Guidance Document

Reducing Emissions from Goods Movement via Maritime Transportation in North America

Technical Guidance on Updating the Mexican National Ship Emissions Inventory and Collecting Ships Emissions Data from the United States and Canada

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For more information:

Commission for Environmental Cooperation
393, rue St-Jacques Ouest, bureau 200
Montreal (Quebec)
H2Y 1N9 Canada
t 514.350.4300 f 514.350.4314
info@cec.org / www.cec.org

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List of Abbreviations and Acronyms

AIS	Automatic Identification System
BSFC	brake specific fuel consumption
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
DWT	dead weight tonnage
ECA	Emission Control Area
GIS	Geographic Information System
HC	hydrocarbon
HFO	heavy fuel oil
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
kW	kilowatt
kW-hr	kilowatt-hour
kg	kilogram
LPG	liquefied petroleum gas
LNG	liquefied natural gas
m	meters
Marpol	Convention for the Prevention of Maritime Pollution from ships
MDO	marine diesel oil
MMSI	Maritime Mobile Service Identification
N_2O	nitrous oxide
NA-ECA	North American Emission Control Area
nm	nautical miles
NOx	nitrogen oxides
PM	particulate matter
PM_{10}	particulate matter less than 10 microns (micrometers) in diameter
$PM_{2.5}$	particulate matter less than 2.5 microns in diameter
ppm	parts per million
RSZ	reduced speed zones
RO	residual oil
Ro-Ro	roll-on/roll-off vessels
Semarnat	*Secretaría de Medio Ambiente y Recursos Naturales*

SCR	selective catalytic reduction
SO_2	sulfur dioxide
SO_X	sulfur oxide
ULCC	ultra large crude carrier
VHF	very high frequency
VLCC	very large crude carriers
VOC	volatile organic compound

Abstract

This guidance document provides a framework for Mexico's environment ministry, the *Secretaría de Medio Ambiente y Recursos Naturales* (Semarnat), to develop marine vessel (ship) emissions inventories based on local data that accurately represent all domestic and international marine vessel traffic occurring in Mexico's territorial waters. The methodology recommended in this document quantifies fuel usage and emissions, and accounts for improvements in fuel efficiency and reduced ship emissions through the use of low sulfur fuels, add-on controls, and operational changes such as slow steaming. To a large extent, the approach presented in this document relies on vessel-specific data in order to develop the most accurate emission estimates. Obtaining vessel-specific data requires the collection of detailed data from individual ports, as well as compiling data via the vessel electronic Automatic Identification System (AIS). This framework applies to the development of ship emissions inventories for any inventory year, as it includes emission factors that represent uncontrolled engines as well as those that comply with current and future Emission Control Area (ECA) regulations. The approach presented here was developed based on consideration of US, Canadian and other international marine vessel air quality methodologies, in order to provide fuel and emission estimates of comparable international quality.

Disclaimer

Executive Summary

In 2008, the International Convention for the Prevention of Pollution from Ships (Marpol Convention) adopted new amendments to Annex VI to address the prevention of air pollution from ocean-going vessels. As part of these amendments, a country (or collection of countries) can propose an Emission Control Area (ECA), a buffer area a defined distance from shore where stricter emission standards apply. These standards control emissions of sulfur oxides (SO_x), particulate matter (PM), and/or nitrogen oxides (NO_x) within the ECA, in order to reduce air pollution transported to populated areas and lessen other environmental impacts, such as deposition of air pollutants into water and soil. In 2009, the United States and Canada (joined later by France) submitted a joint ECA proposal, referred to as the North American ECA (NA-ECA), to the International Maritime Organization (IMO). The Mexican government has since expressed its commitment to accede to Annex VI of Marpol and establish an ECA. To do this, Mexico must submit an ECA designation proposal to the IMO showing how the proposed ECA meets Annex VI criteria. Should Mexico be successful, the existing NA-ECA would become truly North American, as it would include territorial waters of all North American countries.

To support this objective, the Commission for Environmental Cooperation (CEC) has undertaken a project entitled *Reducing Emissions from Goods Movement via Maritime Transportation in North America,* with the aim of developing the additional technical analyses needed for submission of a Mexican ECA designation proposal to the IMO. The present guidance document is a product of this project. It will support future updates of the ship emissions inventory produced by Mexico's Environment Ministry, the *Secretaría de Medio Ambiente y Recursos Naturales* (Semarnat), to accurately represent domestic and international vessel traffic and account for Mexican and international initiatives that reduce marine vessel emissions. Mexico's ability to develop ship emissions inventory updates in the future will be crucial to inform approaches to reducing ship emissions through Marpol Annex VI and an ECA, as well as for developing an accurate picture of ship emission status and trends throughout the North American region, when combined with data from the United States and Canada.

As part of this initiative, Semarnat and the US Environmental Protection Agency (EPA) collaborated to produce a national ship emissions inventory using marine vessel emission estimates developed from the Ship Traffic, Energy and Environment Model (STEEM). To ensure that the inventory is comprehensive, the approach presented here includes all marine vessel activities in Mexican waters. Estimates should be developed for basic criteria pollutants—carbon monoxide (CO), NO_x, particulate matter less than 10 microns in diameter (PM_{10}), particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), sulfur dioxide (SO_2), and volatile organic compounds (VOC); as well as major greenhouse gases—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The recommended approach to calculating emissions from marine vessels is to use power-based emission factors together with activity profiles for individual vessels. This requires gathering vessel-specific data from Mexican ports and via electronic vessel Automatic Identification System (AIS) tracking from terrestrial towers and satellites. Vessel data are linked to individual vessel characteristics to determine propulsion and auxiliary engine attributes, vessel size, and speed data elements. The information relative to the vessel's hours of operation in Mexican waters can be applied to engine power ratings and appropriate load factors to get kilowatt-hours, which can be applied to available emission factors to estimate emissions. Adjustments may be needed to account for the sulfur content of the fuels, application of control devices such as scrubbers and selective catalytic reduction (SCR) to comply with IMO standards, fuel conservation and operational changes such as slow steaming, and so on.

A critical element of this recommended approach is the compilation of accurate vessel activity data, accounting for vessels operating out of Mexican ports that are involved in: 1) domestic traffic; and, 2) international traffic. This includes compiling vessel identification data that can be matched to individual vessel operating parameters (e.g., maximum vessel speed) and engine characteristics (e.g., maximum propulsion and auxiliary engine power, engine speed) obtained from classification societies such as Lloyd's Register or the American Bureau of Shipping. The compiled port data should also include previous and next port-of-call information to facilitate mapping of shipping routes.

In addition to the marine vessel emissions estimating methodology, this guidance document includes discussions on quality assurance checks that should be implemented, documentation needed to allow for independent replication of the calculations, and a summary of "data out" formatting issues that will need to be considered to allow others to use the output in other applications.

1. Introduction

This document provides technical guidance to Semarnat for developing future vessel emission inventories. Such inventories would use local data that accurately represent domestic and international vessel traffic, quantify fuel usage and emissions, and account for Mexican and international initiatives that reduce marine vessel emissions through the use of low sulfur fuels, add-on controls, and operational changes such as slow steaming.

To a large extent, the approach presented in this guidance relies on vessel-specific data in order to develop the most accurate emission estimates. Obtaining vessel-specific data will require the collection of detailed data from the port itself, as well as collection of data via electronic vessel AIS from terrestrial towers and satellites.

This guidance is organized as follows. Section 2 provides background information about Mexican ports and shipping lanes. Section 3 discusses the types of vessels that visit Mexican ports or transit Mexican waters. Section 4 presents the recommended methodology to estimate vessels emissions. Section 5 presents the recommended methodology to estimate cargo-handling emissions. Quality assurance activities related to the development of the inventory data are presented in Section 6, and Section 7 addresses issues of documentation of the inventory approach. The general structure of the final data set is discussed in Section 8. Section 9 includes the references used in this report.

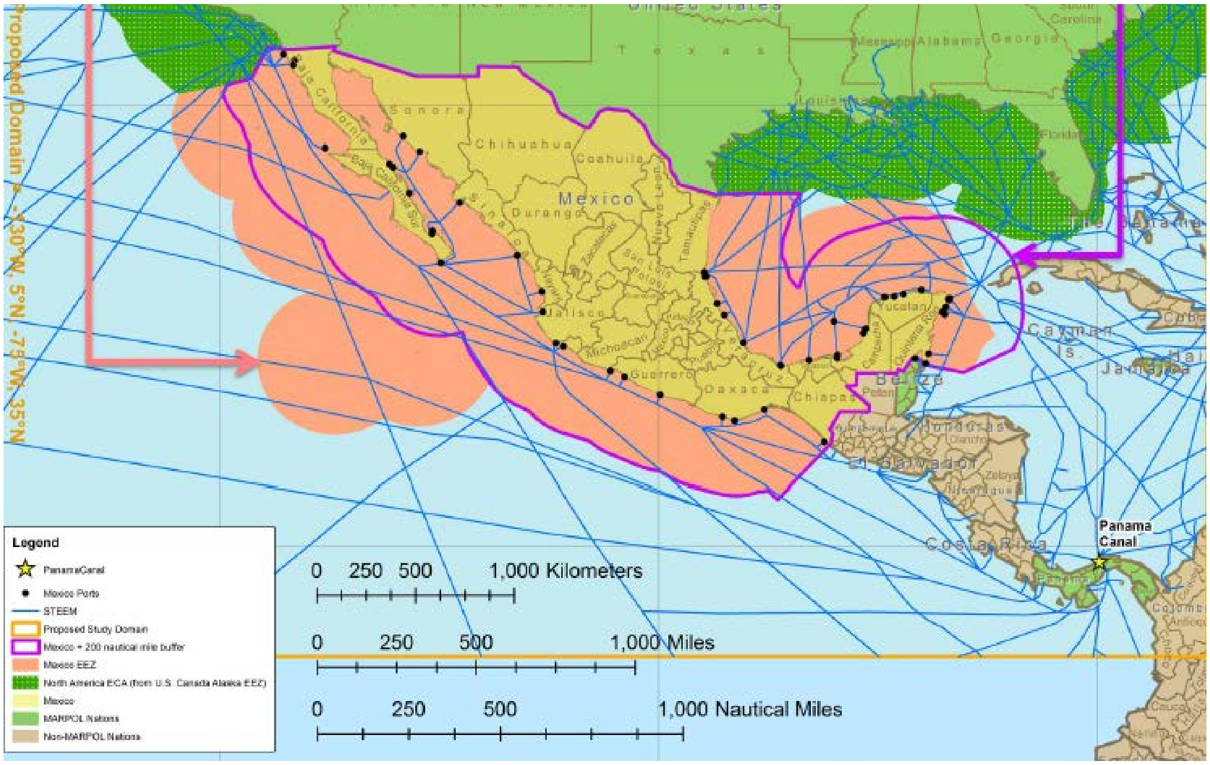
2. Mexican Ports/Shipping Lanes

A large volume of freight traffic from Asia and South America passes through Mexican ports and waterways, including vessels originating from the Panama Canal, en route to Gulf (of Mexico) ports in the United States. If a Mexican ECA[1] were established in addition to the existing North American ECA, it would include 8-11% of shipping activity in the North American region (Corbett and Silberman 2013).

The Mexican *Secretaría de Comunicaciones y Transportes* collects data on 40 Mexican cargo ports (Figure 1) (Corbett and Silberman 2013). Battelle Labs and Energy and Environmental Research Associates (EERA) under contract to US EPA estimated that the top 12 ports account for 95% of ship calls and 94% of port-related emissions (Boyle 2014). Of these 12 ports, six (81% of all vessel calls) currently provide residual heavy fuel oil (HFO) to visiting marine vessels, which are primarily ships involved in international freight traffic (e.g., tankers, container ships).

[1] This assumes that the Mexican ECA would reach out 200 nm from the shoreline, as does the current North American ECA.

Figure 1. Mexican Ports and Shipping Lanes



Source: Corbett and Silberman 2013.

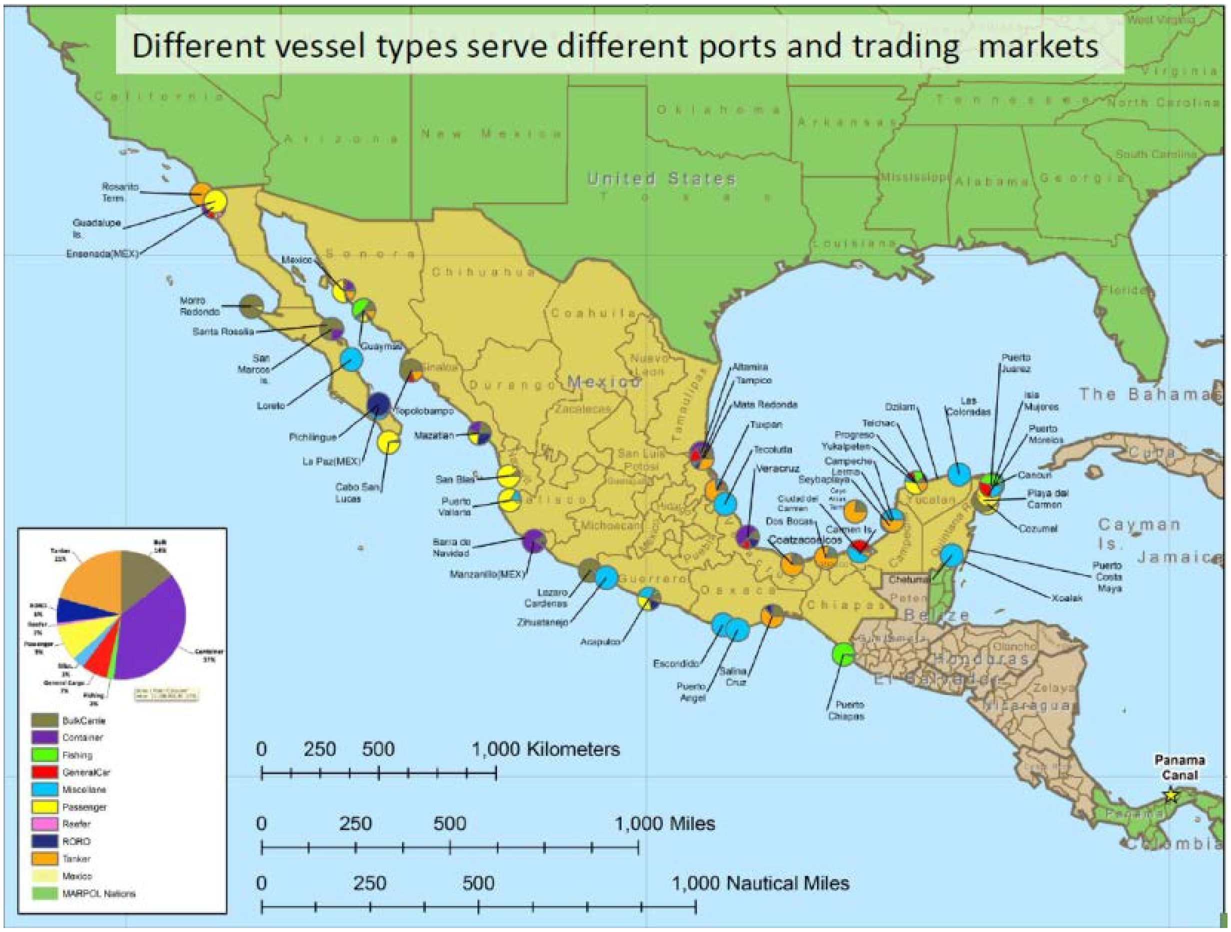
3. Vessel Types

Marine vessels provide a wide range of services, requiring many different types of vessels. Figure 2 shows the distribution of vessel types that are associated with the 40 individual Mexican ports that are covered in this guidance.

Studies of marine vessels aggregate vessel types into different groupings. For the purpose of this guidance, we are recommending the vessel groupings used in the US Department of Energy (DOE) Argonne National Laboratory, Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to ensure that the vessels are easily matched to the recommended emissions factors that are provided in this guidance (US DOE 2013). These vessel categories include the following:

- Auto carriers
- Bulk carriers
- Container ships
- Cruise lines
- Ferries
- Fishing boats
- General cargo vessels
-
- LNG/liquified petroleum gas (LPG) tankers
- Oil/chemical tankers
- Reefers
- Ro-Ros
- Support vessels (Offshore)
- Tug/towboats
- Other vessel types

Figure 2. Vessel Types That Call on Mexican Ports



Source: Corbett and Silberman 2013

Within each vessel type, further differentiation is possible that accounts for the wide range of vessel sizes, including a variety of international standard sizes such as:

> ***Aframax*** – Stands for Average Freight Rate Assessment and represents medium-sized oil tankers with a dead weight tonnage (DWT) between 80,000 and 119,999 tons.
>
> ***Capesize*** – These include very large and ultra large cargo vessels with a capacity over 150,000 DWT.
>
> ***Chinamax*** – Large bulk carriers (maximum length 360 meters (m), beam 65 m and draft 24 m) that are able to enter Chinese ports.
>
> ***Handymax and Supramax*** – Smaller vessels that can enter most ports and canals (less than 60,000 DWT).

Handysize – Similar to Handymax but smaller (15,000–30,000 DWT).

Malaccamax – Represents the largest ship that can pass through the Strait of Malacca (maximum length 400 m, beam 59 m, and draught 14.5 m).

Panamax and New Panamax – Largest ships that can pass through the Panama Canal, including the recently widened canal (maximum length 294.13 m, beam 32.31 m and draught 12.04 m; New Panamax: maximum length 427 m, beam of 55 m and draft of 18.3 m).

QMax – LNG carrier that can dock in Qatar (maximum length 345 m, beam 53.8 m, height 34.7 m, and a draft 12 m).

Seawaymax – Largest ship that can pass through the St. Lawrence Seaway (maximum length 225.6 m, beam 23.8 m, height 35.5 m, and a draft 7.92 m).

Suezmax – Largest ship that can pass through the Suez Canal (maximum draft 20.1 m with the maximum beam 50 m, or 12.2 m draft with maximum beam of 77.5 m).

VLCC and ULCC – Very large crude carriers and ultra large crude carriers (VLCC 180,000 – 320,000 DWT; ULCC greater than 320,000 DWT).

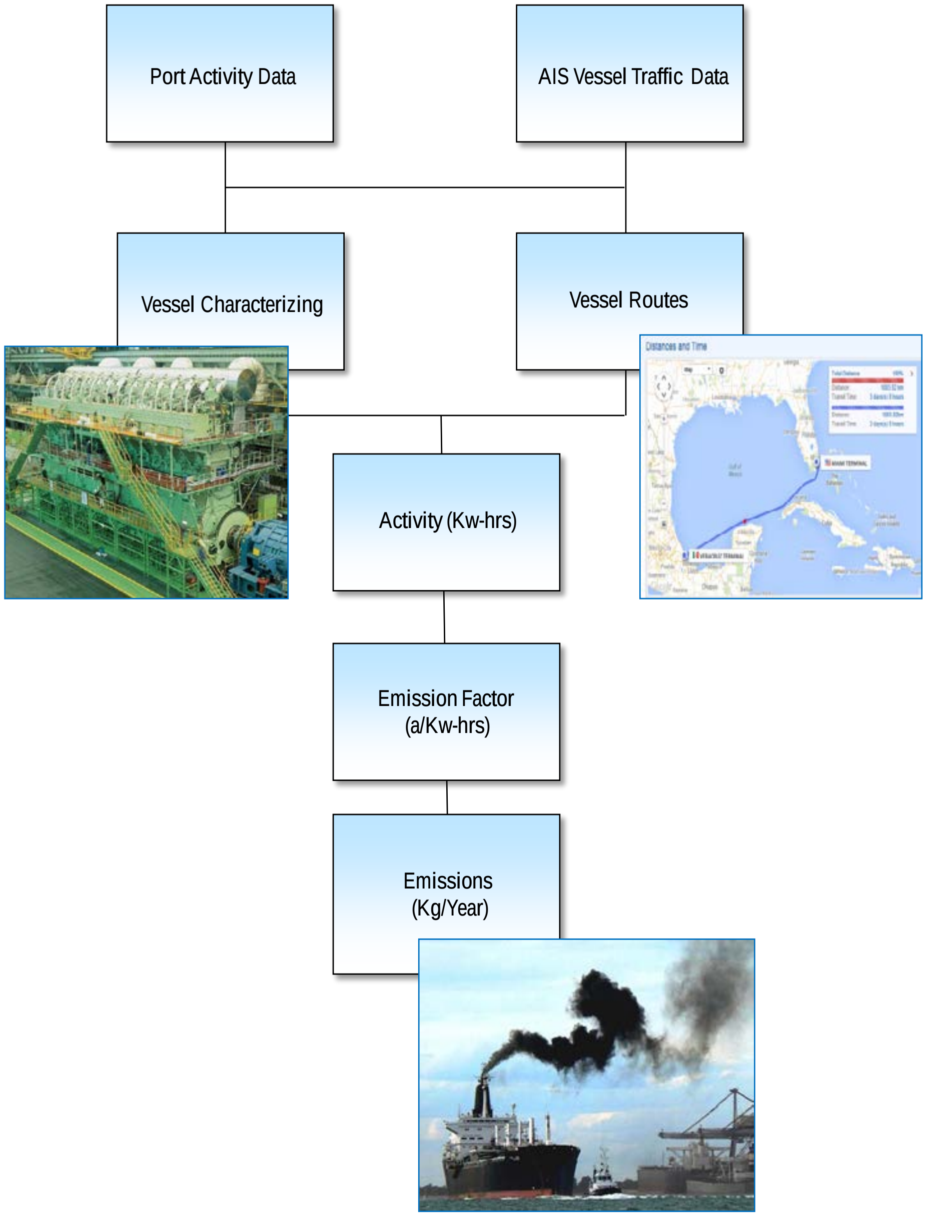
Vessels can be grouped into the above categories based on vessel characteristics data provided from classification societies such as Lloyd’s Register and the American Bureau of Shipping.

4. General Marine Vessel Emission Inventory Approach

To ensure that Mexico’s marine vessel emission inventory is comprehensive, it should include all marine vessel activities in Mexican waters and also be based on experience in Canada and the US. Estimates should be developed for basic criteria pollutants—CO, NO_x, PM_{10}, $PM_{2.5}$, SO_2, and VOC; as well as major greenhouse gases—CO_2, CH_4, and N_2O. If the intended use of the inventory data is to assess health impacts associated with marine vessel activities, then hazardous air pollutants should also be included.

The recommended approach to calculate emissions from marine vessels is to use power-based emission factors together with activity profiles for individual vessels. The approach relies on vessel-specific data to provide the most accurate emission estimates. This will require gathering detailed vessel data from Mexican ports as well as gathering data via electronic vessel AIS tracking from terrestrial towers and satellites. Vessel data are linked to individual vessel characteristics to determine propulsion and auxiliary engine attributes as well as vessel size and speed data elements. The vessel speed data are used to estimate hours of operation while in Mexican waters. These hours of operation can be applied to engine power ratings and appropriate load factors to get kilowatt-hours, which can be applied to available emission factors to estimate emissions, as summarized in Figure 3.

Figure 3. Recommended General Approach for Mexico's Marine Vessel Emission Inventory



In order to calculate emissions from marine vessels, use power-based emission factors together with activity profiles for individual vessels using the following equation:

$$E = P \times LF/100 \times A \times EF \times CF$$

Where:

E	=	Emissions for a specific vessel, with a specific engine (grams/year)
P	=	Maximum Continuous Rating Power for vessel i (kilowatts)

LF = Operating Load Factor (percent)
A = Activity (hours/year)
EF = Emission Factor (grams per kilowatt-hour)
CF = Gram to tons conversion factor

The recommended emission factors are provided in Appendix A. Selection of the correct factor is critical to ensure that emissions are accurately estimated. Adjustments may be needed to account for use of low- and ultra-low-sulfur fuels, application of control devices such as scrubbers and SCR to comply with ECA and International Maritime Organization IMO standards (Table 1), as well as fuel conservation and operational changes such as slow steaming, use of wind kites/sails, LNG, or photovoltaic electricity.

Table 1. International Maritime Organization (IMO) Engine and Fuel Standard (Marpol Annex VI)

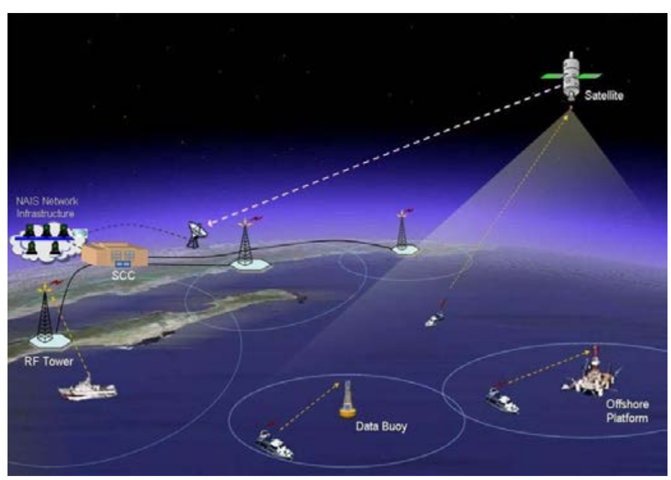
	Year	Fuel Sulfur	NOx
Emission Control Area	2010	10,000 ppm	NA
	2015	1,000 ppm	NA
	2016	NA	Tier III (Aftertreatment-forcing)
Global	Today to January 2011	NA	Tier I (Engine-based controls)
	2011	NA	Tier II (Engine-based controls)
	2012	35,000 ppm	NA
	2020a	5,000 ppm	NA

Note: [a] Subject to a fuel availability study in 2018, may be extended to 2025.

A critical element for this recommended approach is the compilation of accurate vessel activity data, such as accounting for vessels operating out of Mexican ports that are involved in 1) domestic traffic and 2) international traffic. This includes compiling vessel identification data that can be matched to individual vessel operating parameters (e.g., maximum vessel speed) and engine characteristics (e.g., maximum propulsion and auxiliary engine power, engine speed) obtained from classification societies such as Lloyd's Register or the American Bureau of Shipping. The compiled port data should also include previous and next port-of-call to facilitate mapping of shipping routes.

Data will also be needed for vessels that transit territorial waters, but do not call on Mexican ports. To account for these vessels, we recommend using AIS data. Vessels that participate in the AIS transmit a signal to a coastal VHF tower, buoy, offshore platform, or satellite every 2-10 seconds (Figure 4). The transmission identifies the vessel, notes the vessel type and shows where the vessel is located, its speed, direction, and ultimate destination. Compiled AIS data allow for detailed mapping of vessel movements.

Figure 4. Automatic Identification System



As with vessels that visit Mexican ports, the vessel identification codes can be linked to classification society datasets to obtain information on the vessels and its engines. Engine characteristics are then applied to hours of operation to estimate vessel-specific kilowatt-hours (kW-hr), which are adjusted to account for operating load and combined with the appropriate emission factors to estimate total emissions for each vessel. AIS data provides a vessel's actual speed along a shipping segment, which can be used along with the vessel's maximum rated speed to estimate operating load.

This approach provides accurate operating load information based on the vessel's actual and maximum speed and it also allows for identification of vessels that operate at or below 20 percent load. Although diesel engines can operate efficiently over a wide range of operating loads, once the operating load drops below 20 percent, emissions increase because the engine is operating outside of its optimal design range.

4.1 Data Collection

In order to use the approach outlined in this guidance, separate data collection efforts must be implemented for port-related data and AIS-related data elements.

4.1.1 Mexican Port Data

Much of the required data to estimate emissions for vessels that visit Mexican ports can be compiled by the harbormaster or a designated staff member of the port authority. This would include recording the following information:

- Vessel name
- Captain's name
- IMO identification code
- Maritime Mobile Service Identification (MMSI) code
- Call sign
- Mexican vessel registration code
- Vessel type
- Date and time of arrival
- Previous port-of-call
- Date and time of departure
- Next port-of-call

Ideally, these data can be collected from the operator of the ship when the vessel docks at a port terminal. It may be helpful to develop a simple electronic database system that allows each port authority to record its compiled data and store the results in a shared drive or on cloud storage such that it can be reviewed and used by Semarnat remotely to estimate emissions.

The combination of vessel name, captain, and identification codes will help to differentiate between unique and duplicate vessels. MMSI codes and call signs can also be used to identify vessels that also appear in the AIS dataset. Note that such vessels should be removed from the AIS data to avoid double counting of emissions. Vessels involved in domestic shipping often will not have an IMO identification code, but are included in the Mexican National Maritime Public Registry (Article 7 Chapter II of the Mexican Law of Navigation and Maritime Commerce of 2006).

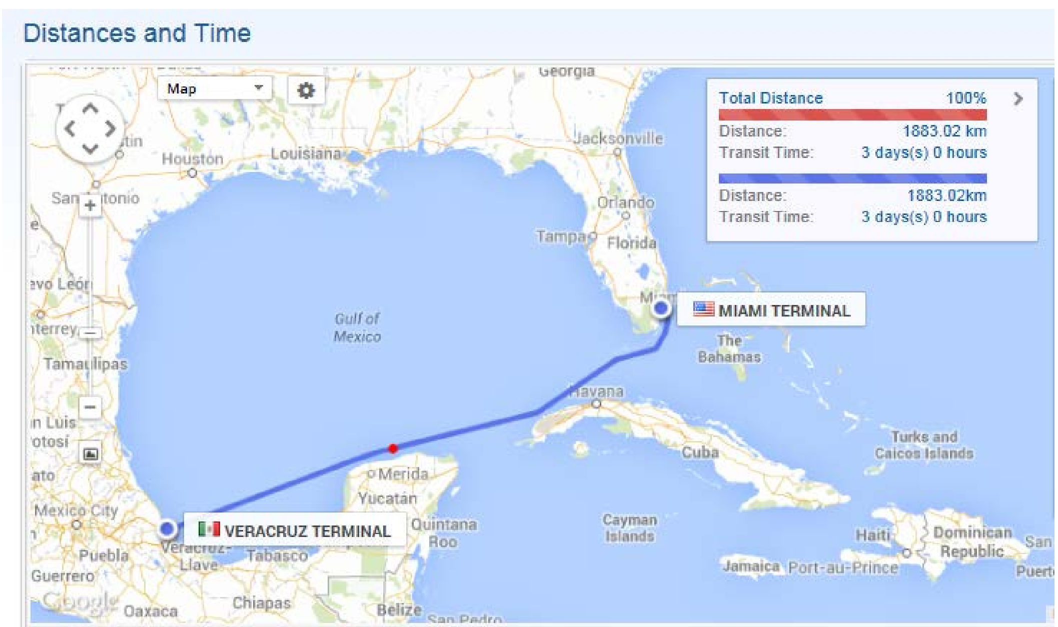
The IMO identifier allows the ship to be linked to vessel and engine characteristics compiled by classification societies. Typically, at least 95 percent of vessels that report IMO identification codes can be matched in classification data sets to their vessel characteristics. For vessels that cannot be matched, port-specific surrogates can be developed based on other vessels of similar type that visit the port that have been matched. Note a subscription to these classification societies is necessary to gain access to their data. Often, classification societies compile data elements that are not pertinent to emission calculations. The most relevant elements include the following:

- Vessel name
- IMO identification
- Call sign
- Year of Manufacture
- Propulsion engine make/model
- Total maximum propulsion power
- Auxiliary engine make/model
- Total maximum auxiliary power
- Max vessel speed

Vessel speed and previous and next port-of-call information will be useful to map out the vessel's route. These routes can be developed as Geographic Information System (GIS) shape files using available ship routing data from sources such as SeaRates.com <http://www.searates.com/reference/portdistance>.

Figure 5 shows an example vessel route from Veracruz, Mexico, to Miami, United States. This shape file route can be overlain with Mexico's territorial water boundaries to calculate the length of the route that occurs in Mexican waters. This length can be divided by the vessel's speed to estimate hours of operation in Mexican waters. To accurately calculate hours of operation, speed adjustments must be made to account for vessels that operate in reduced speed zones.

Figure 5. Vessel Route from Veracruz to Miami



Source: US DOE 2013.

For vessels that operate between two domestic Mexican ports, it is important to evaluate the route data carefully to ensure that duplicate activity data are not compiled. For example, a vessel that is traveling from Tampico to Veracruz will report Veracruz as its next port-of-call when it leaves Tampico and will report Tampico as its previous port-of-call when it arrives in Veracruz. Such information along with date and time of arrival and departure is useful to quality check the completeness of port data and can be used to check hours of operation calculations, but only one of these legs need to be considered when estimating emissions. As a rule, it is recommended that where the next port-of-call is a domestic port, these legs should be flagged and not used in the emission calculations. Note that the date and time of arrival and departure is useful to quality check vessel traffic and can be used to quantify time spent hoteling in port.

For some vessels such as fishing boats, ferries, and offshore support vessels, the current port, previous port-, and next port-of-call may be the same because these vessels typically operate offshore, eventually returning to the same port. In these cases, the departure and arrival data can be useful to estimate the time the vessel spends at sea.

As noted earlier, the maximum engine power (kilowatts) for a vessel can be adjusted to account for operating load, and applied to hours of operation to get kilowatt-hours, which can be applied directly to the emission factors. In addition, the vessel's year of manufacture is useful because it helps to identify applicable IMO engine emission standards.

Vessel type is also a critical data element to confirm that the IMO/Classification data have been correctly linked. Compiling vessel type data is necessary for smaller domestic vessels that do not have an IMO identification code and therefore will need to be matched to generic vessel and engine characteristics in order to estimate emissions. Generally vessels that do not have IMO codes would include general cargo vessels, bulk carriers, tugs, ferries, government vessels, and fishing boats. This guidance proposes to use vessel characteristics from Argonne National Laboratory's GREET model (Table 2), until Mexico-specific data can be compiled.

Table 2. Typical North America Vessel Characteristics

Ship Type	Engine Speed	Draught (m)	Length (m)	Deadweight (Metric Tons)	Total Kilowatts of Main Engines	Total kW of Auxiliary Engines	Speed (knots)
Bulk	Slow	12.33	193.31	58,151.07	8,756.41	320.22	14.33
Bulk	Medium	8.59	123.09	20,552.71	4,874.65	310.01	13.49
Bulk	High	6.24	113.54	5,588.00	4,739.00	570.00	0.00
Car Carrier	Slow	9.01	-	15,433.07	9,697.20	-	18.13
Car Carrier	Medium	9.42	-	16,519.00	10,863.00	-	18.00
Chemical Tanker	Slow	11.20	169.23	36,410.95	8,317.31	606.17	14.55
Chemical Tanker	Medium	8.73	136.52	16,898.87	5,952.13	376.81	13.83
Chemical Tanker	High	6.08	97.89	5,762.47	2,672.06	0.00	12.60
Container	Slow	11.53	276.58	45,630.00	21,231.13	6,850.13	18.34
Container	Medium	6.25	118.60	6,533.00	5,400.00	1,475.00	15.90
Container Large	Slow	12.71	256.97	57,950.83	39,711.08	1,026.26	23.36

Table 2. Typical North America Vessel Characteristics

Ship Type	Engine Speed	Draught (m)	Length (m)	Deadweight (Metric Tons)	Total Kilowatts of Main Engines	Total kW of Auxiliary Engines	Speed (knots)
Container Large	Medium	7.93	135.71	11,461.59	8,374.54	120.32	18.21
Dredge	Medium	8.41	124.01	9,950.00	10,150.00	0.00	15.00
Ferry	Medium	6.01		3,896.00	11,621.00		17.50
Ferry	High	0.00	66.53	677.00	1,692.00	0.00	0.00
Fishing	Slow	8.03	-	8,827.40	6,991.20	-	16.00
Fishing	High	2.44	37.09	212.80	1,026.60	0.00	9.10
General Cargo	Slow	10.52	154.16	31,702.11	8,469.52	254.75	14.89
General Cargo	Medium	7.44	123.09	9,798.98	4,801.79	430.93	14.41
General Cargo	High	4.87	87.12	3,390.81	1,683.05	152.98	11.46
Integrated Tug	Medium	6.55	40.16	429.50	5,909.00	184.17	11.21
Integrated Tug	High	4.45	38.12	448.13	4,846.75	0.00	6.25
LNG	Slow	12.94	324.03	121,374.33	36,805.44	11,258.91	19.16
LNG	Medium	11.30	253.35	69,113.08	31,869.27	2,843.09	18.88
LNG	High	11.70	284.30	79,275.30	28,274.90	1,799.40	19.35
LPG	Slow	10.47	170.42	28,379.57	9,445.17	1,062.40	16.15
LPG	Medium	7.66	115.67	7,467.66	4,669.25	1,126.82	15.10
Offshore support	Slow	6.90	89.96	3,266.00	11,840.00	0.00	16.00
Offshore support	Medium	6.66	108.00	6,470.77	12,036.10	187.76	13.68
Offshore support	High	4.26	58.88	1,997.40	3,833.57	2.11	11.26
Other	Slow	12.58	37.61	58,525.22	8,576.71	177.66	14.34
Other	Medium	5.91	109.17	3,939.20	6,072.27	111.15	13.87
Other	High	4.59	70.65	2,178.58	3,888.49	0.00	11.73
Passenger	Slow	7.67	178.01	5,324.67	16,154.67	0.00	19.83
Passenger	Medium	7.90	268.39	8,240.11	53,007.05	1,845.37	21.10

Table 2. Typical North America Vessel Characteristics

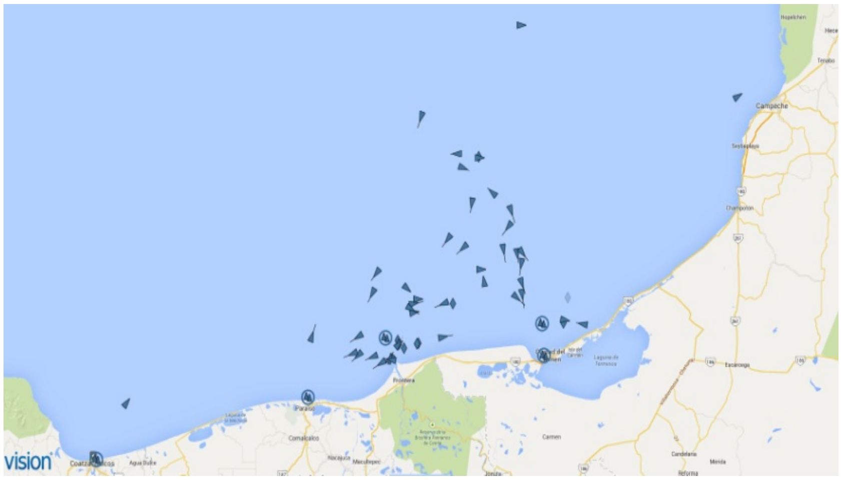
Ship Type	Engine Speed	Draught (m)	Length (m)	Deadweight (Metric Tons)	Total Kilowatts of Main Engines	Total kW of Auxiliary Engines	Speed (knots)
Passenger	High	7.35	250.25	9,278.74	57,682.84	1,502.11	21.44
Reefer	Slow	8.71	138.50	10,379.42	9,206.18	1,384.46	19.33
Reefer	Medium	7.57	117.39	6,508.08	5,466.97	506.14	16.51
Reefer	High	7.11	109.01	6,124.50	4,044.00	879.00	16.00
Ro-Ro	Slow	9.65	188.49	18,470.82	13,564.20	401.12	19.54
Ro-Ro	Medium	7.16	98.51	10,112.33	9,167.06	1,010.09	16.21
Ro-Ro	High	3.27	73.94	1,887.10	4,012.80	87.06	13.65
Tanker	Slow	12.19		40,090.50	7,784.17		14.75
Tanker PanaMax	Slow	13.08	202.45	60,085.65	10,599.56	674.57	14.90
Tanker PanaMax	Medium	8.64	146.82	20,375.29	6,261.33	605.80	13.85
Tanker PanaMax	High	5.54	74.74	5,145.85	2,270.50	142.50	8.49
Tanker VLCC	Slow	15.53	249.26	125,089.78	14,930.74	805.60	15.04
Tanker VLCC	Medium	11.37	99.55	72,117.20	10,215.20	0.00	13.98
Tanker VLCC	High	2.88	47.27	730.00	536.00	0.00	9.00
Tugs	Medium	5.45	55.23	1,612.57	7,588.57	290.79	12.19
Tugs	High	3.47	31.31	87.51	2,525.57	11.19	7.44

4.1.2 Automatic Identification System Data

The Automatic Identification System (AIS) was initially developed to improve navigation and reduce collisions at sea. However, AIS is also used to monitor fishing vessel activities, improve search and rescue operations, maintain coastal security, and help with accident investigations. The IMO's *International Convention for the Safety of Life at Sea* requires that freight vessels with gross tonnage greater than 300 tons and all passenger ships, must transmit AIS signals. Vessels that are less than 300 tons can voluntarily participate in AIS to enhance navigation and safety. In 2012, an estimated 250,000 vessels have already been fitted with AIS transceivers and it is anticipated that future regulations will increase this number significantly.

Vessels that participate in the AIS transmit a signal every two seconds that identifies the vessel, shows its current and previous locations, as well current speed, direction, and destination. These signals are picked up by near-by ships, terrestrial VHF towers, offshore platforms, buoys, and satellites. VHF signals can extend up to 60 miles offshore. Transmissions from vessels further out can be picked up by satellites. Figure 6 presents sample AIS data for the Bay of Campeche.

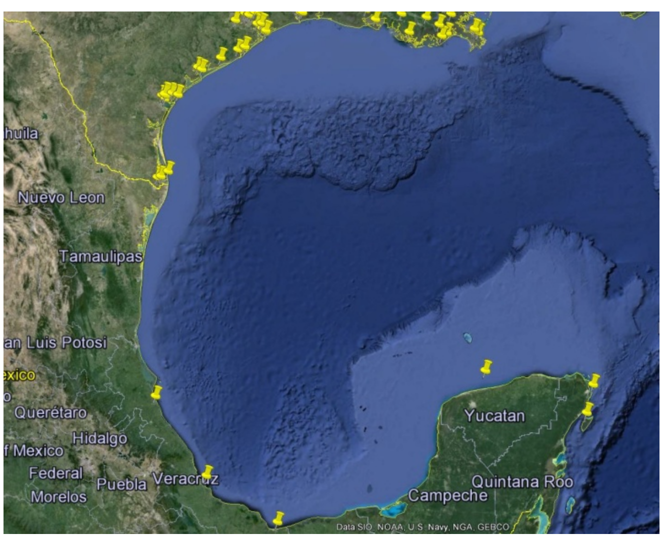
Figure 6. AIS Data for Bay of Campeche



Source: PortVision

AIS data have been successfully used for emission inventory studies by linking the individual vessels to their vessel characteristics as compiled by classification societies to obtain data on the power rating of the vessel propulsion and auxiliary engines. AIS also provides data on the vessel's previous and current locations as well as its direction and destination, making it possible to assign ships to an appropriate shipping lane. AIS shows vessel speed data that can be applied to the length of the shipping lane to determine hours of operation. The vessel speed can also be compared with the maximum vessel speed to calculate engine load. Combining the engine power rating with the operating load and hours of operation yield the vessel's kilowatt-hours, which can be applied to available emission factor to estimate emissions.

Figure 7. Location of PortVision Receivers



One advantage of AIS data is that they allow for the inclusion of vessels that transit Mexican waters but do not enter a Mexican port. But there are also limitations to the system; AIS provides vast amounts of data (every 2 to 10 seconds), which needs to be distilled into hourly or daily vessel movement data. Also given the limited range of VHF signals, it is important to be able to access a comprehensive network of receptors. Data handling firms such as PortVision are recommended to preprocess the data for inventory applications. PortVision has experience in distilling AIS data into more appropriate time intervals and also has a growing number of sensors that service Mexican ports (Figure 7).

PortVision currently ingests over 50 million worldwide vessel positions daily with over 30 billion positions in their historical database. Note that there are limitations with the satellite component of AIS. Each satellite receiver is able to track a limited number of vessels and can be overloaded at high traffic areas such as the Yucatan Channel. This issue is being addressed by increasing the number of AIS satellites in orbit, better integration of terrestrial and satellite data, and use of next-generation receivers on new satellites.

4.2 Emission Calculations

Whether port or AIS data are used to quantify vessel traffic, the emission calculations are similar: activity data are developed in terms of adjusted power that is applied to appropriate emission factors that are matched to the types of engines and fuel used.

4.2.1 Basic Fuel Usage and Emissions Calculation Equation

To calculate fuel usage and emissions, the compiled activity data and emission factors are linked together based on engine type, general engine size, fuel type, and area of operation (e.g., state waters (without ECA), Reduced Speed Zones (RSZ), ECA, and global waters).

As noted earlier, emissions are calculated for all vessel categories using the following equation:

$$E_{ijk} = A_{ij} \times LF/100 \times EF_k \times CF$$

Where:

E_{ijk} = Emissions for vessel i, with engine k (grams [g/temporal period j])
Ai_j = Activity (kilowatt-hours per year)
LF = Operating Load Factor (percentage)
EF_k = Emission Factor for engine k (grams per kilowatt-hour (g/kWh))
CF = Conversion factor (g = 1.10231 E-6 ton)
i = For specific vessel (e.g., Vessel "Mary Lou II" (IMO: 898765) or group of vessels (e.g., fishing boats)
j = Temporal period (e.g., hourly, daily, monthly, annual)
k = Engine type (e.g., large, medium speed propulsion engine)

For dockside emissions, the same approach applies, except that the power rating used is for the auxiliary engine, if no auxiliary is noted, the propulsion engine should be used assuming an operating load of 10%. Hours of operation can be estimated by subtracting the arrival day/time and the departure day/time.

Example Calculation:

Offshore support vessel total kilowatt-hours operating in Mexican waters were summed to be 912,492,000 kW-hr. The load factor is 0.83, and the emission factor for NO_X is 14 g/kW-hr.

E = 912,492,000 × 0.83 × 14 × 1.10231 × 10-6
E = 11,688 tons of NO_x

4.2.2 Activity Data

The recommended approach requires activity data in terms of kilowatt-hours. The approach to calculate activity is different depending on whether vessel-specific data or more generic vessel type data are used.

To calculate activity for vessel-specific data, it is necessary to disaggregate vessel routes into: 1) State waters (without ECA), 2) Reduced Speed Zones (RSZ), 3) Emission Control Areas (ECA), and 4) global waters, because vessel speed or type of fuel (ECA = low sulfur fuels) used may vary, which affects how the emissions should be calculated.

Hours of operation are calculated by dividing the distance within the zone by the adjusted average speed (92% of maximum speed for normal cruising or for cruising operation in RSZ, if the maximum speed set for the RSZ is less than the cruising speed, then the RSZ speed should be used when calculating time spent in the RSZ). Some vessels, such as large container ships, may voluntarily reduce their speed (referred to as slow steaming) to reduce fuel consumption rates. To determine the extent that slow steaming is implemented, it may be reasonable to add to the port-related data collection effort a question about use of slow steaming while in Mexican waters. As with RSZ, operating hours of vessels that use slow steaming can be increased to more accurately quantify these activities.

Dockside hours of operation can be estimated by subtracting the arrival day/time from the departure day/time.

To estimate activity for a fleet of vessels that does not have vessel-specific data, it is necessary to estimate typical annual hours of operation per year for a vessel in the fleet of interest. Estimate total hours using the following equation:

$$A_i = VP_i \times UR_i \times EN_i \times P_i \times DO_i \times 24$$

Where:

A_i = Total hours of operation for vessel type i in mode j
VP_i = Population of vessel type i
UR_i = Utilization rate for vessel fleet i
EN_i = Average number of engines on vessel type i
P_i = Typical engine power rating for vessel type i
DO_i = Days of operation for vessel type i
24 = hours per day
i = Vessel type (i.e., tugs/tow, ferries, fishing, offshore support, military, and short sea shipping vessels)

In order to calculate the total hours of operation, vessel type data are necessary to help quantify vessel power and can be obtained by implementing a targeted survey.

4.2.3 Emission Factors

Fuel consumption rate data and criteria pollutant emission factors (Appendix A) are listed in terms of kilowatt-hours for:

- Different engine types (i.e., diesel, steam turbine, and LNG)
- Engine size (e.g., small = EPA Category 1, medium = EPA Category 2 and large= EPA Category 3)
- Fuel types: distillate and residual blends for global waters, and ECA compliant fuels.

The US EPA defines the three engine categories for marine vessel main propulsion engines and auxiliary engines as Category 1 and 2 and Category 3 (EPA 2009). Category 1 and 2 engines (used by most harbor and fishing vessels) are engines between 5 and 30 liters per cylinder displacement. Category 3 engines (used by larger ocean going vessels) are engines over 30 liters per cylinder displacement. Category 3 engines are similar to large utility diesel engines. For the purpose of this guidance, we present emission factors in terms of small and medium engines, which would be similar to EPA Category 1 and 2 engines and large engines, which would be similar to EPA Category 3 engines.

Emission factors are also grouped by fuel type based on sulfur content. The three liquid fuel categories are residual, distillate, and low-sulfur distillate residual blend. An additional fuel that is starting to have application in marine vessels is LNG.

The residual fuel has sulfur content up to 27,000 ppm. The distillate fuel, also referred to as marine distillate oil, has a range of sulfur content from less than 1,000 up to 2,000 ppm. Low-sulfur distillate residual blend fuels have sulfur content of 5,000 ppm.

For this guidance, the emission factors used for engines utilizing residual fuel are listed in Appendix A as uncontrolled. Uncontrolled refers to engines not subject to current regulations. Engines subject to IMO regulations (included both Global and ECA standards) that are using distillate fuels are included in the emission factors listed in Appendix A as controlled.

4.2.4 Operating Loads

Operating loads are expressed as a percent of the vessel’s total propulsion or auxiliary power. The typical cruising load for propulsion engines is 83 percent. Because AIS data include actual vessel speeds, it is possible to calculate propulsion loads using the equation below:

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

Where:

LF	=	Load Factor (percent)
AS	=	Actual Speed (knots)
MS	=	Maximum Speed (knots)

If AIS data are not available, load factors of 83% can be used for normal cruising and 60% for operations within a RSZ or slow steaming. Auxiliary engine operating loads vary by vessel type and mode, as noted in Table 3.

Table 3. Typical Operating Loads for Auxiliary Engine by Vessel Type

Ship-Type	Mode of Operation			
	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
OG Tug	0.17	0.27	0.45	0.22
Ro-Ro	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

As noted earlier, it is important to identify vessels that operate at or below 20% load because these operations are associated with higher emission rates because the engines are operating outside the engine's optimal range. Emissions can be adjusted to account for low operating loads by using the adjustment factors in Table 4.

Table 4. Emission Adjustment Factors for Operating Loads Less than 20%

Load	NO_x	HC	CO	PM	SO_2	CO_2
1%	11.47	59.28	19.32	19.17	5.99	5.82
2%	4.63	21.18	9.68	7.29	3.36	3.28
3%	2.92	11.68	6.46	4.33	2.49	2.44
4%	2.21	7.71	4.86	3.09	2.05	2.01
5%	1.83	5.61	3.89	2.44	1.79	1.76
6%	1.60	4.35	3.25	2.04	1.61	1.59
7%	1.45	3.52	2.79	1.79	1.49	1.47
8%	1.35	2.95	2.45	1.61	1.39	1.38
9%	1.27	2.52	2.18	1.48	1.32	1.31
10%	1.22	2.20	1.96	1.38	1.26	1.25
11%	1.17	1.96	1.79	1.30	1.21	1.21
12%	1.14	1.76	1.64	1.24	1.18	1.17
13%	1.11	1.60	1.52	1.19	1.14	1.14
14%	1.08	1.47	1.41	1.15	1.11	1.11

Table 4. Emission Adjustment Factors for Operating Loads Less than 20%

Load	NO_x	HC	CO	PM	SO_2	CO_2
15%	1.06	1.36	1.32	1.11	1.09	1.08
16%	1.05	1.26	1.24	1.08	1.07	1.06
17%	1.03	1.18	1.17	1.06	1.05	1.04
18%	1.02	1.11	1.11	1.04	1.03	1.03
19%	1.01	1.05	1.05	1.02	1.01	1.01
20%	1.00	1.00	1.00	1.00	1.00	1.00

Representative data on engine load for auxiliary engines can be developed by implementing Mexican-specific studies to better quantify operations within Mexico's territorial waters. In lieu of such studies, the default values listed in Table 5 can be used.

Table 5. Typical Auxiliary Engine Operating Loads by Mode

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
OG Tug	0.17	0.27	0.45	0.22
Ro-Ro	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

4.3 Temporal Adjustments

The recommended approach provides annual emission estimates. Monthly, daily, and/or hourly emissions can be calculated based on the dates and times of arrival and departure from either port or AIS datasets. These temporal allocations can be helpful in developing seasonal, diurnal, or hourly estimates for use in local or regional modeling activities.

4.4 Spatial Allocations

To visually represent emissions in Mexico's waters, emissions can be spatially allocated to Mexico's territorial water boundaries based on route information compiled from the ports or AIS. Route-specific emissions can be directly linked to vessel routes using GIS attribute tables. Port-specific emissions can be directly applied to individual ports-of-call.

The routes can be spatially intersected with the water boundaries, and the length of each segment can be calculated. The underway emissions along each route and water boundary segment can be calculated by multiplying the emissions along each route by the proportion of the total route represented by each segment, as shown in the following equation:

$$WEm = REm \times ((LengthR_iS_j) / \Sigma\ (*LengthR_iS_j))$$

Where:

WEm	=	Underway emissions by Mexican water boundary (tons/year)
REm	=	Route specific underway emissions (tons/year)
$LengthR_iS_j$	=	Length of segment for water boundary j for specified Route i (km)

The allocation percentages derived for emissions should also be applied to activity and fuel data to ensure that the emissions data are consistent with the activity elements at the individual underway water boundary level. After processing, emissions and activity data should be summed to the water boundary level to provide total emissions per water boundary.

5 Cargo Handling Equipment Emission Inventory Approach

5.1 Cargo Handling Equipment

Ports typically use equipment specifically designed for the removal and loading of cargo from and onto marine vessels. A list of cargo handling equipment (CHE) typically found in ports is provided in Table 6.

Table 6. Cargo Handling Equipment and Associated US EPA Source Classification Codes (SCC)

Equipment	Engine Type	SCC Assignment	SCC Description
Yard tractor	Gasoline	2265003070	4-Stroke Terminal Tractors
Forklift	Propane	2267002057	LPG - Rough Terrain Forklift
Tractor	Propane	2267002066	LPG - Tractors/Loaders/Backhoes
Sweeper	Propane	2267003030	LPG - Sweepers/Scrubbers
Miscellaneous	Propane	2267003050	LPG - Other Material Handling Eqp
Yard tractor	Propane	2267003070	LPG - Terminal Tractors
Excavator	Diesel	2270002036	Diesel - Excavators
Crane	Diesel	2270002045	Diesel - Cranes
RTG crane	Diesel	2270002045	Diesel - Cranes
Truck	Diesel	2270002051	Diesel - Off-highway Trucks
Reach stacker	Diesel	2270002057	Diesel - Rough Terrain Forklifts
Loader	Diesel	2270002060	Diesel - Rubber Tire Loaders
Tractor	Diesel	2270002066	Diesel - Tractors/Loaders/Backhoes
Bulldozer	Diesel	2270002069	Diesel - Crawler Tractor/Dozers
Skid steer loader	Diesel	2270002072	Diesel - Skid Steer Loaders
Man lift	Diesel	2270003010	Diesel - Aerial Lifts
Forklift	Diesel	2270003020	Diesel - Forklifts
Side handler	Diesel	2270003020	Diesel - Forklifts
Top handler	Diesel	2270003020	Diesel - Forklifts
Sweeper	Diesel	2270003030	Diesel - Sweepers/Scrubbers
Material handler	Diesel	2270003050	Diesel - Other Material Handling Eqp
Miscellaneous	Diesel	2270003050	Diesel - Other Material Handling Eqp
Yard tractor, offroad	Diesel	2270003070	Diesel - Terminal Tractors
Rail pusher	Diesel	2285002015	Diesel - Railway Maintenance

CHE operate by combusting petroleum based fuels such as gasoline, diesel, and propane. The combustion of these fuels emits criteria pollutants, greenhouse gases, and toxic compounds.

5.2 Equipment Census

To insure the highest level of accuracy in developing CHE emission estimates it is recommended that an equipment census be implemented that quantify the CHE used in Mexican ports that handle 2 million or more metric tons of cargo per year. A list of ports and their 2010 cargo tonnage has been provided by the *Secretaría de Comunicaciones y Transportes* (SCT 2014) and is presented in Table 7.

Table 7. Port Cargo Tonnage

Port Name	Cargo Tonnage (2010)
Cayo Arcas, Camp.	48,664,121
Manzanillo, Col.	17,791,133
Veracruz, Ver.	15,327,690
Altamira, Tamps.	15,071,869
Isla Cedros, B.C.	13,633,266
Salina Cruz, Oax.	13,164,629
Tuxpan, Ver.	11,064,560
Dos Bocas, Tab.	9,232,219
Playa del Carmen. Q. Roo	8,481,443
Lázaro Cárdenas, Mich.	8,015,297
Guerrero Negro, B.C.S.	6,900,032
Guaymas, Son.	5,663,535
Topolobampo, Sin.	5,124,244
Ensenada, B.C.	4,982,776
Coatzacoalcos, Ver.	4,401,188
Progreso, Yuc.	4,355,061
Tampico, Tamps.	4,328,498
La Paz, B.C.S.	4,281,972
Mazatlán, Sin.	3,173,951
Rosarito, B.C.	2,528,348
Isla San Marcos, B.C.S.	916,683
Campeche, Camp.	861,980
Cozumel, Q. Roo	767,579
Acapulco, Gro.	592,514
Puerto Libertad, Son.	587,503
El Sauzal, B.C.	356,691
San Carlos, B.C.S.	171,066
Puerto Morelos, Q. Roo	63,123
Puerto Chiapas, Chis.	44,179
Santa Rosalia, B.C.S.	35,886
Isla Holbox, Q. Roo	28,760

Table 7. Port Cargo Tonnage

Port Name	Cargo Tonnage (2010)
Ciudad del Carmen, Camp.	9,306
San Felipe, B.C.	517
Frontera, Tab.	128
Total	210,621,747

For the larger ports noted in green on Table 7, a CHE census should be implemented that includes the following elements:

- Equipment type
- Number of equipment units in operation
- The age of each unit
- Fuel type associated with each unit
- Sulfur content of CHE fuel
- Power rating of each unit
- Annual hours of operation
- Typical operating loads
- Control device applied to each unit

5.3 NONROAD Emission Model

The survey data collected in Section 5.2 can be compiled into an input file to be applied to the US EPA's NONROAD emission estimation model. The NONROAD2008 model is intended for Windows 98 and later. Its primary use is for estimation of air pollution inventories by professional mobile source modelers. The NONROAD model calculates past, present, and future emission inventories (i.e., tons of pollutant) for all nonroad equipment categories except commercial marine, locomotives, and aircraft. Fuel types included in the model are: gasoline, diesel, compressed natural gas, and liquefied petroleum gas. The model estimates exhaust and evaporative hydrocarbons (HC), CO, NO_x, PM, SO_2, and CO_2. Note that HC and PM output from the NONROAD model can be speciated into the toxic air pollutants, if needed.

Note that NONROAD also requires inputs for typical weather for each port.

5.4 Scaling NONROAD Results to Other Ports

Where port-specific data cannot be obtained or for smaller ports (noted in brown on Table 7) for which it is not reasonable to implement an equipment survey, it may be necessary to match the port to similar ports for which data are available. To facilitate such matching it is important to also compile the following data to ensure the matched ports are similar:

- Type of cargo handles

- Annual tonnage handled
- Types and number of vessels that visit the port

Based on information provided by Semarnat it is anticipated that smaller ports are unlikely to have some of the equipment types used at larger ports, such as large tractors, excavators, and railway maintenance equipment. As such, it is necessary to review the equipment list and removed equipment specific emissions from the larger port profile in order to provide more reasonable estimate of emissions. For example, ports which handle less than 2 million metric tons of cargo per year probably do not have the following equipment:

2265003070	4 – Stroke Terminal Tractors
2267003030	LPG – Sweepers/Scrubbers
2267003050	LPG – Other Material Handling Equipment
2270002036	Diesel – Excavators
2270002051	Diesel – Off-highway Trucks
2270002072	Diesel – Skid Steer Loaders
2270003030	Diesel – Sweepers/Scrubbers
2270003050	Diesel – Other Material Handling Equipment
2270003070	Diesel – Terminal Tractors
2285002015	Diesel – Railway Maintenance

Once the ports have been matched and equipment profiles have been tailored, the emissions can be adjusted by using cargo tonnage ratios between the matched ports, as noted in the following equation:

$$Es = El \times Ts/Tl$$

Where:

Es	=	Nonroad Emission estimate for port without census data (metric tons)
El	=	Nonroad Emission estimate for port with census data (metric tons)
Ts	=	Total cargo (metric tons) for port without census data
Tl	=	Total cargo (metric tons) for the port with census data

6. Quality Assurance Checks

Quality assurance procedures are important to ensure the quality of the data. These checks include data handling requirements, checks on the calculating procedures, and assessments of the reasonableness of the output. For example, all large files transferred and or downloaded should be reviewed to ensure that all records are transferred and that the files were not corrupted during the transfer.

The compiled vessel characteristics data can be compared to other similar published vessel type data to ensure that our vessel characteristics are reasonable. This would include data from the IMO Greenhouse Gas Inventory, Intergovernmental Panel on Climate Change (IPCC) guidance, European Monitoring and Evaluation Program/European Environmental Agency’s Emission Inventory Guidance, and US EPA Regulatory Impact Analysis and Port Sector Guidance.

The compiled fuel and emission factors should also be compared to other similar datasets to ensure that they too are reasonable. Fuel and emission calculation version control issues can be addressed by storing final fuel and emission factor data tables in a specific shared computer drive where only the project manager has access to dataset used in the calculations. Similarly, final rolled up vessel characteristics data and final route distance data can also be compiled and stored in a limited access shared drive.

As fuel and emission calculations are developed, it is important for all calculations to be clearly documented and reviewed by a technical reviewer to assess whether the calculations are implemented correctly. It is also important to back calculate conversions to confirm that they were correctly applied.

The methodology, data files, and calculations should be reviewed by an external independent reviewer to insure that the procedures and estimates are correct and reasonable.

7. Documentation

To allow for independent review of the approach used, it is critical that documentation be developed that clearly notes the data sources and steps used to estimate emissions, this includes:

- Documenting how activity data were collected and compiled, including a summary of the activity data collected from ports.
- Use of reliable studies to quantify local data.
- Summarizing QA/QC procedures after receipt of the activity data and preparation of data for use in developing emission calculations. Include the approach used to identify duplicate data elements and efforts to gap fill missing data.
- Documenting calculation methods. Include equations, emission factors, load factors, and other assumptions (if is often helpful to include example calculations).
- Summarizing emission estimates by vessel type and pollutant.
- Document QA/QC procedures implemented for emissions calculations. Include any comparisons with similar studies.
- Provide maps of vessel routes in Mexico’s territorial water boundaries, and spatially allocated emissions.
- Document limitations of the inventory and possible areas of improvement.

8. Data Files

In compiling the inventory datasets, it is important to pull together the data used to estimate emissions. Typically large marine vessel emission inventories are developed using relational databases such as Microsoft® Access. The advantage of using relational databases over spreadsheets is that independent data such as vessel characteristics, load factors, emission factors, and vessel routes can be compiled into separate data tables and linked together using queries that can be easily checked. Because data files are not necessarily transparent, it is important to provide a README file that clearly documents the database structure, noting the data tables used to develop the emissions. It is also important to include in the README file a table that provided definitions of each data field including the units for the data. If the intended use of the emission data is for modeling purposes, the database can be developed to provide output in a format compatible with the model that will be used.

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Appendix A. Fuel and Emission Factors

A-1. Fuel/ Emission Factors for Uncontrolled Engines

Main/ Auxilary Engine	Engine Type	Fuel	S ppm	Emission Factors (g/kW-hr)										
				BSFC	NO_X	VOC	CO	SO_2	PM_{10}	PM_{25}	CO_2	CH_4	N_2O	Black Carbon
Main	Steam turbine	Global RO	27,000	305	2.1	0.1	0.2	16.1	1.47	1.35	971	0.002	0.08	0.0294
Main	Small/medium Diesel	Global RO	27,000	213	14	0.5	1.1	11.24	1.43	1.32	678	0.004	0.031	0.0286
Main	Large Diesel	Global RO	27,000	195	18.1	0.6	1.4	10.29	1.42	1.31	621	0.006	0.031	0.0284
Main	Steam turbine	Natural Gas	-	10	0.42	0.01	0.13	0.00	0.01	0.01	180	0.003	0.003	0.0007
Auxiliary	Steam turbine	Global RO	27,000											0
Auxiliary	Small/medium Diesel	Global RO	27,000	227	14.7	0.4	1.1	11.98	1.44	1.32	722.54	0.004	0.031	0.0288
Auxiliary	Large Diesel	Global RO	27,000	227	14.7	0.4	1.1	11.98	1.44	1.32	722.54	0.004	0.031	0.0288

A-2. Fuel/ Emission Factors for Controlled Engines

Engine Type	Fuel	S ppm	Emission Factors (g/kW-hr)										
			BSFC	NO_X	VOC	CO	SO_2	PM_{10}	PM_{25}	CO_2	CH_4	N_2O	Black Carbon
Steam turbine	Global marine diesel oil (MDO)	5,000	290	1.93	0.10	0.20	2.82	0.58	0.53	923.32	0.0020	0.0772	0.0116
Small/medium Diesel	Global MDO	5,000	203	8.64	0.38	1.02	0.86	0.20	0.18	646.08	0.0030	0.0203	0.0041
Large Diesel	Global MDO	5,000	185	16.40	0.60	1.39	1.80	0.30	0.27	589.01	0.0060	0.0299	0.0061
Steam turbine	ECA MDO	1,000	290	1.93	0.10	0.20	0.56	0.58	0.53	923.67	0.0020	0.0772	0.0116
Small/medium Diesel	ECA MDO	1,000	203	8.64	0.38	1.02	0.17	0.18	0.14	646.33	0.0030	0.0203	0.0036
Large Diesel	ECA MDO	1,000	185	12.63	0.60	1.39	0.36	0.19	0.16	589.24	0.0060	0.0299	0.0037
Steam turbine	Natural Gas	-	10	0.42	0.01	0.13	0.00	0.01	0.01	180	0.003	0.003	0.0007