280
2030	$ 599,178,471	$ 984,364,631	$ 1,626,341,564	$ 246,918	$ 311,896	$ 415,862	$ 731,007	$ 1,072,143	$ 1,624,459
2040	$ 727,573,858	$ 1,155,558,480	$ 1,840,333,875	$ 350,883	$ 428,857	$ 545,818	$ 893,453	$ 1,283,323	$ 1,949,351
2050	$ 855,969,244	$ 1,326,752,329	$ 2,054,326,186	$ 454,849	$ 545,818	$ 688,771	$ 1,072,143	$ 1,510,747	$ 2,274,243
2060	$ 984,364,631	$ 1,497,946,178	$ 2,268,318,498	$ 558,814	$ 662,779	$ 818,728	$ 1,234,589	$ 1,786,905	$ 2,436,689
2070	$ 1,112,760,018	$ 1,626,341,564	$ 2,439,512,346	$ 649,784	$ 766,745	$ 935,689	$ 1,380,790	$ 1,949,351	$ 2,761,581
2080	$ 1,198,356,942	$ 1,754,736,951	$ 2,567,907,733	$ 753,749	$ 883,706	$ 1,065,645	$ 1,543,236	$ 2,111,797	$ 2,924,027

Interagency Working Group on Social Cost of Greenhouse Gases (2021) Social Cost of Carbon

	Social Cost of CO2, 2020 – 2050 (in 2020 dollars per metric ton of CO2)				SC-CO2 (2020 dollars)			
	5%	3%	2.50%	3% 95th Percentile	5%	3%	2.50%	3% 95th Percentile
2020	$ 14	$ 51	$ 76	$ 152	$ 59,917,847	$ 218,272,157	$ 325,268,313	$ 650,536,626
2025	$ 17	$ 56	$ 83	$ 169	$ 72,757,386	$ 239,671,388	$ 355,227,236	$ 723,294,011
2030	$ 19	$ 62	$ 89	$ 187	$ 81,317,078	$ 265,350,466	$ 380,906,314	$ 800,331,243
2035	$ 22	$ 67	$ 96	$ 206	$ 94,156,617	$ 286,749,697	$ 410,865,237	$ 881,648,322
2040	$ 25	$ 73	$ 103	$ 225	$ 106,996,156	$ 312,428,774	$ 440,824,161	$ 962,965,400
2045	$ 28	$ 79	$ 110	$ 242	$ 119,835,694	$ 338,107,852	$ 470,783,084	$ 1,035,722,786
2050	$ 32	$ 85	$ 116	$ 260	$ 136,955,079	$ 363,786,929	$ 496,462,162	$ 1,112,760,018

From: Table ES-1: Social Cost of CO2, 2020 – 2050 (in 2020 dollars per metric ton of CO2)3 https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

	Social Cost of CH4, 2020 – 2050 (in 2020 dollars per metric ton of CH4)				SC-CH4 (2020 dollars)			
	5%	3%	2.50%	3% 95th Percentile	5%	3%	2.50%	3% 95th Percentile
2020	$ 670	$ 1,500	$ 2,000	$ 3,900	$ 87,071	$ 194,935	$ 259,914	$ 506,831
2025	$ 800	$ 1,700	$ 2,200	$ 4,500	$ 103,965	$ 220,926	$ 285,905	$ 584,805
2030	$ 940	$ 2,000	$ 2,500	$ 5,200	$ 122,159	$ 259,914	$ 324,892	$ 675,775
2035	$ 1,100	$ 2,200	$ 2,800	$ 6,000	$ 142,952	$ 285,905	$ 363,879	$ 779,741
2040	$ 1,300	$ 2,500	$ 3,100	$ 6,700	$ 168,944	$ 324,892	$ 402,866	$ 870,710
2045	$ 1,500	$ 2,800	$ 3,500	$ 7,500	$ 194,935	$ 363,879	$ 454,849	$ 974,676
2050	$ 1,700	$ 3,100	$ 3,800	$ 8,200	$ 220,926	$ 402,866	$ 493,836	$ 1,065,645

From: Table ES-2: Social Cost of CH4, 2020 – 2050 (in 2020 dollars per metric ton of CH4) https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

	Social Cost of N2O, 2020 – 2050 (in 2020 dollars per metric ton of N2O)				SC-N2O (2020 dollars)			
	5%	3%	2.50%	3% 95th Percentile	5%	3%	2.50%	3% 95th Percentile
2020	$ 5,800	$ 18,000	$ 27,000	$ 48,000	$ 94,219	$ 292,403	$ 438,604	$ 779,741
2025	$ 6,800	$ 21,000	$ 30,000	$ 54,000	$ 110,463	$ 341,136	$ 487,338	$ 877,208
2030	$ 7,800	$ 23,000	$ 33,000	$ 60,000	$ 126,708	$ 373,626	$ 536,072	$ 974,676
2035	$ 9,000	$ 25,000	$ 36,000	$ 67,000	$ 146,201	$ 406,115	$ 584,805	$ 1,088,388
2040	$ 10,000	$ 28,000	$ 39,000	$ 74,000	$ 162,446	$ 454,849	$ 633,539	$ 1,202,100
2045	$ 12,000	$ 30,000	$ 42,000	$ 81,000	$ 194,935	$ 487,338	$ 682,273	$ 1,315,812
2050	$ 13,000	$ 33,000	$ 45,000	$ 88,000	$ 211,180	$ 536,072	$ 731,007	$ 1,429,524

From: Table ES-3: Social Cost of N2O, 2020 – 2050 (in 2020 dollars per metric ton of N2O). https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

Avoided Social Costs for Vineyard Mid-Atlantic

EPA (2023) Avoided Social Costs Summary

	SC-CO2 (2020 dollars)		SC-CH4 (2020 dollars)		SC-N2O (2020 dollars)		Total avoided social costs (2020 dollars)	
	min (2.5%)	max (1.5%)	min (2.5%)	max (1.5%)	min (2.5%)	max (1.5%)	min (2.5%)	max (1.5%)
2030	$ 599,178,000	$ 1,626,342,000	$ 247,000	$ 416,000	$ 731,000	$ 1,624,000	$ 600,156,000	$ 1,628,382,000
2040	$ 727,574,000	$ 1,840,334,000	$ 351,000	$ 546,000	$ 893,000	$ 1,949,000	$ 728,818,000	$ 1,842,829,000
2050	$ 855,969,000	$ 2,054,326,000	$ 455,000	$ 689,000	$ 1,072,000	$ 2,274,000	$ 857,496,000	$ 2,057,289,000

IWG (2021) Avoided Social Costs Summary

	SC-CO2 (2020 dollars)		SC-CH4 (2020 dollars)		SC-N2O (2020 dollars)		Total avoided social costs (2020 dollars)	
	min (5%)	max (2.5%)	min (5%)	max (2.5%)	min (5%)	max (2.5%)	min (5%)	max (2.5%)
2030	81,317,000	380,906,000	122,000	325,000	127,000	536,000	81,566,000	381,767,000
2040	106,996,000	440,824,000	169,000	403,000	162,000	634,000	107,327,000	441,861,000
2050	136,955,000	496,462,000	221,000	494,000	211,000	731,000	137,387,000	497,687,000