

PORT EMISSIONS TOOLKIT

GUIDE
NO. 01

Assessment of port emissions



Port Emissions Toolkit

Guide No.1: Assessment of port emissions



Published in 2018 by the
GloMEEP Project Coordination Unit
International Maritime Organization
4 Albert Embankment
London SE1 7SR
United Kingdom

and

International Association of Ports and Harbors (IAPH)
7th Floor, South Tower New Pier Takeshiba
1-16-1 Kaigan, Minato-ku, Tokyo 105-0022
Japan

© GEF-UNDP-IMO GloMEEP Project and IAPH

Typeset by Eyetooth-Art.co.uk

Printed by Elephant Print, Lewes, East Sussex



Copyright Notice: *All rights reserved. This document, or any part thereof, may not be photocopied, stored in any medium by electronic means or otherwise, published, transferred, reproduced or performed in public in any form or by any means without prior written permission from the copyright owner. Enquiries should be directed to the address above.*

GEF, UNDP, IMO or IAPH shall not be liable to any person or organisation for any loss, damage or expense caused by reliance on the information or advice in this document or howsoever provided.

Please cite this document as: *GEF-UNDP-IMO GloMEEP Project and IAPH, 2018: Port Emissions Toolkit, Guide No.1, Assessment of port emissions.*

The GloMEEP Project is a cooperative initiative of the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) and the International Maritime Organization (IMO) to assist developing countries in the uptake and implementation of energy efficiency measures for shipping, with the aim of reducing greenhouse gas emissions and preventing air pollution from ships. For more information, please visit <http://glomeep.imo.org>

The International Association of Ports and Harbors (IAPH) is a global alliance representing over 180 members ports and 140 port related businesses in 90 countries. The principal aim of IAPH revolves around promotion of the interests of Ports worldwide, building strong member relationships and sharing best practices among our members. For more information, please visit <https://www.iaphworldports.org/>

Contents

	<i>Page</i>
List of figures	iv
List of tables	v
List of abbreviations.....	vi
Acknowledgements	ix
Preface	xi
1 Background	1
1.1 Introduction to a port emissions assessment	1
1.2 The issues	2
1.3 Port-related sources	3
1.4 GHG emissions sources	5
1.5 Regulatory frameworks	6
1.6 The port response	7
2 Planning for a port emissions assessment	9
2.1 Catalogue and group drivers	10
2.2 Define intended uses	11
2.3 Select air pollutants and greenhouse gases	12
2.4 Select emissions sources	12
2.5 Select geographical and operational domains	13
2.6 Identify other major emissions sources near port	16
2.7 Select inventory temporal period and frequency	17
2.8 Identify documentation and reporting requirements	17
2.9 Select level of detail	17
2.9.1 Scaled inventories	18
2.9.2 Screening inventories	18
2.9.3 Comprehensive inventories	18
2.10 Select assessment platform	21
3 Port emissions assessment methods	25
3.1 Port emissions assessment basics	25
3.2 Port emissions inventory estimating methods	27
3.2.1 Mobile sources.....	28
3.2.2 Electrical grid emissions	61
3.3 Equipment, activity and emissions metrics	62
3.4 Port emissions forecasts	64
4 Evaluation of results	71
4.1 Evaluating results of a port emissions assessment	71
4.2 Comparing the results of a port emissions assessment	74
5 Resources	77
Annex 1 – Port emissions assessment planning checklist	81

List of figures

	<i>Page</i>
Figure 1.1: Port-related GHG emissions sources by scope	5
Figure 2.1: Planning steps for a port emissions assessment	9
Figure 2.2: Examples of priority grouping of drivers for a port emissions assessment	11
Figure 2.3: Geographic domain for the Port of Los Angeles emission inventory	16
Figure 2.4: Scaled approach	19
Figure 2.5: Screening approach	20
Figure 2.6: Comprehensive approach	20
Figure 3.1: Seagoing vessel propulsion types	32
Figure 3.2: Auxiliary power systems	33
Figure 3.3: Direct drive/gear drive operational modes	35
Figure 3.4: Diesel electric – operational modes (cruise/ferry)	36
Figure 3.5: Steam ship – operational modes	37
Figure 3.6: Recommended screening approach for estimating emissions from seagoing vessels	45
Figure 3.7: Global inland waterways	47
Figure 3.8: Comprehensive port emissions forecasting elements matrix, by emissions source category	66
Figure 3.9: 2010 SPBP CAAP update diesel particulate matter forecast	67
Figure 3.10: 2010 SPBP CAAP update NO _x forecast	67
Figure 3.11: 2010 SPBP CAAP update SO _x forecast	68
Figure 3.12: 2005-2014 POLA diesel particulate matter emissions reductions	68
Figure 3.13: 2005-2014 POLA NO _x emissions reductions	69
Figure 3.14: 2005-2014 POLA SO _x emissions reductions	69
Figure 4.1: 2015 POLA cargo handling equipment counts, by engine type	71
Figure 4.2: 2015 POLA cargo handling equipment energy consumption, by engine type	72
Figure 4.3: 2015 POLA cargo handling equipment NO _x emissions, by engine type	72
Figure 4.4: 2015 POLA cargo handling equipment energy consumption, by engine type & US EPA non-road diesel engine tier	73
Figure 4.5: 2015 POLA cargo handling equipment NO _x emissions, by engine type & US EPA non-road diesel engine tier	73
Figure 4.6: 2005-2015 POLA cargo handling equipment energy consumption, by engine type, GWh	74
Figure 4.7: 2005-2015 POLA cargo handling equipment energy consumption, by US EPA non-road diesel engine tier, GWh	74
Figure 4.8: 2005 vs 2015 POLA cargo handling equipment NO _x emissions, by engine type & US EPA non-road diesel engine tier, tons	75

List of tables

	<i>Page</i>
Table 1.1: Port-related emissions source categories	3
Table 1.2: Port-related pollutants, sources and health and environmental effects	3
Table 1.3: Potential regulatory spheres for port-related emissions sources	6
Table 2.1: Port-related emissions source categories by energy type	13
Table 3.1: Global warming potentials	27
Table 3.2: IHS ship group and classes	29
Table 3.3: Cargo carrying category; class, sub-class, StatCode5 and description	30
Table 3.4: Emission factors for propulsion and boiler engines using HFO with 2.7% sulphur content, g/kWh	41
Table 3.5: Emission factors for auxiliary engines using HFO with 2.7% sulphur content, g/kWh	42
Table 3.6: Selected 2016 sub-class global counts, MCR and rated speeds	43
Table 3.7: Harbour craft engine load factors	49
Table 3.8: Cargo handling equipment engine load factors	54
Table 3.9: Estimated load factors by notch	60
Table 3.10: Examples of equipment, activity and emissions metrics	62

List of abbreviations

AIS	Automated Identification System
AGV	Automated Guided Vehicles
ATB	Articulated Tug-Barges
BC	Black Carbon
BSFC	Brake Specific Fuel Consumption
CAAP	Clean Air Action Plan
CARB	California Air Resources Board
CEIP	Center for Emission Inventories and Projections
CF	Control Factor
CH ₄	Methane
CHE	Cargo Handling Equipment
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
COPERT	Air Pollutant and Greenhouse Gas Emissions Tool
CSR	Corporate Social Responsibility
DCMR	Joint Environmental Protection Agency of Rijnmond (Holland)
DPM	Diesel Particulate Matter
ECA	Emission Control Area
EEA	European Environment Agency
EF	Emission Factor
EIAPP	Engine International Air Pollution Prevention Certificate
EMEP	European Monitoring and Evaluation Programme
EMFAC	Emissions Model for On-Road Vehicles (CARB)
ERS	Emissions Reduction Strategy
ETV	EU Environmental Technology Verification
EU	European Union
FCF	Fuel Correction Factor
FHWA	US Federal Highway Administration
GB	gigabytes
GEF	Global Environment Facility
GHG	Greenhouse Gas
GloMEEP	Global Maritime Energy Efficiency Partnerships Project
GVWR	Gross Vehicle Weight Rating
GWh	gigawatt hours

GWP	Global Warming Potential
HC	Hydrocarbon
HFO	Heavy Fuel Oil
HPA	Hamburg Port Authority
IAPH	International Association of Ports and Harbors
IAPP	International Air Pollution Prevention Certificate
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IHS	IHS Markit
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ITB	Integrated Tug-Barge
IVL	IVL Swedish Environmental Research Institute
LF	Load Factor
LNG	Liquefied Natural Gas
LRTAP	Long range transboundary air pollution
MCR	Maximum Continuous Rated (Power)
MDO	Marine Diesel Oil
MEPC	Marine Environmental Protection Committee
MOVES	Motor Vehicle Emissions Simulator (US EPA)
MRP	Maximum Rated Power
MW	Megawatts
N ₂ O	Nitrous Oxide
NECA	Nitrogen Emission Control Area
NFR	nomenclature for reporting (new format for UN)
NGO	Non-governmental organisation
NO _x	Nitrogen Oxides
OCR	Optical Character Recognition
OECD	Organization for Economic Co-operation
OFFROAD	Emissions Model For Off-Road Sources (CARB)
OGV	Ocean-Going Vessel
OPS	Onshore Power Supply
PANYNJ	Port Authority of New York & New Jersey
PEV	Port Everglades
PM	Particulate Matter
POLA	Port of Los Angeles
POLB	Port of Long Beach
POP	Port of Portland
POR	Port of Rotterdam
RDBMS	Relational Database Management System
RFID	Radio Frequency Identification Device

RMG	Rail-Mounted Gantry (Cranes)
RoRo	Roll-on roll-off vessel
RTG	Rubber-Tyred Gantry (Cranes)
SECA	Sulphur Emission Control Area
SO _x	Sulphur Oxides
SPBP	San Pedro Bay Ports
SQL	Structured Query Language
TEU	Twenty-Foot-Equivalent Unit
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USEPA	United States Environmental Protection Agency
VBP	Vessel Boarding Program
VMT	Vehicle Miles Travelled
VOC	Volatile Organic Compounds
VTs	Vessel Traffic System
WPCI	World Ports Climate Initiative (IAPH)

Acknowledgements

This Guide is the product of a collaboration between the GEF-UNDP-IMO Global Maritime Energy Efficiency Partnerships (GloMEEP) Project and the International Association of Ports and Harbors (IAPH).



The content of this Guide was developed by the Starcrest Consultancy Group (Bruce Anderson, Paul Johansen, Lauren Dunlap, Archana Agrawal, Joe Ray, Denise Anderson, Melissa Silva, Sarah Flagg, Guiselle Aldrete and Jill Morgan), under a contractual agreement with IAPH.



Great thanks are also due to the GloMEEP Project Coordination Unit (Astrid Dispert and Minglee Hoe), the IMO Marine Environment Division and Leigh Mazany who provided invaluable contributions to the development of this Guide.

Great thanks are also due to IAPH (Fer van de Laar) who provided important input and support.

For further information please contact:

GloMEEP Project Coordination Unit

Marine Environment Division
International Maritime Organization
4 Albert Embankment
London SE1 7SR
United Kingdom
Web: <http://glomeep.imo.org>

International Association of Ports and Harbors (IAPH)

7th Floor, South Tower New Pier Takeshiba
1-16-1 Kaigan, Minato-ku
Tokyo 105-0022
Japan
Web: <https://www.iaphworldports.org/>

Preface

Maritime ports are major hubs of economic activity and are usually located in the vicinity of highly populated areas. The growth of global trade has resulted in a corresponding rapid increase in the amount of goods being shipped by sea. Despite the enormous growth of the marine shipping sector, in many parts of the world pollution prevention efforts have not focused on port-related sources. As more attention is focused on reducing emissions from the marine shipping sector, ports are driven to understand the magnitude of the air emissions impact from their operations on the local and global community and to develop strategies to reduce this impact.

The key to this effort is to provide a systematic approach to the assessment of air pollutant emissions from port-related sources through the development of port emissions inventories that provide the basic building block to the development of a port emissions reduction strategy. Without an emissions inventory, it may be difficult to determine where to best focus resources to reduce emissions. Further, without a baseline emissions inventory, and subsequent updates, it will be difficult to monitor the effectiveness of any emissions reduction strategy that is implemented.

This *Port Emissions Toolkit*, therefore, includes two individual guides as follows:

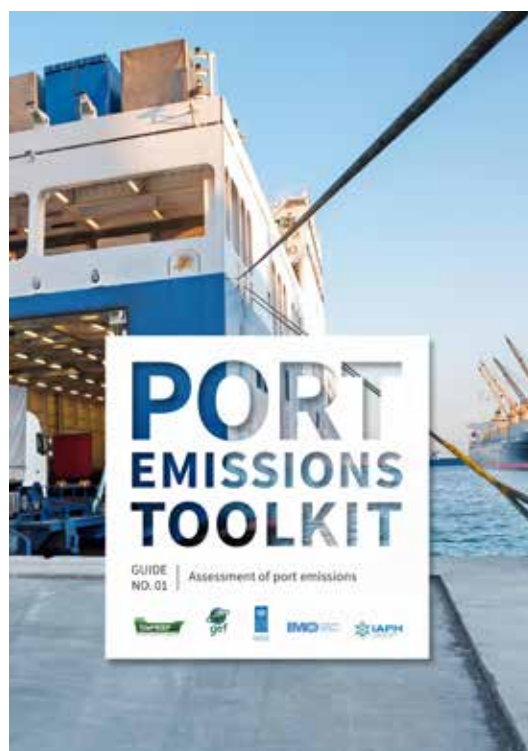
Guide No.1: Assessment of port emissions

This guide is intended to serve as a resource guide for ports intending to develop or improve their air pollutant and/or GHG emissions assessments. This guide builds on and updates previous work of IAPH and its members, incorporating the latest emissions inventory methods and approaches.

Recognising that ships do not operate independently from shore-based entities in the maritime transportation system, port emissions considerations therefore must extend beyond the ships themselves to include all port-related emissions sources including: seagoing vessels, domestic vessels, cargo handling equipment, heavy-duty vehicles, locomotives and electrical grid.

This guide is intended to be relevant to users at different levels of experience, from those just beginning the emissions inventory process, to those having extensive experience with developing port-related emissions assessments.

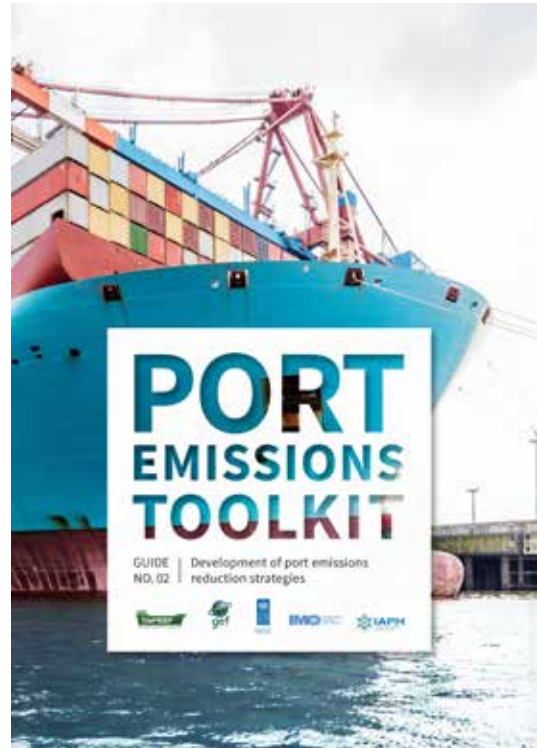
This guide focuses on planning and key decision steps related to port emissions assessments. As the technical methods for estimating activity levels and related emissions from port-related sources continue to be updated and improved, this guide also points the reader to those organisations and ports that are at the forefront of emissions inventories, metrics and forecasts and, through their published work, provide up-to-date methods and proxy data for the development of port emissions assessments.



Guide No.2: Development of port emissions reduction strategies

This guide is intended to serve as a resource guide for ports intending to develop an emissions reduction strategy (ERS) for port-related emissions sources. This guide builds on the principles discussed in Guide No.1 and describes the approaches and methods that can be used by ports to develop, evaluate, implement and track voluntary emissions control measures that go beyond regulatory requirements.

This guide focuses on measures to be considered as part of an ERS plan for those port-related mobile emissions sources that are associated with cargo movement. This guide highlights key elements that ports should consider when developing an ERS, which includes evaluating, planning and implementing mobile source emissions control measures as part of an overall ERS. This guide also contains links to resources that provide further details into specific areas.



1 Background

Note to the reader: There is a heavy reliance on US port information in this document. This is because several ports in the US have undertaken port emissions assessments and because published information from other ports on the subject is limited.

1.1 Introduction to a port emissions assessment

A port-related emissions assessment consists of three parts: an emissions inventory; equipment, activity and emissions metrics; and, optionally, an emissions forecast. Each of these is further defined as follows:

- **Emissions inventories** catalogue the various port-related emissions sources and their activities, translate those activities into energy consumption levels and then translate energy consumption into emissions. They provide insight on activities and related emissions of the various source categories, within defined geographical, operational and temporal domains.
- **Equipment, activity and emissions metrics** provide context to the inventory through inter-related data on equipment, activities, energy consumption, emissions sources, cargo throughput, as well as other indicators to create standards against which the design and performance of efforts to reduce emissions can be accomplished. For example, an emissions metric, such as emissions-per-tonne of cargo, can be tracked over time and used to determine whether the ratio improves or worsens. In the case of the latter, the identification of inefficiencies can help inform corrective measures that would decrease the emissions intensity of the activity.
- **Emissions forecasts** are future projections of emissions based on estimates of cargo throughput increases and changes in equipment and operations over time. Forecasts are used to: evaluate emissions reduction scenarios; estimate benefits from regulation of port-related sources; identify the potential emissions reduction magnitudes when developing future emissions reduction targets; and energy efficiency planning.

Port-related air pollutant emissions inventories are the foundation upon which both emissions metrics and emissions forecasts are built. Port emissions inventories can be developed with different levels of detail, depending on the purpose of the inventory, the data and resources available to compile the inventory, and the timeframe available to complete the work.

Port emissions inventories can be conducted by environmental regulatory bodies, port authorities, private operators/terminals, or as joint port authority-regulatory agency collaborations. Inventories may be conducted by an individual port authority, or jointly by several ports in a region. Inventories are undertaken to respond to questions or conditions (drivers) related to addressing air pollutant issues. The parameters, methods, data quality and level of detail can vary widely by inventory, depending on the questions it is designed to answer and the availability of data. Thus, one of the most important elements of a port air emissions inventory is data. Data come in a variety of forms and from a variety of sources. Some data elements, like ship-parameters, can be purchased. Government agencies may publish certain data elements, such as emission factors for engines and operational profiles in form of load factors for different equipment. The port itself may collect other data elements, such as activity and cargo throughput. Most of the data used in an inventory should be gathered directly from the sources being inventoried and validated for use. It is not only important to understand each data element but also the uncertainty associated with each data element.

Data collection can be the most time intensive phase of an emissions assessment. Port-specific data that define activity, operational and physical parameters are critical if the assessment is going to be used to set policy, manage emissions from local sources, or plan and implement emissions reduction strategies. Without port-specific data as a starting point to assess the order of magnitude of emissions from a port's source(s),

proxy data will be needed. For example, a port with no access to data specific to its own operation could look for a port with similar operation (sources, activity, etc.) that does have available data. These data could be used as surrogate, or proxy, data to make assumptions about the port emissions sources, activity, etc. However, proxy data from another port may not reflect local operations, which can lead to estimates that do not reflect actual conditions in a particular port. Proxy data bring a significant level of uncertainty to the results and jeopardise the success of policy decisions related to managing and reducing emissions and should only be used in the absence of any port-specific data.

Equally important are the methodologies used to estimate energy consumption and air pollutant emissions from the data collected. The complexity and specificity of these methodologies range from simple equations that use broad assumptions to detailed equations and port-specific data covering every specific engine and activity type in the port.

Based on the drivers and intended uses of the assessment, it is important to match data with a commensurate estimating methodology so that results best match actual conditions for the selected level of detail. This will minimise uncertainty in the results and improve the ability to manage emissions sources and track emissions reduction measures in the most cost-effective way.

1.2 The issues

Increasingly, there is growing pressure at ports around the world to address air pollution generated by cargo movement operations to minimise its impacts on human health and the environment. There has been a myriad of well-documented studies^{1,2,3} over the past decade that link serious health effects and climate impacts to the combustion of fossil fuels in diesel and other engines of maritime-related equipment such as marine vessels and cargo handling equipment. As a result, there is an increased focus on ports and the maritime industry to reduce emissions to protect public health and the environment.

Air pollutants have direct adverse health impacts and those effects increase with proximity of the population to their release. Greenhouse gases, on the other hand, have the same impact regardless of where they are emitted. In other words, health-based air pollutant effects are generally local and climate-related pollutant effects are global.

In most cases, port area stakeholders are most concerned with air pollutants that have more near-term and localised impacts. On a local level, oxides of nitrogen (NO_x) (associated with ground-level ozone), particulate matter (PM) and oxides of sulphur (SO_x) (which contributes to PM) are the most critical pollutants affecting air quality around port areas. The adverse health impacts of ground-level ozone and PM are the two most common drivers of air quality initiatives worldwide and will be central to almost any port area effort to reduce air pollutant emissions. Several countries have air quality standards that define clean air. These standards specify geographical boundaries within which standards must be met.

Even though effects of climate change, such as sea level rise and extreme weather events, are a general concern for many ports over the long term, climate-related pollutants do not have the same level of local and near-term impacts as pollutants that cause health concerns. As such, most countries do not have specific greenhouse gas emissions targets, or standards, for industries such as ports and the maritime sector. Nonetheless, most nations are committed to addressing climate-related pollutants through the United Nations Framework Convention on Climate Change (UNFCCC) and have or will establish goals for greenhouse gas emissions, which justifies inclusion of greenhouse gas emissions in a port emissions assessment.

For example, in April 2018, the Marine Environmental Protection Committee (MEPC) of the IMO developed a pathway forward to identify greenhouse gas targets from international shipping. These targets will include emissions from ships on international voyages only, however, and not emissions from port activities or domestic vessels operating in the port area.

¹ Daniel Mueller, Stefanie Uibel, et al., 2011. *Ships, Ports and Particulate Air Pollution – An Analysis of Recent Studies*; J Occup Med Toxicol. 2011; 6: 31.

² Sebastian Oeder, Tamara Kanashova, et al., 2015. *Particulate Matter from Both Heavy Fuel Oil and Diesel Fuel Shipping Emissions Show Strong Biological Effects on Human Lung Cells at Realistic and Comparable In Vitro Exposure Conditions*; PLoS One. 2015; 10(6): e0126536.

³ Additional references in Resources.

While the immediate purpose of an emissions inventory might be to address emissions that affect public health risk on a local basis, it is relatively simple to also include greenhouse gas emissions in an inventory in support of international concern over climate change.

1.3 Port-related sources

There are broad and diverse emissions sources associated with port operations, but not all source types may be found in every port. Port operations can range from simple cargo handling to industrial and commercial operations intermixed with cargo handling. Some ports handle primarily international marine traffic; while others handle a mix of international and domestic marine traffic. The identification of port-related emissions sources focuses on port controlled or influenced activities, categorised by emissions source category and energy type. Port emissions inventories focus on emissions sources related to the movement of cargo, associated electrical grid and administrative sources. These source categories are presented in Table 1.1.

Table 1.1: *Port-related emissions source categories*

Source type	Emissions source category	Cargo movement related?
Mobile	Seagoing vessels	Yes
	Domestic vessels	Yes
	Cargo handling equipment	Yes
	Heavy-duty vehicles	Yes
	Locomotive	Yes
	Light-duty vehicles	Yes
Stationary	Electrical grid	Associated
	Power plant	No
	Industrial facilities	No
	Manufacturing facilities	No
	Administrative offices	Associated

This document focuses on the mobile and stationary source types that are related to the movement of cargo. Stationary sources that are not directly related to the movement of cargo are usually excluded from a port-related emissions assessment for the reasons detailed in sections 2.4 and 3.2.2.

An overview of the most common port-related operational pollutants, sources and their associated health and environmental effects is provided in Table 1.2.

Finally, more recently, the quantification of black carbon (BC) particulate matter, which occurs from the incomplete combustion of carbon-based fuels, has become a concern due to its short-lived climate forcing impacts on the acceleration of the melting of ice in the Arctic and Antarctic. Consideration of BC in port emissions assessments is just beginning.

Table 1.2: *Port-related pollutants, sources and health and environmental effects*

Air pollutant	Sources	Health and environmental effects
Oxides of nitrogen (NO_x) is the generic term for a group of highly reactive gases; all of which contain nitrogen and oxygen in varying amounts. Most NO _x are colourless and odourless.	NO _x form when fuel is burned at high temperatures, as in a combustion process. The primary port-related NO _x sources are from the exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel.	NO _x can react with other compounds in the air to form tiny particles adding to PM concentrations. NO _x can also bind with VOCs and sunlight to form ground level ozone or smog. NO _x and VOCs are ozone precursors. Ozone is linked to shortness of breath, coughing, sore throat, inflamed and damaged airways, and can aggravate lung diseases such as asthma, emphysema and chronic bronchitis.

Air pollutant	Sources	Health and environmental effects
<p>Particulate matter (PM) refers to discrete solid or aerosol particles in the air. Dust, dirt, soot, smoke and exhaust particles are all considered PM. PM is typically categorised as Total PM (or just PM) or divided into two smaller size categories: PM₁₀, which consists of particles measuring up to 10 micrometres in diameter; and PM_{2.5}, which consists of particles measuring 2.5 micrometres in diameter or smaller. Diesel particulate matter (DPM) is a species of particulate matter important in some jurisdictions.</p>	<p>Airborne PM is a mixture of solid particles and liquid droplets generated in numerous ways. The primary port-related PM sources are from the exhaust of engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel. PM can also be generated from large open areas of exposed earth or dirt roads, where vehicles and equipment can disperse PM into the air.</p>	<p>Fine particles are a concern because their very tiny size allows them to travel more deeply into lungs and enter the blood stream, increasing the potential for health risks. Exposure to PM_{2.5} is linked with respiratory disease, decreased lung function, asthma attacks, heart attacks and premature death.</p>
<p>Oxides of sulphur (SO_x) is a group of colourless, corrosive gases produced by burning fuels containing sulphur.</p>	<p>SO_x (a group of gases) is released when fuels containing sulphur are burned in the combustion process. The primary port-related SO_x sources is exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fossil fuel.</p>	<p>SO_x is associated with a variety of respiratory diseases. Inhalation of SO_x can cause increased airway resistance by constricting lung passages. Some of the SO_x become sulphate particles in the atmosphere adding to measured PM levels. High concentrations of gaseous SO_x can lead to the formation of acid rain, which can harm trees and plants by damaging foliage and decreasing growth.</p>
<p>Volatile organic compounds (VOCs) are any compound of carbon (other than CO, CO₂, carbonic acid, metallic carbides or carbonates and ammonium carbonate) which participates in atmospheric photochemical reactions.</p>	<p>VOCs are generated when fuel is burned in the combustion process. The primary port-related VOCs sources are from the exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel. In addition, liquids containing VOCs are used by numerous industrial and commercial applications, where they can volatilise into the air.</p>	<p>In addition to contributing to the formation of ozone, some VOCs are considered air toxics which can contribute to a wide range of adverse health effects. Some VOCs are also considered PM.</p>
<p>Carbon monoxide (CO) is a colourless, odourless, toxic gas commonly formed when carbon-containing fuel is not burned completely.</p>	<p>CO forms during incomplete combustion of fuels. The primary port-related CO sources are from the exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel.</p>	<p>CO combines with haemoglobin in red blood cells and decreases the oxygen-carrying capacity of the blood. CO weakens heart contractions, reducing the amount of blood pumped through the body. It can affect brain and lung function.</p>
Climate change pollutant	Sources	Health and environmental effects
<p>Greenhouse gases (GHGs) that are typically emitted from port-related sources include carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Additional gases that are not significantly emitted by maritime-related sources or included in this inventory also contribute to climate change.</p>	<p>GHGs come from both natural processes and human activities. The primary port-related GHG sources are from the exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel.</p>	<p>Most climate scientists agree that the main cause of the current global warming trend is the human expansion of the 'greenhouse effect'. Warming results when the atmosphere traps heat radiating from Earth towards space. Certain gases in the atmosphere block heat from escaping, otherwise referred to as GHGs. Climate change results in extreme and unusual weather pattern shifts within the Earth's atmosphere.</p>

1.4 GHG emissions sources

From a carbon perspective, the relationship of the port's administrative authority to its operating terminals is important in defining the source categories into which various activities fall. Emissions sources for greenhouse gas inventories are treated differently from other air pollutants. A number of GHG quantification protocols^{4,5,6} recommend that the emissions-producing activities should be grouped into three categories, termed "scopes", primarily based on ownership or control of the sources. These scopes have been adapted for ports as follows:

- **Scope 1** – Port direct sources. These sources are directly under the control and operation of the port administration entity and include port-owned fleet vehicles, port administration owned or leased vehicles, boilers and furnaces in buildings, port-owned and operated cargo handling equipment and any other emissions sources that are owned and operated by the port administrative authority.
- **Scope 2** – Port indirect sources. These sources include purchased electricity for port administration owned buildings and operations. Tenant power and energy purchases are not included in this scope.
- **Scope 3** – Other indirect sources. These sources are associated with tenant operations and include ships, trucks, cargo handling equipment, rail locomotives, harbour craft, tenant buildings, tenant purchased electricity and port employee vehicles. For a port with a large number of tenants, this will likely be the largest source of greenhouse gas emissions.

The scopes are illustrated graphically in Figure 1.1. This figure shows the scopes for a landlord port (cargo operations handled by tenants). For an operating port (cargo operations handled by the port itself), the sources shown under Scope 3 in the figure would be considered under Scope 1. Emissions from the generation of purchased electricity will be Scope 2 or Scope 3 emissions, depending on the ownership of the electricity consuming operation; an operating port will have relatively more Scope 2 purchased electricity emissions than a landlord port.

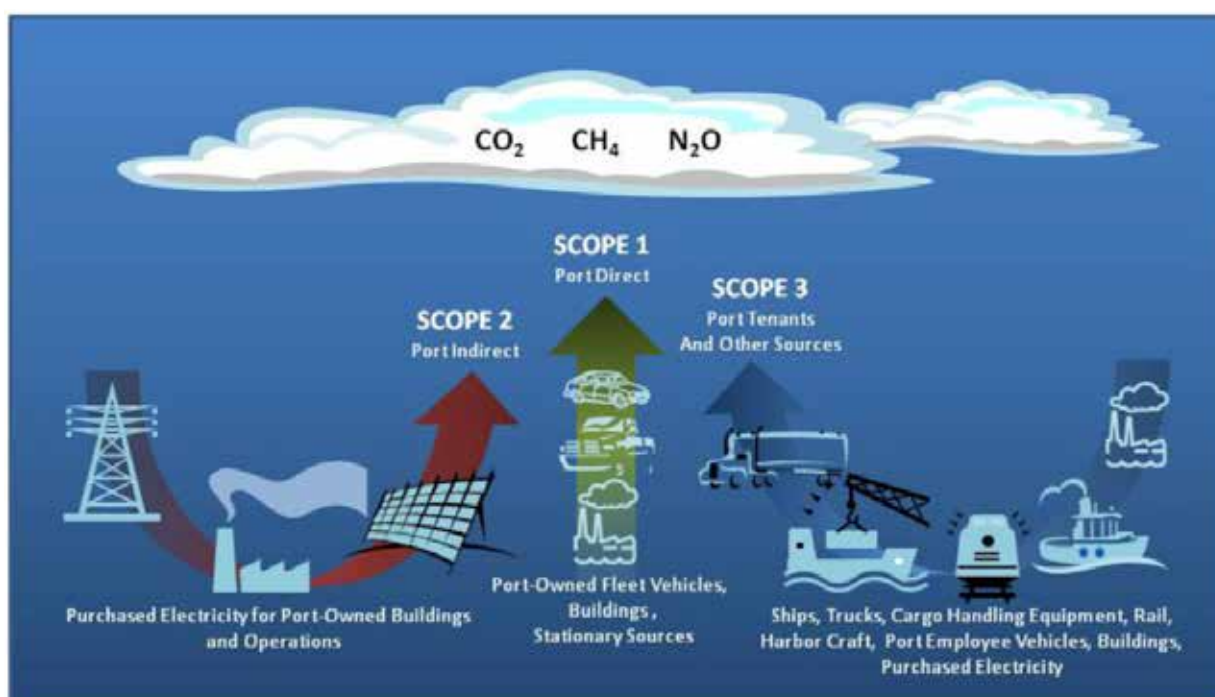


Figure 1.1: Port-related GHG emissions sources by scope

⁴ WRI and WBCSD 2004. *GHG Protocol Corporate Accounting and Reporting Standard. Revised Edition*; World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), 2004. See <https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf>

⁵ WRI 2014. *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*; World Resources Institute (WRI), 2014. See https://ghgprotocol.org/sites/default/files/standards/GHGP_GPC_0.pdf

⁶ Additional references in Resources.

Identifying and categorising the source categories and air pollutant and greenhouse gases that will be included in the assessment is the first step. The second step is to evaluate these sources and pollutants against the port’s specific regulatory environment, or framework, that governs the identified sources and pollutants.

1.5 Regulatory frameworks

The regulatory responsibility for setting air quality and carbon performance standards, as well as emissions reduction goals and targets for the various source categories or in total falls to regulatory agencies. These agencies can be at the local, regional, national, or international level. In some cases, often in concert with active local port communities, proactive port authorities may also set air pollutant and greenhouse gas emissions reduction targets. There are two types of regulatory frameworks that relate to port emissions: emissions standards for source categories and regulatory emissions inventories. These two frameworks are further discussed below.

Emissions standards

The regulatory framework for various emissions source categories may differ by source and port. Regulatory authorities at different levels, from local, state or province, national, supranational or international, have the authority to set emissions performance standards for new and existing equipment and vessels, or to adopt another regulatory authority’s rules and standards. Some agencies may also have the authority to set air pollutant and GHG emissions reduction targets. Authorities at different levels may focus on different sources. Multiple authorities may regulate some emissions sources. Examples of the various tiers of regulatory authorities include:

International	International Maritime Organization
Supranational	European Union
National	United States Environmental Protection Agency, China Ministry of Transport, Netherlands Environmental Assessment Agency
State or Province	California Air Resources Board, New South Wales Environmental Protection Authority
Local	South Coast Air Quality Management District, Greater Vancouver Regional District, DCMR Milieudienst Rijnmond, Shanghai Environmental Protection and Monitoring Bureau

Source categories can have overlapping regulatory tiers from country to country or area to area within the same country. The potential regulatory spheres by source category is presented in Table 1.3.

Table 1.3: Potential regulatory spheres for port-related emissions sources

Source type	Emissions source category	Regulatory spheres
Mobile	Seagoing vessels	International, Supranational, National, State or Province, Local
	Domestic vessels	Supranational, National, State or Province, Local
	Cargo handling equipment	Supranational, National, State or Province, Local
	Heavy-duty vehicles	Supranational, National, State or Province, Local
	Locomotive	Supranational, National, State or Province, Local
	Light-duty vehicles	Supranational, National, State or Province, Local
Stationary	Electrical grid	Supranational, National, State or Province, Local
	Power plant	Supranational, National, State or Province, Local
	Industrial facilities	Supranational, National, State or Province, Local
	Manufacturing facilities	Supranational, National, State or Province, Local
	Administrative offices	Supranational, National, State or Province, Local

Regulatory emissions inventories

Government or regulatory agencies may conduct emissions inventories that include port-related sources. These agencies do not usually have access to or an in-depth understanding of port-related activity or equipment data. As a result, these inventories are usually high level and use averages, proxy, or surrogate information that can significantly depart from actual conditions and lead to poor policy decisions.

It is recommended that any port that is planning an emissions inventory should identify, contact and coordinate with regulatory agencies that conduct emissions inventories based on port-related emissions sources. This will ensure that the port has input on latest emissions estimating methodologies and ensure that the regulatory agencies have understanding of port operations to ultimately result in an inventory that can be used by both the port and associated agencies. This has become a critical strategy in the US to avoid poor policy decisions and improper allocation of port-related emissions contributions in a region. Development of a port-related emissions inventory in collaboration with a regulatory agency helps build trust and allows stakeholders to understand the true context of port-related emissions. As one example, in California, several ports prepare their own inventories (in consultation with and review by the state level agency – California Air Resources Board) that are then inserted into the statewide inventory for port sources. These emissions inventories serve both a local and state level emissions control strategy planning purpose.

1.6 The port response

A number of ports around the world have conducted port emissions assessments in order to respond to concerns regarding the health risks of port operations (see section 5 below). There are several interrelated reasons for developing a port-related emissions assessment, although each port will have a unique set of drivers that determine the actual content of their particular emissions inventory. One reason may be to simply disclose the emissions of particular air pollutant and/or greenhouse gas pollutants from port operations. If done in advance of regulatory requirements, inventorying emissions can not only present the port in the light of a forward-looking organisation to stakeholders, but also engage the stakeholders from the beginning in the conversation of how best to reduce emissions from port activities. An inventory provides a solid foundation for the evaluation of viable emissions strategy analyses and can serve as the tracking and reporting mechanism for future assessments.

Improved energy use or emissions performance can also be a reason to conduct an emissions inventory. The development of a structured inventory of energy users that produce emissions can help identify areas in which improvements can be made in energy efficiency or improved port operations. This can greatly facilitate the development of cost-effective emissions reduction strategies that can provide a financial benefit as well as an environmental benefit. In addition to these beneficial uses of port-related inventories, some ports may face a current or future requirement to assess and document emissions to a government-mandated registry or agency.

2 Planning for a port emissions assessment

To maximise the success and minimise the effort of conducting a port emissions assessment, it is strongly suggested that a series of planning steps be followed before starting the actual assessment. The recommended steps are illustrated in Figure 2.1 and further discussed in the following sections.

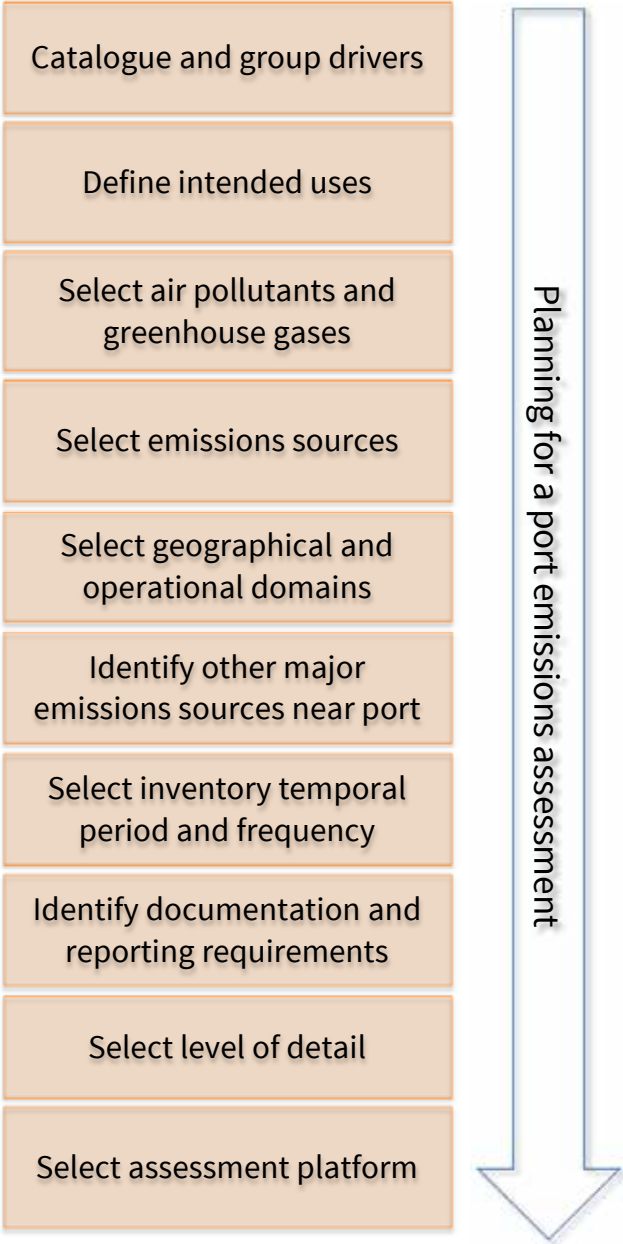


Figure 2.1: Planning steps for a port emissions assessment

2.1 Catalogue and group drivers

The reasons why a port conducts an emissions assessment are called “drivers.” The following are examples of drivers that led individual ports to develop a port emissions assessment.

- Opposition to proposed port expansion/redevelopment projects based on concerns related to future air quality due to these projects.
- Health effects studies showing significant adverse impacts from air pollutant and/or GHG emissions from sources related to port operations.
- Stakeholder and/or nearby resident pressure to reduce air quality and/or GHG impacts from port operations.
- Threat by an environmental regulatory agency to develop a proposed regulation to reduce port-related emissions.
- Designation of the port area as not meeting air quality regulatory standards.
- Requirements to meet GHG reduction targets from an environmental regulatory agency or regional, national, or state policies.
- To ensure that the most accurate emissions assessment is used by environmental regulatory agencies to avoid poor policy decisions.
- Lawsuit associated with proposed port development projects.
- Political forces interacting with port executive management to address air quality and/or GHG impacts from port operations.
- Requirement related to a financial instrument such as a grant or loan.
- Required for project development permits.
- Corporate ethos relating to ‘license to operate’, being a corporate leader.
- Pressure because peers have conducted port emissions assessments.
- General curiosity of the magnitude of port-related emissions.

Once it is decided to conduct a port emissions assessment, it is important to catalogue all current drivers and try to anticipate emerging or future drivers, so that the inventory is developed to address all drivers.

The nature and number of the drivers being considered by a port when designing a port emissions assessment determines the assessment’s level of detail.

When cataloguing drivers, it is helpful to group the drivers by their importance to maintaining continued port operations. An example of groups is illustrated in Figure 2.2. For this example, the three priority categories used to group the drivers are:

- **High** – those drivers that require immediate direct action and are only addressed through an emissions assessment.
- **Medium** – those drivers that do not immediately call for direct action but are significant enough to inform the design of an emissions assessment.
- **Low** – those drivers that would require only general information and additional context to be provided and/or for demonstrating progress through action.

It is important to note that drivers can shift between the different priority categories based on the port’s specific circumstances and therefore some of the drivers occupy one or more categories in the illustration below.

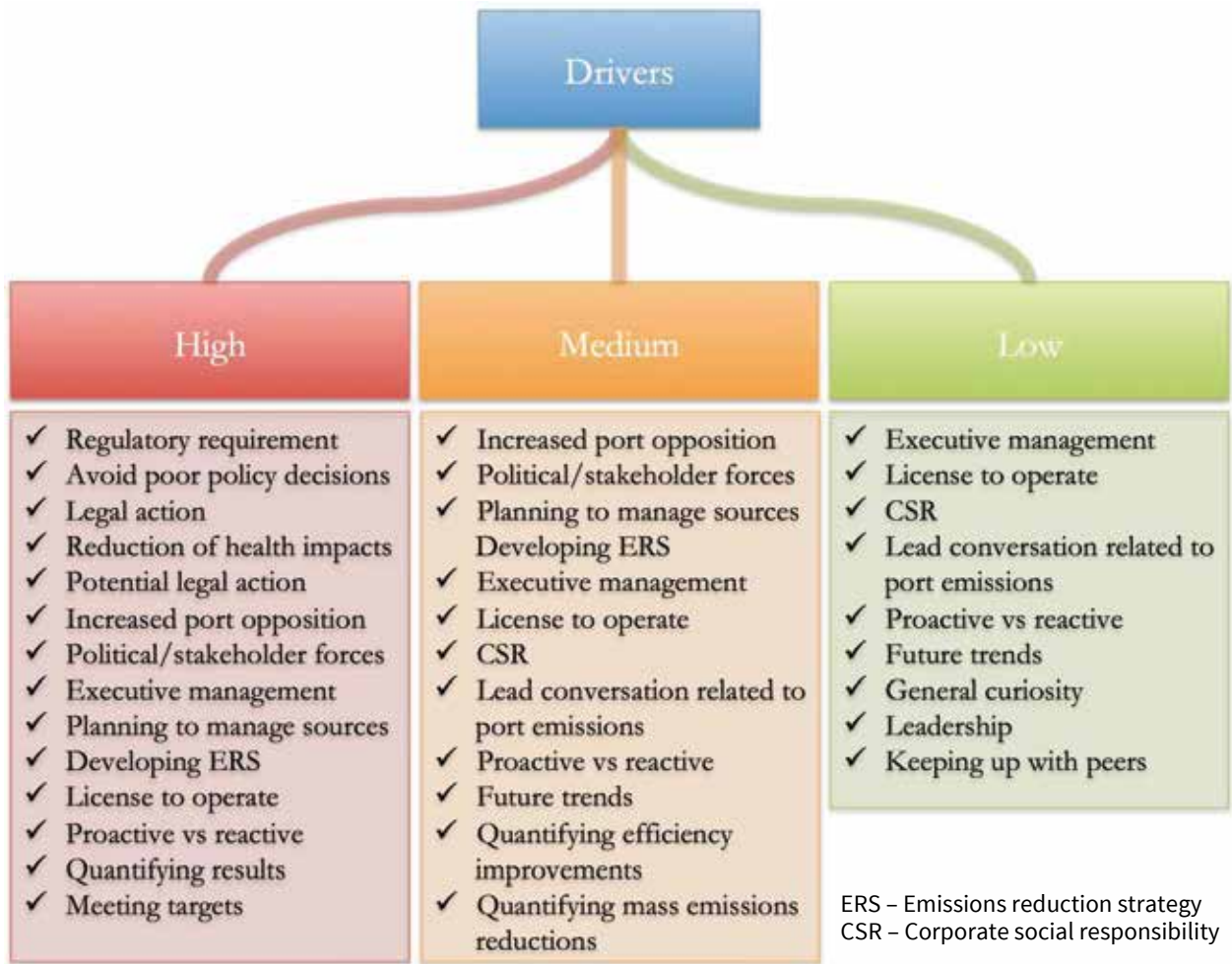


Figure 2.2: Examples of priority grouping of drivers for a port emissions assessment

2.2 Define intended uses

It is important to identify the intended uses for the information collected during the port emissions assessment and the resultant output. The intended uses will be influenced directly by the identified drivers and will have a direct impact on other planning steps such as reporting. Like drivers, there are a wide variety of potential intended uses. For example, reporting port emissions to decision-makers and development and tracking of emissions reduction strategies are the most common intended uses of a port assessment.

In addition, it is important to determine if the assessment is to be used only internally, will be shared publicly, or will be used to inform environmental regulatory policy development. In some locales, state- or province-wide emissions inventories are conducted by regulatory agencies. These will include an estimate of port emissions. In this case, the port emissions assessment should be designed so that it meets the agency’s technical requirements and the results of the assessment can be compared with or included in the state- or province-wide inventory.

In addition, a clear understanding of the assessment’s audience is important to ensure that confidential data is appropriately aggregated for public dissemination. Concern about the handling of data from operators can be a significant barrier to collecting data that is needed for a port emissions assessment. Thus, ensuring that confidential data can be used in a manner to guard confidentiality will enhance the port’s ability to collect data.

2.3 Select air pollutants and greenhouse gases

As stated above, there are both air pollutant and greenhouse gas emissions that are generated from sources used for maritime operations at a port. It is important to select which pollutants are going to be included in the assessment and their associated units of measure. The common air pollutants estimated for port-related sources include:

- Nitrogen oxides (NO_x)
- Particulate matter⁷ (PM), which is further classified by size: PM₁₀ and PM_{2.5}
- Sulphur oxides (SO_x)
- Volatile organic compounds (VOCs)
- Carbon monoxide (CO)

Common greenhouse gases included in a port-related emissions assessment include:

- Carbon dioxide (CO₂)
- Nitrous oxide (N₂O)
- Methane (CH₄)

Due to increasing concern of black carbon (BC), inclusion of BC emissions is just beginning to emerge in port emissions assessments. Refrigerants are not usually included in a port emissions assessment since consumption and discharge rate data can be difficult to obtain and their quantities are small in comparison with other greenhouse gas emissions.

2.4 Select emissions sources

The selection of emissions sources to be included in a port emissions assessment is linked to the drivers and the intended uses of the assessment. Emissions sources included in an assessment should be linked to port operations. There are wide ranges of port configurations ranging from small ports with simple cargo movement operations to large ports with industrial and commercial operations intermixed with cargo movement operations. Depending upon the type of port and its operation different emissions sources will be considered. It is important to identify the emissions sources related to the specific port in question and identify the details of those operations. This will also help in defining the geographical and operational boundaries, or domains, as the next step of a port emissions assessment.

It is important to delineate which emissions sources are under direct port control (for example, equipment directly managed by a port) versus sources under indirect port control (for example, equipment associated with tenant operations). It is highly recommended that only those sources and operations that are linked to port operations be included in the assessment. Any emissions sources beyond those either directly or indirectly linked to port operations will impede the use of the assessment, as the port will neither have control nor influence over these non-port sources or their operations or be able to control implementation of any necessary emissions reduction strategies for this equipment.

Emissions sources are normally organised by source type. There are two source types associated with port operations: mobile sources and stationary sources. Sources can be further divided into emissions source categories within each source type. Finally, each emissions source category is further subdivided by energy type used to power the equipment. Examples of port-related emissions source categories and energy types, by source type, are presented in Table 2.1.

⁷ In some ports, particularly in California in the United States, Diesel Particulate Matter (DPM) is also an important air pollutant to include. As described in Table 1.2, DPM is a species of particulate matter resulting from the combustion of diesel fuel. It has been labelled as a toxic air contaminant in California based on published evidence of a relationship between diesel exhaust exposure and lung cancer and other adverse health effects.

Table 2.1: Port-related emissions source categories by energy type

Source type	Emissions source category	Energy types
Mobile	Seagoing vessels	fuel oil, diesel, natural gas (NG), methanol
	Domestic vessels	fuel oil, diesel, NG
	Cargo handling equipment	diesel, NG, propane, gasoline, methanol, electricity
	Heavy-duty vehicles	diesel, NG, electricity
	Locomotive	diesel, NG, electricity
	Light-duty vehicles	diesel, NG, propane, gasoline, electricity
Stationary	Electrical grid	coal, NG, diesel, renewable
	Power plant	coal, NG, diesel, renewable
	Industrial facilities	electricity, renewable, diesel
	Manufacturing facilities	electricity, renewable, diesel
	Administrative offices	electricity, renewable, diesel

Another emissions source type related to port operations is unpaved areas used for cargo or equipment storage. Vehicles and equipment moving through these unpaved areas can disturb the soil surface with winds lifting fine dirt particles into the air generating PM. These areas are classified as ‘area sources’ and are usually not included in a port emissions assessment as they are highly variable and difficult to quantify.

In terms of operational control by port authorities or administrative bodies, port operations can be classified by three general types with varying degrees of overlap:

- **Landlord ports** – own the land or are given responsibility for managing the land on which the port is located and in most cases develop the port facilities, such as marine terminals, but lease the land and/or facilities to terminal operators who are responsible for the equipment used on the terminals.
- **Operating ports** – develop, own and operate the marine terminal facilities and the equipment used on the terminals.
- **Private ports/terminals** – privately owned, operated and are not tenants of a port authority.

Some ports incorporate features of both landlord and operating types, such as a port that owns the land and the major infrastructure and leases some terminals to an operator but operates other terminals themselves. A port area may include a combination of all three types of port operations.

2.5 Select geographical and operational domains

An important consideration in the development of a port-related emissions inventory is the geographical and operational domains that encompass the activities to be included in the inventory. Defining both domains helps to answer the questions of “where, geographically, is the inventory going to account for emissions from port-related sources and which activities are going to be included?” The answers to these two fundamental questions are informed and shaped by the drivers, intended uses, pollutants and sources to be included in the emissions inventory.

The geographical domain is the maximal extent of area to be included in the emissions inventory. It may be broader than the footprint of the port itself. Some ports accept responsibility for control of emissions sources, such as vessels, trucks and rail well beyond port boundaries. The geographical domain for a port emissions inventory can consist of overland and/or overwater boundaries, depending on the intended uses of the inventory (e.g. in an assessment that includes both land-based and water-based port-related emissions sources). Since there is a vast array of diverse geographical layouts and features of ports around the world and a widely diverse range of drivers and intended uses for port-related emissions inventories, there is no single geographical definition to define port assessment domain that can be applied to all ports. For example, a commonly used geographical domain is the port’s administrative boundary. If, however, the inventory is used to support the development of local or regional regulatory emissions inventories, the geographical domain will need to match the typically larger emissions modelling domain used by the local regulatory authorities.

Matching these regulatory emissions modelling domains can significantly extend the inventory's geographical domain beyond a port's administrative boundary.

The operational domain describes which port-related activities within the geographical domain will be included in the inventory. Since the intent of the emissions assessment is to manage sources, develop emissions reduction strategies and/or track progress of control measures, then the port needs to determine which activities it can influence. Port activities are usually those that directly touch port terminals and extend to and from the geographical boundary, as applicable. Examples of activities that directly involve port terminals include:

- Cargo-related operations within the port's administrative boundaries:
 - All port-related emissions sources' cargo-related activities conducted within the administrative boundaries. Cargo handling equipment operations are almost always confined to the port's administrative boundaries.
- Cargo-related operations beyond the port's administrative boundaries:
 - Within the geographical domain, a ship's transit from the geographical boundary to an anchorage, time at anchorage, then shift to a port terminal, time at-berth and then transit to the geographical boundary.
 - Within the geographical domain, the last cargo pickup/first cargo drop-off prior to entering/after leaving a port terminal for a truck or locomotive. This excludes any moves not directly coming to or leaving a port terminal and therefore does not include the total distance travelled by that truck during a day.

It should be emphasised that port-related emissions inventories do not necessarily account for all the emissions in the geographical domain, only those emissions sources and activities directly linked with port operations.

The pollutants to be included in the inventory will provide an additional consideration when defining the inventory domains. Air pollutants, such as NO_x, SO_x and PM, have localised effects; therefore, location and proximity of the port to populated areas should play a role in determining boundaries for the emissions inventory as well as any subsequent control strategies. When focusing on air pollutants, the geographical domain could be set to match any applicable environmental regulatory domain, or broader area where port-related sources are operating in close proximity to populated areas.

The effect of GHG emissions are not location specific and have the same impacts regardless of where they are emitted (an exception is short-lived climate forcers such as BC in Arctic areas). International GHG protocols may make boundary considerations for a carbon footprint inventory different than an air emissions inventory. The boundaries for the three scopes⁸ evaluated in GHG emissions inventories will need to be considered, based on the definition explained in section 1.4 above with following additional considerations:

- **Scope 1 emissions sources** – The boundary encompasses a local or regional area where these sources are located and operate. As noted above, the inventory domain is not necessarily exclusive to the port, as in the case of port-owned motor vehicles that travel on public roads outside the port itself.
- **Scope 2 emissions sources** – They may be local or relatively close by, but they can also be remote from the port. For example, in the case of electrical power generation, a power plant may be located well outside the maximal extent of the geographical domain for all other pollutant sources. For this reason a geographical boundary is typically not set for Scope 2, and Scope 2 emissions are reported in total for the port.
- **Scope 3 emissions sources** – The domain may be global (for example, to include entire ocean voyages), national, regional, or more local, such as a political border or the port's own administrative boundary. Life cycle analysis (emissions associated with every aspect of sources, i.e. forging steel to build a ship, mining copper, transporting to be made into wire, etc.) is not usually included in Scope 3 source emissions analysis.

⁸ Please refer to section 1.4 for GHG scope definitions.

As a result of the above considerations, the EU and some ports have expanded the emissions inventory domains when addressing GHGs.

Port emissions assessment domains can be established by local political entities (such as port governing boards, city mayors, etc.) or regulatory agencies or by international agreement.⁹ If the port has leeway to establish its own boundaries or domain, then the question of the “ability to affect emissions sources” is an important consideration, because once a port has “claimed” emissions as part of its inventory, the logical expectation is that the port will work toward reducing those emissions. If the inventory is limited to activities or sources over which the port has some measure of control, then the port has the potential to reduce those emissions. If the inventory includes emissions from area sources or from activities over which the port has no control (e.g. military activities, non-port related ship transits, etc.), then it will be significantly more difficult to affect changes in those emissions sources.

To illustrate the broad and diverse geographic and operational domains ports have set for their emissions inventories the following examples are provided:

- The Port of Los Angeles (POLA) and Port of Long Beach (POLB) have incorporated the broad South Coast Air Basin air quality modelling geographic domain, as their emissions inventories are intended to be used by both ports and the regulatory communities to develop port-related emissions control policies and track progress. The overwater geographical domain extends over 130 nautical miles (nm) out to sea and is bounded by the basin’s land borders to the north and south. The overland geographical domain includes outer boundaries for four adjacent counties. All direct port-related cargo operations are included as the operational domain within the geographic domain. The geographic domain covers a region with a population of over 10 million people (Figure 2.3).
- The Port Authority of New York & New Jersey (PANYNJ) set its overwater geographical domain to include all waterways to and from the Port Authority marine terminals to the three-nautical mile (nm) demarcation line off the coast. The overland boundary is limited to the port district boundary.
- The Port of Everglades has limited its emissions inventory to the port’s administrative boundary and out to sea to the three-nautical mile demarcation line offshore.
- The Port of Rotterdam has limited its geographical domain to include its administrative boundary and its operational domain to its owned and operated emissions sources.
- The Hamburg Port Authority has limited its emissions inventory to the local port administrative boundary. This boundary was set in conjunction with the Hamburg environmental agency’s emissions inventory geographical domain.
- The Puget Sound Maritime Air Emission Inventory includes an overland boundary of the 12 counties that make up the Puget Sound Air Basin and includes 6 major ports and numerous smaller ports and private terminals. The overwater geographical domain ends at the Canadian border or the sea buoy at the entrance to the Straits of Juan De Fuca. The operational domain includes port-related direct cargo activities within the geographical domain.
- The Port of Vancouver Port Emission Inventory includes cargo-related and administrative emissions sources and includes an overwater and overland boundary related to the air quality modelling domain for Metro Vancouver (greater than the port’s administrative boundary).
- The Port of Houston Authority’s emissions inventory overland geographical domain includes the 8-county non-attainment area and the overwater geographical domain includes all channels leading to and from port terminals to the three-nautical mile (nm) demarcation line. The operational domain includes port-related direct cargo activities within the geographical domain.

⁹ The US EPA and Environment Canada work collaboratively to address present and future air quality issues in the Georgia Basin-Puget Sound (Salish Sea) airshed (a single geographic airshed spanning international boundaries). See https://www.epa.gov/sites/production/files/2015-09/documents/salish_sea_us-canada_soi_airshed_aug2002.pdf

- The Port of Oakland has limited its overland domain to its terminal boundaries and includes an overwater boundary to the sea buoy. The operational domain includes only cargo-related activities at its terminals for both land-based and water-based emissions sources and direct transits to and from the sea buoy to their terminals.



Figure 2.3: Geographic domain for the Port of Los Angeles emission inventory

2.6 Identify other major emissions sources near port

It is valuable to put port-related emissions into context of the regional emissions in the broader area surrounding the port. Therefore, it is important to identify and categorise other major emissions sources that are present in the inventory geographical domain but not under port control. It is also important to note other major sources outside the geographical domain, but near the port. This becomes even more important if air quality is being monitored near or adjacent to the port. Air quality monitoring equipment measures the pollutants in the air at a particular location; however, the monitors do not apportion observed pollutants to their emissions sources. This can result in stakeholders assuming all pollutants detected by monitoring equipment at the port are generated from port operations, which is not usually the case for ports located in or near industrial areas.

Examples of other major non-port emissions sources that may share the inventory geographical domain include: major roadways, freeways and highways; airports, industrial, manufacturing, or commercial facilities; and power generation facilities. While these sources may be located within or adjacent to a port area, their emissions are not directly associated with goods movement activities within the port. To put port emissions in context with regional emissions, these other major sources need to be identified and discussed (but not modelled) in the port emissions inventory.

2.7 Select inventory temporal period and frequency

Usually, the temporal period for a port emissions inventory is a calendar year. The first emissions inventory a port conducts is considered the 'baseline.' Selecting a baseline calendar year can be any calendar year in the past, from the most recently completed year to a year prior to a major enhancement or expansion of port operations. If past emissions reduction efforts can be documented, it may be decided to choose a baseline year that is before those reductions took place, so that progress made can be quantified. An important consideration is that, the further back you go in years, the more likely the required data will be not readily available, if at all. This in turn can have significant impacts on the resources and time needed to conduct the assessment. The more recent the baseline year selected for the inventory, the greater likelihood that necessary data is readily available.

Some reporting protocols, for example for greenhouse gases,¹⁰ provide for assessing emissions to a specified baseline year where base year emissions goals or base year intensity goals have already been set (e.g. to reduce emissions to a level emitted during a specific year in the past, such as 1990).

Frequency refers to how often, if at all, an emissions inventory will be updated. As noted previously, this depends on the drivers and the intended uses of the assessment. Those ports with critical drivers requiring long-term emissions reduction strategies may update inventories annually. Ports with less critical drivers may choose to update inventories every three to five years. The update frequency has implications for the comparability of the inventory over time, since the greater the time between assessments the greater the likelihood that the assumptions and methodologies underlying the inventory will have changed. Documentation of assumptions and methodologies, as well as data sources, is important so that when the assessment is updated, a complete understanding of the previous assessment is possible. Also, previous versions of each assessment will likely need to be updated to ensure the previous and current assessments use the same methods, factors and assumptions to ensure comparability. It is important to allocate sufficient time and resources for these updates as well.

2.8 Identify documentation and reporting requirements

Documentation and reporting requirements vary from port to port and depend on the drivers and intended uses of the port emissions inventory. Documentation of methods and assumptions should be included in an assessment. If an emissions inventory is being developed by a port in conjunction with an environmental regulatory agency to set policy framework and develop emissions reduction programmes, then the documentation will be required to meet a much higher level of rigour than, for example, an emissions assessment for a public relations news piece or advertising campaign.

Knowing the audience for the assessment is critical. Where the audience is internal to the port, the results and findings may be technical. If the audience is the general public, the results and findings need to be designed so the intended audience can understand them. Most likely, documentation and reporting will need to satisfy both lay and technical audiences. Providing appropriate context and engaging stakeholders on the interpretation of the results of the assessment is critical to the success of the process.

2.9 Select level of detail

Port-related air emissions inventories are the foundation upon which emissions metrics and emissions forecasts are built. Port emissions inventories can be developed with different levels of detail, depending on the purpose of the inventory, the data and resources available to compile the inventory and the timeframe available to complete the work. Regardless of the starting point, however, a port emissions inventory can be expanded to include greater levels of detail or cover more operations over time, as needs and/or resources change.

The approach taken to develop the port emissions inventory will depend on the level of detail that has been decided. The three most common approaches are:

- Scaled
- Screening
- Comprehensive

¹⁰ WRI 2014. *GHG Protocol Mitigation Goal Standard. An Accounting Standard for National and Subnational Greenhouse Gas Reduction Goals*; World Resources Institute (WRI), 2014. See <https://ghgprotocol.org/mitigation-goal-standard>

2.9.1 Scaled inventories

Scaled inventories use approximations to obtain an order-of-magnitude estimate of a port's emissions. Scaled inventories are based on published external data produced for one (representative or "proxy") port, which are then extrapolated to estimate the emissions inventory at another (target) port using a scaling factor. The usual scaling factor is cargo throughput, by cargo type, based on energy consumption (kWh) or emissions intensity (tonnes pollutant). Consideration of differences in the cargo types, terminal types, terminal sizes, vessel types and other elements between the two ports is needed to select the 'best fit' scaling factors. It is recommended that source energy consumption should be scaled. Emission factors that are most representative of the target port's emissions sources would then be applied to the scaled consumption figures to achieve emissions results. This approach assumes that operations between the two ports are comparable. However, given the large variability between operations at different ports, except in narrow cases, the resulting emissions inventory is unlikely to be representative of actual conditions at the target port. In fact, other than providing a quick and inexpensive way to estimate an emissions inventory when there is limited information available, this approach is not generally recommended due to the high level of uncertainties associated with it. Key elements of scaled emissions inventories include:

- Use of published data from a "proxy" port
- Estimation of emissions based on scaling parameters
- High level of uncertainty

2.9.2 Screening inventories

Screening inventories are more detailed than scaled inventories in that they utilise more port-specific activity data, although still with a simplified emissions quantification method and incomplete level of detail on activities or equipment, to get a better order-of-magnitude result. Screening emissions inventories use a range of local activity data but may make substantial use of assumptions or external data sources to fill data gaps on energy consumption, distances, time at berth, propulsion type, auxiliary power systems, boilers, modes, equipment usage time, equipment parameter specifics, load factors, deterioration rates, and so forth. Screening emissions inventories also simplify or consolidate activity modes. Screening emissions inventories then apply the assumptions or proxy data, to activity from the port being inventoried employing a simplified emissions estimation approach. Screening emissions inventories still have significant uncertainties as a result of the simplification of data and estimating methods. Key elements of screening emissions inventories include:

- Some locally generated activity data
- Simplified or proxy data sets
- Simplified estimating approaches
- Limited or no validation of data, methods, or results
- Significant level of uncertainty

2.9.3 Comprehensive inventories

Comprehensive emissions inventories are considered "best practice" as they are based on detailed port-specific activity information for each emissions source category and utilise detailed and sophisticated emissions estimating methods. Comprehensive emissions inventories use validated data and estimating methods, may use regulatory agency-approved or specified factors or models and are suitable for use to meet regulatory requirements. Comprehensive inventories have the least uncertainty in their estimates compared with scaled or screening emissions inventories since they are more complex and take more time than the other two approaches to complete an initial emissions inventory, as there may be data elements that need to be collected that are not readily available. Comprehensive emissions inventories are usually developed in phases as a result and the resolution and refinement of the data sets and estimating methods are enhanced during each update

cycle; therefore, the results are improved with each update. Key elements of comprehensive level emissions inventories include:

- Significant amounts of locally generated activity data
- Minimised use of proxy data
- Detailed estimating approaches
- Validation of data, methods and results
- Minimisation of uncertainty

Examples of comprehensive emissions inventories conducted annually are the POLA¹¹ and the POLB¹² air emissions inventories, as they have had to meet the most rigorous drivers for any ports worldwide. These emissions inventories are coordinated with federal, state and local air quality regulators and reviewed by third parties. The regulatory agencies have agreed to include resulting emissions inventories as their emissions inventories for port-related sources in the South Coast Air Basin, replacing the agency-developed inventories for the two ports.

The advantages, disadvantages and appropriate uses for the scaled, screening and comprehensive inventory approaches are presented in Figures 2.4 through 2.6.

To summarise, comprehensive emissions inventories use the greatest level of port- and source-specific detail and provide the highest level of accuracy, as the data reflect the actual operational conditions being modelled. Screening emissions inventories use less port-specific data and rely more on external data sources than comprehensive emissions inventories. They can be accomplished in less time and at lower cost but are based on simplified methods and assumptions that can significantly increase the uncertainty associated with the estimates so that the results may not reflect actual operational conditions. Care should be taken with screening approaches when utilising their findings for emissions reduction planning, reporting, or forecasting. A scaling inventory is recommended only for developing a high-level approximation to determine order of magnitude level of port emissions.

A hybrid approach is sometimes taken, which mixes the above approaches, by source category; using the comprehensive approach on the largest source categories or where the detailed operational data is available and evaluating the other source categories using screening or scaling approaches. In later reassessments, one might replace the screening or scaling approaches with a comprehensive approach as resolution and refinement of the data sets and estimating methods are enhanced.

Scaled		
<p>Advantages</p> <ul style="list-style-type: none"> ✓ Quick implementation timeframes ✓ Limited resources & lowest costs needed ✓ Limited understanding of operations & methodology needed ✓ Consolidated & simplified methods ✓ Requires limited to no local data needs ✓ Ready made tools available 	<p>Disadvantages</p> <ul style="list-style-type: none"> ✓ Lowest level of detail ✓ Highest level uncertainty ✓ Overly simplified data inputs & methods can make results significantly depart from actual conditions ✓ Results can be assumed to be of a higher level of detail ✓ Does not build understanding ✓ Tools generally lack documentation, transparency, validation, quality assurance, ability incorporate port-specifics, etc. 	<p>Appropriate uses</p> <ul style="list-style-type: none"> ✓ Quick level magnitude estimate that is used to put port-related emissions into context with broad nationally reported levels <p>Uses to be avoided</p> <ul style="list-style-type: none"> ✓ Any drivers that go beyond 'general curiosity' ✓ Publically documenting emissions ✓ Regulatory development ✓ Regulatory compliance ✓ Reporting port-related emissions in public forums ✓ Managing sources ✓ Planning emissions reduction strategies ✓ Measuring progress

Figure 2.4: Scaled approach

¹¹ See https://www.portoflosangeles.org/environment/studies_reports.asp cited February 2018.

¹² See <https://www.polb.com/environment/air/emissions.asp> cited February 2018.

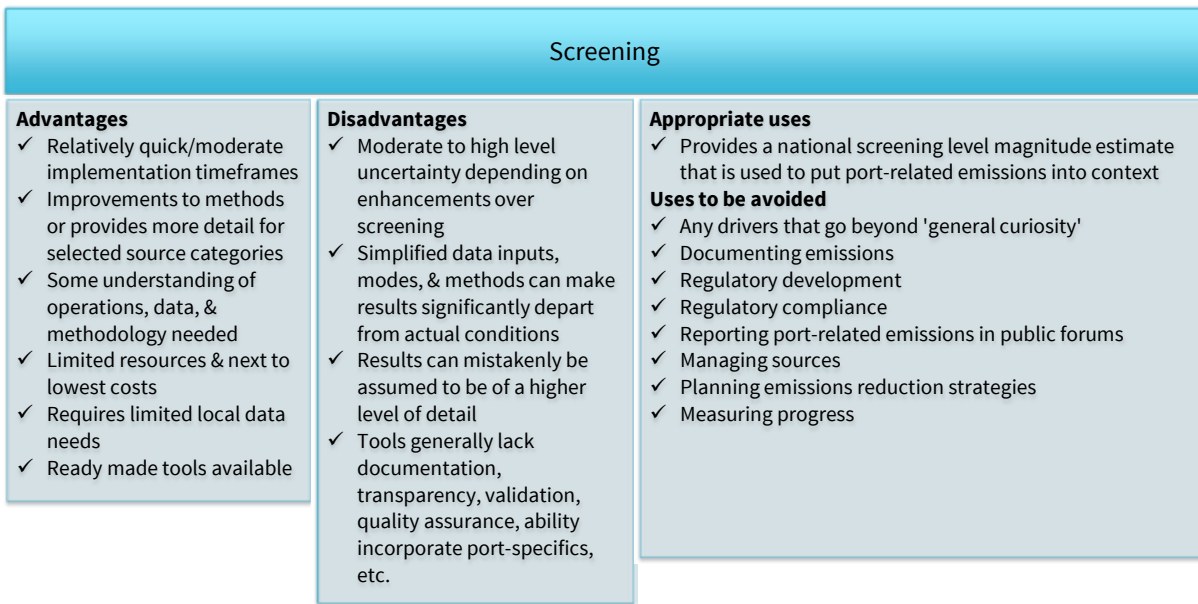


Figure 2.5: Screening approach

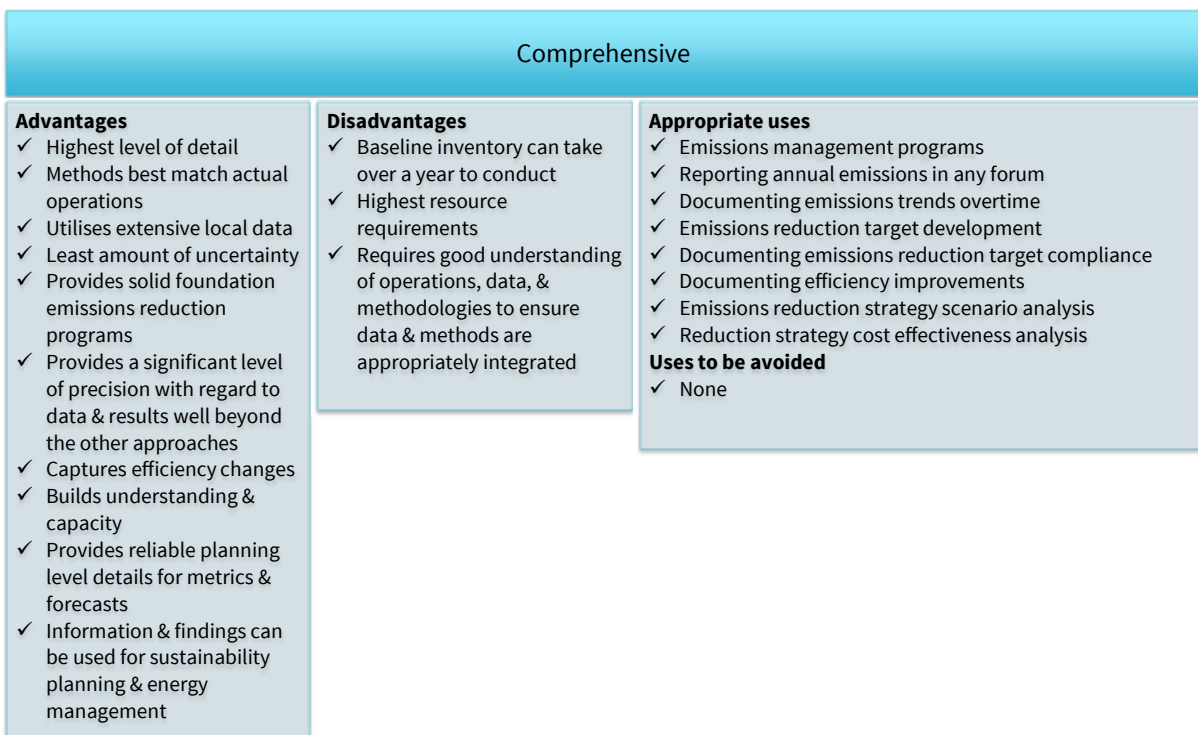


Figure 2.6: Comprehensive approach

The choice of emissions inventory approach can cause significant differences between emissions inventories either between ports or across years at the same port. This must be considered before comparing emissions inventories. For example, it would not be valid to compare a detailed emissions inventory with a screening emissions inventory.

2.10 Select assessment platform

An emissions assessment platform is the set of tools used to undertake the emissions inventory and evaluate emissions strategies. The appropriate platform depends again on the drivers, the level of detail needed and decisions made on a number of considerations taken during the planning phase to ensure that the assessment is conducted in an efficient and effective manner. There are three common types of assessment platforms used for a port emissions assessment:

- **Spreadsheets** – The best attributes of a spreadsheet-based assessment are that it is the simplest and quickest to implement and generally does not require special training to use the software. It is common for spreadsheets to be prepared and updated by a single user. For large datasets and complex calculations, however, spreadsheets often become unstable due to large file sizes. While 100 MB may seem large, a detailed seagoing vessel emissions estimate alone for a major port could be well in excess of 100 MB. Quality assurance and control is relatively more difficult to achieve with spreadsheets since it is easy for typographic errors to be introduced and for errors to propagate, particularly in models that use large spreadsheets with data in hundreds of columns and rows. Further, cell reference errors and inadvertent data or equation changes can cause significant quality assurance challenges for spreadsheets, especially the larger and more complex they are.

When designing a spreadsheet-based port emissions assessment, it is recommended to identify all elements that will need to be printed from the start and that all worksheets be formatted to enable printing. More important, it is vital to document all assumptions and factors used in the spreadsheet model and group them in their own worksheet such that they are easy to find and update.

A spreadsheet platform is best suited for scaled and screening approaches. Spreadsheets can also be helpful as a quality assurance tool for the other assessment platforms due to their ease of use. For example, if using a desktop database or a full multi-user relational database management system for the inventory, a user can export all the variables being used in a calculation to a spreadsheet, which can then be used to manually verify that the right variables are being used and ensure that the correct calculation is being applied in each case.

- **Desktop database software** – Desktop database software, such as Microsoft Access, FileMaker Pro, or iThink, can be used as an assessment platform. These database software packages are usually easy to install as single-user applications but also allow multi-user access. They may also provide both a database and user interface design component. Microsoft Access is probably the most widely available and used database software and is designed for use to create small, relatively simple databases with custom user interfaces. Access 2016 has a maximum database size of 2 gigabytes (GB) minus the space needed for system objects.¹³ The best attributes of desktop database software applications are that they are relatively simple to develop with minimal training, provide some of the benefits of a larger relational database¹⁴ system (for example, provide a data structure of related tables, allow multi-user access, provide authorisation and privilege control over access to individual data elements, provide network access, ease data retrieval and can handle large data sets). They also avoid spreadsheet issues, such as invalid cell references, inadvertent data changes and mis-copied calculations. With this platform, there are usually simplified and modifiable user interface elements, query builders and reporting functions.

This platform has limitations with performance and data storage as emissions assessments grow. This may limit the ability to store multiple years in a single database. A solution to this problem is to run each inventory in its own database; however, this becomes problematic when making comparisons between the previous year's activity and emissions with the current year's data. A potential limitation of this platform is that, although database software can sometimes handle multiple users, they are usually installed on desktop or workstation computers and may lack the robust multi-user support of a true server-based relational database management system.

¹³ See https://www.quackit.com/microsoft_access/tutorial/microsoft_access_versus_sql_server.cfm cited March 2018.

¹⁴ A relational database is a collection of data items organised as a set of formally described tables from which data can be accessed or reassembled in many different ways without having to reorganise the database tables.

When designing a port emissions assessment using a desktop database, it is important to develop an appropriate data structure, grouping like-data in individual tables, assigning unique indexes and keys to data records and assigning relationships between data elements. Quality assurance and quality control measures are needed to ensure data is being used correctly and the resulting energy and emissions estimates are credible. Quality assurance is usually easier to undertake than in a spreadsheet, as reusable, programmed calculations are used instead of multiple copied equations. However, care must be taken that the programmed calculations are set up for all conditions and not miscalculating estimates using inappropriate data and relationships.

- **Server-based multi-user relational database management system (RDBMS)** – this platform is required for the most comprehensive assessments but is also the most complex to design and manage. Data integrity on a server-based relational database system is quite high due to the nature of the database engine and the controls that can be applied to data access and modification inherent with these systems.

Server-based multi-user relational database systems lend themselves to web-based user interfaces (front end). User interfaces for this platform can be developed and updated on the server. Users can then access the data from a web browser at any location with internet access.

A server-based multi-user relational database management system requires specialised understanding of relational databases, structured query language (SQL),¹⁵ computer server systems and interface programming. Developing an assessment using this platform usually requires a team that includes individuals knowledgeable in database and interface programming, as well as those versed in emissions modelling and forecasting, to design and maintain the platform. This platform is the most appropriate one for detailed multi-year emissions inventories that use large datasets and complex modal energy and emissions estimates.

In summary, a number of considerations can help determine the most appropriate platform for a port emissions assessment. There may be times when the use of multiple platforms is appropriate. For example, a port may do an initial assessment on a spreadsheet platform and then undertake future assessments on a more detailed platform. Considerations when determining a port emissions assessment platform include:

- Level of detail needed: scaled – spreadsheet; screening – spreadsheet, database software, or server-based multi-user database; comprehensive – server-based multi-user database.
- Personnel knowledge of each type of assessment platform and availability.
- Use of multi-year inventories to track progress year-over-year or against reduction targets – depends on the desired level of detail of data, factors and estimates. For less detailed inventories, spreadsheets may suffice, depending mostly on volume of data. As more detail is included in the emissions assessment, database software or server-based multi-user databases are appropriate. For inventories that track activities at an engine-by-mode level of detail, a server-based multi-user database would be most appropriate.
- Granularity of emissions estimates and parameters, activity and operational data: high level – spreadsheet; consolidated- or grouped-level – spreadsheet, database software, or server-based multi-user database; engine-by-mode level – server-based multi-user database.
- Budget and schedule considerations: spreadsheets can be faster to set up and the least expensive initial investment, while database software and server-based multi-user databases require more set-up time and there are higher upfront costs associated with development.

¹⁵ SQL (Structured Query Language) is a standardised programming language used for managing relational databases and performing various operations on the data in them.

‘Off-the-shelf tools’

A number of off-the-shelf ‘tools’ and ‘calculators’ are being marketed for estimating port emissions. These tools have been developed by governments, non-governmental organisations (NGOs), consultants and others. Most of these calculators generalise and simplify geographical elements, data inputs and estimating methods so that any port can use them. Given these simplifications, these calculators should be considered screening tools, at best. Due to the limitations of screening tools discussed above, these off-the-shelf tools are probably not appropriate for any port planning to undertake multi-year assessments, make policy decisions on where to reduce emissions, or track emissions reductions year-over-year.

Before using an off-the-shelf emissions tool or calculator, the following should be considered to determine whether its use is appropriate:

- **Methods** – what are the methods being used in the tool and do they represent the latest accepted methodologies; are they appropriate for the selected level of detail of the port inventory? For example, when a tool vendor states that the methodologies in the IMO Third Greenhouse Gas Study 2014 are being used in its particular tool, it is important to ask specifically how the study is being used in the tool, because the IMO study was not designed for the level of detail needed in a screening or comprehensive port emissions inventory.
- **Transparency** – is there sufficient documentation that details the methods, factors, assumptions and other parameters used by the tool? ‘Black box’ calculators and tools (where calculation assumptions or details are hidden from the user) are difficult or impossible to validate. In many cases, the result of emissions inventories leads to development of costly emissions reduction strategies. Insufficiently transparent tools raise the risk of inappropriate modelling results and therefore should not be used where the result will drive costly decision-making.
- **Experience** – are the developers of the tool or calculator experienced in the fields of data collection and estimation of emissions from port-related sources? Are the methods being used in the tool well understood by the developer, or is the developer simply packaging material gathered from various other sources?
- **Flexibility** – to what level of detail is the user able to define port-specific activities and operations and does the tool provide the appropriate methodologies for the selected level of detail of the port emissions assessment?
- **Year-over-year comparisons** – can the tool store multi-year activity data and does it have the ability to estimate year-over-year comparisons? How does the tool consider changes in methods, factors, or data over time?
- **Validation** – to what level has the provider validated their tool or calculator? Has the tool been tested against other published emissions estimates using the same input data to determine if the assumptions and methodologies used in the tool produce similar results? Has a regulatory body validated the tool or calculator, or is a regulatory body using the tool to make policy decisions?

Finally, the main disadvantage to off-the-shelf tools and calculators is that the user loses control of the calculations and data to the tool’s algorithms. Without control over emissions calculations, the port staff is removed from the design process and discussions of the assumptions being made, the level of detail, simplification of port specific operations and the ability to incorporate unique features of their port that are critical to the results. It is noteworthy that regulatory and port authorities engaged in quantifying and managing port-related emissions sources do not usually use off-the-shelf tools and calculators for their programs.

3 Port emissions assessment methods

Once the planning discussed in section 2 is completed, then the port emissions assessment can be conducted. Again, the port emissions inventory is the foundation for metrics and forecasting, so should be completed before later steps.

This section starts with a discussion of the basics, including quality assurance and quality control, data and units. Section 3.2 provides information and resource links on the recommended methods for estimating energy consumption and emissions for port-related sources. The focus is on mobile emissions sources and estimating electrical grid-related emissions. Section 3.3 discusses how emissions estimates can be combined with other figures to create activity, energy and emissions metrics that can be used to measure performance by source category. Finally, section 3.4 discusses emissions forecasting as a way to look into the future with projections of emissions changes due to increases in trade and performance enhancements.

3.1 Port emissions assessment basics

Quality assurance

Quality assurance and quality control are critical to the success of any assessment. It is recommended that quality assurance and quality control considerations be taken at every level of the assessment to limit the uncertainty associated with the inputs, methods and results and to provide those making policy decisions with the best information to support policy development.

Data

Data constitutes the single most important element across all three parts of a port emissions assessment. Some data elements can be purchased, such as ship parameter data; ports already collect some data, such as activity and cargo throughput data. Most of the data used in a port emissions assessment, however, must be newly collected, such as equipment parameter data and operational data for all selected source types. It is important to understand the individual data, what they do (and do not) represent and their uncertainties. Data collection is the most time intensive phase of an emissions assessment. Use of port-specific data that defines activity, operational and physical parameters is preferred if the assessment is to be used to set policy, manage emissions sources, or plan and implement emissions reduction strategies.

How data is collected has an impact on its uncertainty and its value for the assessment. Operational data are collected from a number of providers, such as terminal operators. Data collectors need to understand how specific data is going to be used so that they can ensure that the data they collect from individual providers matches the intended use. If the data collector is unclear on his or her task, there is a risk that the data provider will misinterpret the data collector's request, or the data provided will not be applicable for the assessment at hand.

The availability of the data elements will influence the selection of the methods and approach to develop the emissions inventory. Careful attention should be paid to the desired accuracy, the purpose of the inventory and timeframe or other constraints. It is important to match the emissions estimating methodologies to the level of detail of the data, such that the results best reflect actual operating conditions. This will minimise uncertainty in the results and improve accuracy in managing emissions sources and in developing emissions reduction scenarios.

There are four key data elements needed for developing activity-based emissions inventories.

- **Emissions source data** – this element details characteristics of each emissions source, including size or rating of the engine or power plant (expressed in kilowatts [kW] or megawatts [MW]), type of fuel consumed, engine technology information (2-stroke, 4-stroke, turbocharged, etc.), equipment model year, engine model year, manufacturer, model, emissions control technology, etc.
- **Activity data** – this element details activity in terms of hours of operation, distance travelled, distance travelled by operating mode, number of calls, number of lifts, etc.
- **Operational data** – this element details how engine loads and/or fuel consumption change by mode of operation (i.e. duty-cycle).
- **Emissions test data or emission factors** – this element allows estimate of emissions based on energy output or fuel consumption.

In order to determine activity, energy and emissions metrics, additional data will be needed. These activities could be cargo throughput, measured in terms of number of lifts, number of tonnes handled, number of containers handled, number of passengers, number of vehicles and pieces of equipment, number of barrels of liquid handled, number of ship calls and so forth. Activity metrics provide information on activity efficiencies such as number of twenty-foot-equivalent units (TEUs) per call, number of passengers per call, autos discharged per call, TEUs per lift, number tugs per call, TEUs per train, etc. Energy metrics combine energy consumption and a measure of either activity or emissions. For example, energy consumption (commonly in kWh) per containership call, per TEU, or per tonne cargo, or per passenger, etc. Similarly, emissions metrics combine emissions and a measure of either activity or energy. Examples include tonnes of NO_x per kWh, or tonnes of PM per TEU, or tonnes of CO₂e per cruise ship call and so forth. Depending on the desired metric, data from the port, operators, or third parties may need to be sourced.

Like emissions inventories, emissions forecasting methodologies can vary from simple to very detailed. Forecasting comes with an elevated level of uncertainty because it includes not only any uncertainties associated with the inventory and metrics, but also those associated with predictions of future operational levels and fleet make-up and other variables. High and low growth forecast scenarios are usually developed to provide a range from worst-case to best-case forecasts. The most simplified forecasting approach is to take a baseline emissions inventory and assume emissions grow at a rate proportionately to cargo growth forecasts. This can be considered a worse-case scenario or high emissions forecast because it “locks in” all the relationships between activity, energy use and related emissions, and projects them into the future without considering efficiency improvements, known future regulatory requirements fleet turnover and other factors.

A more detailed emissions forecast includes upcoming regulations, future port planning, efficiency improvements, fleet turnover, ship calls and changes in vessel-size distributions and other variables. The more detailed the emissions forecast, the more data and input needed from port planners, regulatory analysis, stakeholders and future looking studies.

Units

Units used in the development of emissions estimates can be metric or US/Imperial, depending on the unit system the country uses where the inventory is conducted. In some instances, the units are mixed. For instance, some US port inventories report air pollutants in US/Imperial short tons, but report greenhouse gas emissions in metric tonnes. When reviewing inventories prepared by others, care should be taken to understand the units being used.

Individual greenhouse gases have different global warming impact over a particular period of time (usually 100 years). The global warming potential (GWP) of greenhouse gases are rated in comparison to the global warming potential of CO₂. The Intergovernmental Panel on Climate Change (IPCC) is the authority that calculates and periodically updates the GWP of greenhouse gases based on the latest science. Total greenhouse gas emissions can be calculated in terms of CO₂ equivalence (CO₂e) by multiplying the emissions of each greenhouse gas by its GWP and then summing. A list of GWP¹⁶ values are presented in Table 3.1. The most recent version of the IPCC’s GWP should be used when conducting an assessment.

¹⁶ IPCC 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland. See https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

Table 3.1: Global warming potentials

Gas	Global warming potential	Gas	Global warming potential
CO ₂	1	HFC-227ea	3,220
CH ₄	25	HFC-236fa	9,810
N ₂ O	298	HFC-4310mee	1,640
HFC-23	14,800	PFC-14	7,390
HFC-32	675	PFC-116	12,200
HFC-125	3,500	PFC-3-1-10	8,830
HFC-134a	1,430	PFC-5-1-14	9,300
HFC-143a	4,470	Sulphur hexafluoride	22,800
HFC-152a	124		

3.2 Port emissions inventory estimating methods

Overview

This section discusses methods that can be used to develop estimates of air pollutant and greenhouse gas emissions from port-related sources. While a variety of methods can be used to develop estimates, it is important first to develop a structure for the emissions estimates that will organise the emissions sources based on functional or operational characteristics. This structure will help to identify emissions sources and reduce the chance of double-counting emissions.

As discussed in section 2.4, port-related emissions sources fall into two broad categories: mobile sources and stationary sources. Mobile sources generally include: cargo handling equipment that is not designed to operate on public roads; transport vehicles that move goods on public roads; smaller on-road vehicles that transport people and supplies, such as cars and vans; railroad locomotives; and vessels. Stationary sources include fuel-fired heating units; portable or emergency generators; electricity consuming equipment and buildings; and refrigeration/cooling equipment.

As noted above, the key data elements in developing a detailed emissions inventory from an emissions source are: the type of fuel used, the number, engine size and age; activity data, such as operating hours, miles driven, average load of the engine and fuel consumption; and emission factors, the mass of pollutant per unit of fuel or energy. Emissions source data must be obtained from the owner or operator of the emissions source(s) because it is specific to the facility or the activities being performed. Some activity data, such as annual hours of operation, may be obtained from the owner or operator. Other types of activity information including, for example, average load factors for different types of equipment, may be obtained from published sources, such as documentation published by the US Environmental Protection Agency (US EPA) for their MOVES emissions-estimating model.¹⁷

Besides the basic factors discussed in the paragraph above, emissions from the mobile sources further vary by duty cycle/load of the engine, use of emissions control system such as diesel particulate filters and regulations that apply to the engine such as emissions standards set by the environmental entity for the source. Since fossil-fuelled mobile sources operate on variable duty cycles, some pollutant emissions rates change, on an emissions-per-kWh basis, as the engine load changes. The pollutants that may change with load are NO_x, PM, CO, VOCs, SO_x and CO₂. The effect of engine load on SO_x and CO₂ is relatively low compared to other pollutants. This is a fundamental difference between estimating air pollutants and GHG emissions because the total amount of carbon in fuel is relatively constant and the carbon in fuel is the source of virtually all of the CO₂ emitted by fossil fuel-burning emissions sources. For example, an engine running at its highest fuel efficiency produces significantly more NO_x than the same engine running at lower loads using the same amount of fuel; however, from a carbon perspective, both scenarios produce the same CO₂ emissions because the same fuel

¹⁷ See <https://www.epa.gov/moves>, cited February 2017.

amount is burned. Therefore, when conducting an emissions inventory, either a fuel-based or an energy-based path can be taken. Based on experience gained over nearly two decades of inventory work at ports, if the inventory is to include air pollutants, it is recommended that an energy-based estimating method be used. If the inventory is solely for greenhouse gases, then either a fuel-based or energy-based method can be used, depending on the available data and associated uncertainty.

3.2.1 Mobile sources

Internal combustion engines power most mobile sources operated at ports, although some may be electrically powered. The most common type of fuel used is diesel fuel, with biofuels, gasoline, propane and natural gas (methane) also being used by some types of vehicles or equipment. Electric equipment is nearly always battery powered since the use of power cables can limit mobility. An exception is shore-side power for vessels at berth, in which a vessel's electrical power needs are met by a connection to a shore-side power supply to allow the vessel's diesel engines to be turned off while at berth. Also, modern wharf cranes, rail-mounted gantry cranes, automated guided vehicles and rubber-tyred gantry cranes (RTG) are increasingly being installed with electric drives that use battery, cable, or bus-supplied electricity.

Fossil fuel-powered mobile sources

The predominant air pollutants from fossil fuel-powered mobile sources are NO_x, PM, SO_x, CO and VOCs. The predominant GHG from fossil fuel-powered mobile sources, CO₂, is directly related to the amount of fuel burned, so fuel consumption is the key information needed to estimate CO₂ emissions from these sources. For estimating (non-GHG) air pollutants from these sources in most activity-based emissions inventories, energy output (in terms of kilowatt-hours, or kWh) is used. Fuel consumption and energy output are linked by a brake specific fuel consumption (BSFC), which is a measure of fuel consumption per unit of energy output, in units such as grams of fuel per kWh (g/kWh). The average value of BSFC varies for different types of engine and even for different operating loads for a given engine. In practice, an average value is assigned to different types of engine. Fuel consumption can be estimated from energy output by multiplying the energy output by the relevant value for BSFC, taking care to use appropriate units. Conversely, the energy output can be estimated from fuel consumption by dividing the fuel consumption estimate by the BSFC value. The value of these conversions is that it allows the standardisation of units in cases where data is collected in terms of both energy and fuel consumption.

Electric-powered mobile sources

Electric mobile sources produce secondary, or indirect, greenhouse gas emissions, when the source of electrical power generation is fossil fuel-powered. Therefore, electrification of equipment or activities is not necessarily a zero-carbon solution. Estimates of emissions are made based on the amount of electrical energy used by the equipment during its operation or during battery recharging. Because power is lost in the charging process, estimates based on the energy used by the vehicle must be adjusted by a charging efficiency factor to calculate the amount of electricity used by the charger. Likewise, efficiency factors for transmission and conversion must be considered when comparing the amount of electricity consumed from the generation source with the amount of electricity used by the charger.

3.2.1.1 Seagoing vessels

Seagoing vessels are ships capable of travel in open oceans and seas and are regulated by international standards set by the IMO. They are the most complex source category from an air emissions modelling perspective as ships have several different emissions sources, cargo types, power configurations, and operational modes. Ships are one of the largest emissions source categories in a port emissions inventory and therefore a thorough understanding of the variety of energy/power systems and how they operate is critical in estimating their emissions.

Understanding seagoing vessels

Seagoing vessels come in a wide variety of types and sizes based on the cargo(s) they carry and the operations they were designed for. IHS Markit (IHS), formerly Lloyd's Fairplay, has a comprehensive database of ship registry that classifies ships into four groups: cargo carrying, non-merchant, non-seagoing merchant and work ships. In this IHS Maritime World Register of Ships database, information can be obtained by ship identification number known as IMO number. Port emissions inventories can have one or more ship groups depending on the type of cargo handled at the port. The four IHS ship groups and associated ship classes are presented in Table 3.2, with the cargo carrying transport ships being the most numerous and diverse ship group.

Table 3.2: IHS ship group and classes

Ship group	Ship class
Cargo carrying transport ships	1 Bulk carrier 2 Chemical tanker 3 Container 4 General cargo 5 Liquefied gas tanker 6 Oil tanker 7 Other liquids tanker 8 Ferry-passengers (pax) only 9 Cruise 10 Ferry-roll-on/passengers (RoPax) 11 Refrigerated cargo 12 Roll-on/Roll-off (Ro-Ro) 13 Vehicle
Non merchant ships	14 Yacht 15 Miscellaneous – fishing ¹
Non seagoing merchant ships	16 Miscellaneous – other ²
Work ship	17 Service – tug 18 Offshore 19 Service – other

Notes: ¹ Miscellaneous – fishing ships fall into non merchant ships and non seagoing merchant ships

² Miscellaneous – other ships fall into non seagoing merchant ships and work ships

In the IHS database, the cargo-carrying ship classes are further categorised into sub-classes and each sub-class is assigned a unique designator known as StatCode5, as presented below in Table 3.3.

Cargo ship classes can be further subdivided into cargo capacity bins. For example, container ships might be subdivided into size bins by TEU capacity ranges (i.e. Container 1000, Container 2000, Container 3000). For examples of specific ship class subdivisions, categorised on a global scale, see table 4 of annex 1 of the Third IMO Greenhouse Gas Study 2014.¹⁸

¹⁸ IMO 2015. Third IMO GHG Study 2014; International Maritime Organization (IMO) London, UK, April 2015. See <https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Greenhouse-Gas-Studies-2014.aspx>

Table 3.3: Cargo carrying category; class, sub-class, StatCode5 and description

Ship class	Sub-class	StatCode5 designation	StatCode5 description
Bulk carrier	Bulk dry	A21A2BC	Bulk carrier
		A21A2BG	Bulk carrier, laker only
		A21A2BV	Bulk carrier (with vehicle decks)
		A21B2BO	Ore carrier
	Other bulk dry	A24A2BT	Cement carrier
		A24B2BW	Wood chips carrier
		A24B2BW	Wood chips carrier, self unloading
		A24C2BU	Urea carrier
		A24D2BA	Aggregates carrier
		A24E2BL	Limestone carrier
		A24G2BS	Refined sugar carrier
		A24H2BZ	Powder carrier
	Self discharging bulk dry	A23A2BD	Bulk cargo carrier, self-discharging
		A23A2BD	Bulk carrier, self-discharging
		A23A2BK	Bulk carrier, self-discharging, laker
Bulk dry/oil	A22A2BB	Bulk/oil carrier (OBO)	
	A22B2BR	Ore/oil carrier	
Chemical tanker	Chemical	A12A2TC	Chemical tanker
		A12B2TR	Chemical/products tanker
		A12E2LE	Edible oil tanker
		A12H2LJ	Fruit juice tanker
		A12G2LT	Latex tanker
		A12A2LP	Molten sulphur tanker
		A12D2LV	Vegetable oil tanker
		A12C2LW	Wine tanker
Container	Container	A33A2CR	Container ship (fully cellular with Ro-Ro facility)
		A33A2CC	Container ship (fully cellular)
		A33B2CP	Passenger/container ship
General cargo	General cargo	A31A2GA	General cargo ship (with Ro-Ro facility)
		A31A2GE	General cargo ship, self-discharging
		A31A2GO	Open hatch cargo ship
		A31A2GT	General cargo/tanker
		A31A2GX	General cargo ship
		A31B2GP	Palletised cargo ship
		A31C2GD	Deck cargo ship
		Other dry cargo	A38A2GL
	A38B2GB		Barge carrier
	A38C2GH		Heavy load carrier
	A38C3GH		Heavy load carrier, semi submersible
	A38C3GY		Yacht carrier, semi submersible
	A38D2GN		Nuclear fuel carrier
	A38D2GZ		Nuclear fuel carrier (with Ro-Ro facility)
	Passenger/general cargo	A32A2GF	General cargo/passenger ship

Ship class	Sub-class	StatCode5 designation	StatCode5 description
Liquefied gas tanker	Liquefied gas	A11C2LC	CO ₂ tanker
		A11A2TN	LNG tanker
		A11B2TG	LPG tanker
		A11B2TH	LPG/chemical tanker
Oil tanker	Oil	A13C2LA	Asphalt/bitumen tanker
		A13E2LD	Coal/oil mixture tanker
		A13A2TV	Crude oil tanker
		A13A2TW	Crude/oil products tanker
		A13B2TP	Products tanker
		A13A2TS	Shuttle tanker
		A13B2TU	Tanker (unspecified)
Other liquids tanker	Other liquids	A14H2LH	Alcohol tanker
		A14N2LL	Caprolactam tanker
		A14F2LM	Molasses tanker
		A14A2LO	Water tanker
Ferry-pax only	Passenger	A37B2PS	Passenger ship
Cruise	Passenger	A37A2PC	Passenger/cruise
Ferry-RoPax	Passenger/Ro-Ro cargo	A36B2PL	Passenger/landing craft
		A36A2PR	Passenger/Ro-Ro ship (vehicles)
		A36A2PT	Passenger/Ro-Ro ship (vehicles/rail)
Refrigerated cargo	Refrigerated cargo	A34A2GR	Refrigerated cargo ship
Ro-Ro	Ro-Ro cargo	A35C2RC	Container/Ro-Ro cargo ship
		A35D2RL	Landing craft
		A35A2RT	Rail vehicles carrier
		A35A2RR	Ro-ro cargo ship
Vehicle	Ro-Ro cargo	A35B2RV	Vehicles carrier

Emissions sources on board ships include propulsion systems that move the ship through water; auxiliary power systems that provide electricity during ship operations; and auxiliary boilers that produce hot water and steam for use in the engine room and for crew amenities. Within each of these systems, various pieces of equipment operate differently depending on the current operating mode of the ship. It should be noted that incinerators are not usually included in emissions estimates because incinerators are typically operated only at sea, beyond a port inventory's geographic domain. Interviews with vessel operators and marine industry personnel indicate that vessels do not use their incinerators while at berth or near coastal waters. For an emissions inventory that includes pan-oceanic voyage,¹⁹ then including incinerators may be appropriate. If included, additional information from operators will be necessary, as incinerators are commonly run as batch processes and are not continuous. They are assumed to emit significantly less than the other emissions sources noted above.

Propulsion systems produce power that moves the ship through the water. Most ships use one of four propulsion system types: direct drive, geared drive, diesel/electric and steam powered/gear-drive. There are various other types of propulsion systems such as gas turbine and steam/electric; however, these are relatively uncommon. The following figure illustrates the equipment associated with the four primary types of propulsion systems.

¹⁹ Most emissions assessments limit their domains to coastal waters; however, at least one port has conducted a GHG study that included entire pan-oceanic voyages.

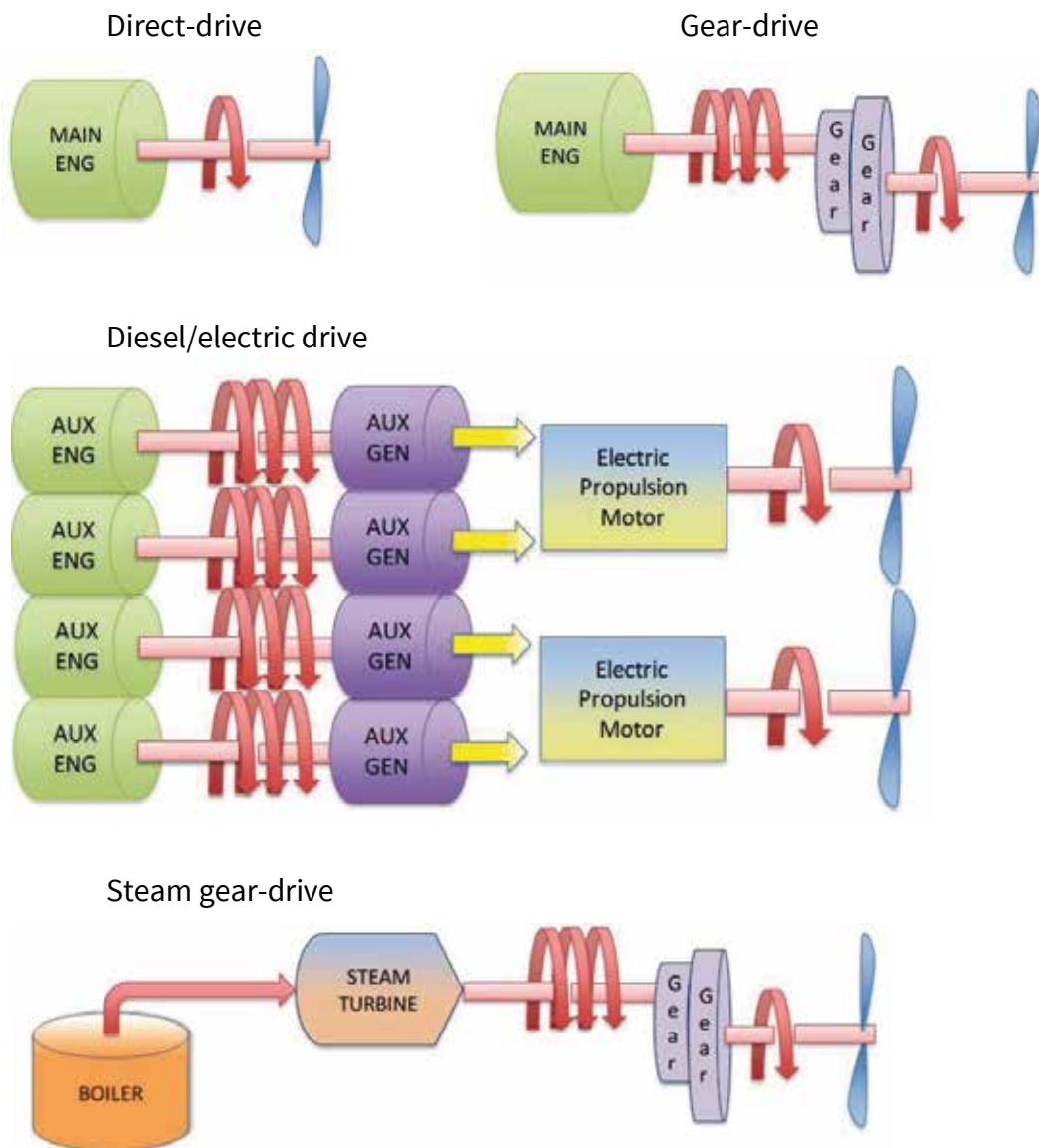


Figure 3.1: Seagoing vessel propulsion types

Direct-drive – A large high-kW rated, slow speed engine that is directly connected to the propeller shaft (i.e. engine rpm = propeller rpm). This propulsion system is the most common propulsion type found in container ships, bulk carriers, large roll-on/roll-off carriers and other large ships.

Gear-drive – A high- to medium-kW rated, medium speed engine that is connected to reduction gearing that reduces the engine rpm to an appropriate propeller rpm, i.e. the engine rpm is higher than the propeller rpm. This propulsion system can be found on reefers, tankers, some cruise ships and small bulk carriers.

Diesel-electric – One or more high- to medium-kW rated, medium speed engines that are connected to an electrical generation system, which produces power for the electrical propulsion motor(s), i.e. the engine rpm is greater than the propeller rpm. This propulsion system is most commonly found in passenger cruise ships, passenger ferries and some tankers, though its use is expanding into other vessel classes.

Steam powered/gear-drive – High- to medium-kW rated boilers that produce steam to turn a steam turbine, which is connected to reduction gearing that reduces the turbine rpm down to an appropriate propeller rpm, i.e. the turbine rpm is greater than the propeller rpm.

Auxiliary power systems supply the ship and crew with on-board generation capacity to meet the ship's power demand (excluding propulsion) that varies depending on the ship's operational mode. In addition, auxiliary power systems are designed with additional capacity in the event that an engine shuts down due to a mechanical failure. Direct-drive and gear-drive configured ships utilise auxiliary engines in a diesel/electric configuration to generate the various power demands of the ship, cargo and crew during each of the operational modes. Some ships that have large steam plants may use a steam turbine to generate auxiliary power. Diesel/electric ships use the same system that produces the propulsion power. The following figure illustrates both the diesel/electric and steam gear configurations for auxiliary power systems. Note that equipment in blue means that it is off.

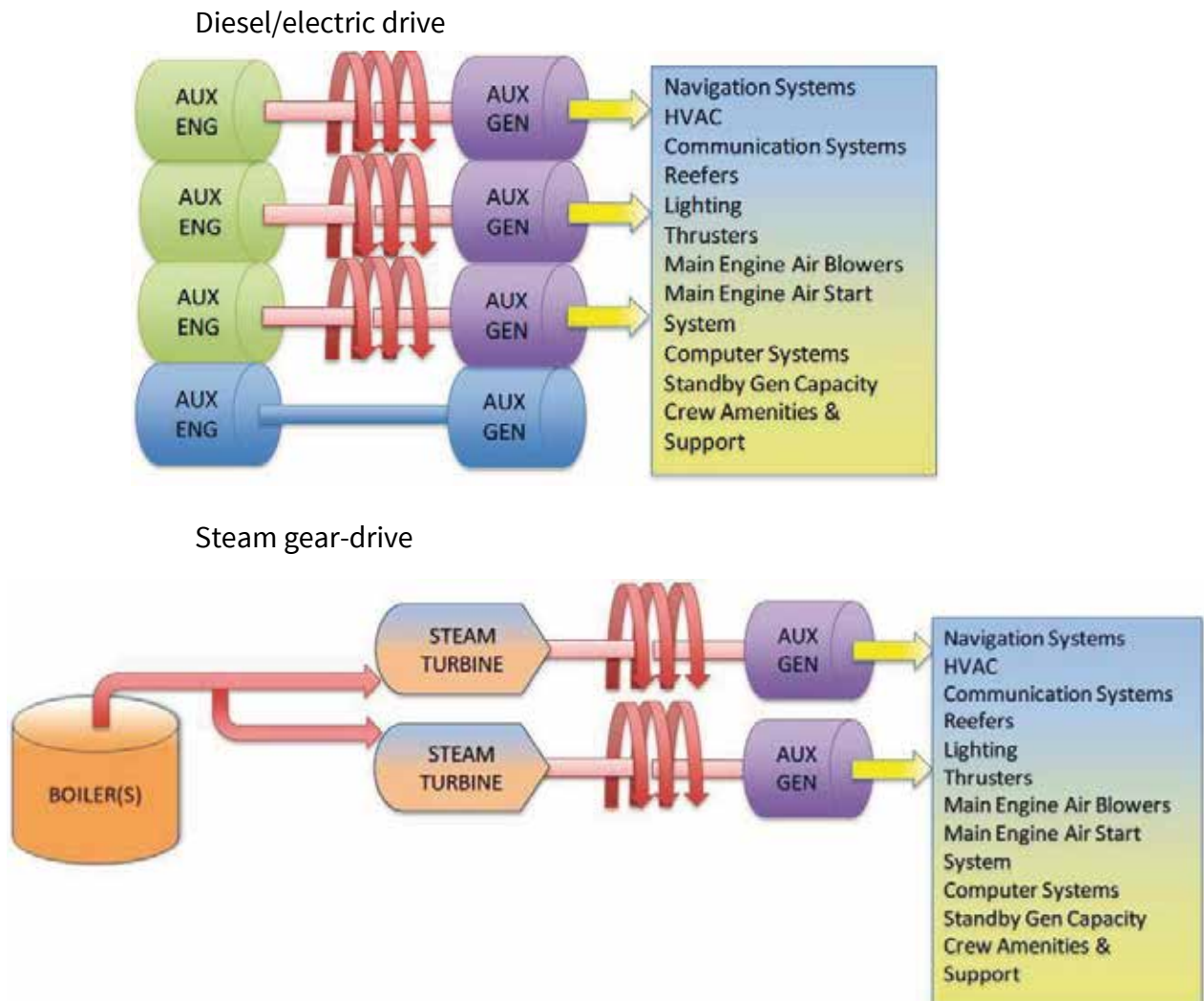


Figure 3.2: Auxiliary power systems

Hot water and steam are generated on a vessel in either on-board boilers or exhaust heat exchangers, also known as economisers. Boilers use fuel oil for heating/boiling water, hot water and steam heating the fuelling system, powering offloading pumps (tankers), engine heat jackets and crew amenities. Economisers or waste heat recovery systems use waste heat from on-board engines (usually propulsion engines) for generating hot water and steam.

As mentioned previously, three modes of operations are commonly included in seagoing vessel emissions inventories: transit, manoeuvring and hotelling. Descriptions of these modes are provided below:

Transit

During this mode, a ship is sailing in the open ocean:

- Ship is travelling at its sea-speed or cruising speed;
- Propulsion engines are operating at their highest loads;
- Auxiliary engine loads required by the ship are at their lowest loads;
- Auxiliary boilers are off and economisers are on because of the high propulsion system loads; and
- Fuel consumption is at its highest level due to the propulsion system's power requirements and auxiliary fuel consumption is low.

Manoeuvring

During this mode, a ship is operating within confined channels and within the harbour approaching or departing its assigned berth. The distance of this mode is unique for each port depending on geographical configuration of the port:

- Ship is transiting at its slowest speeds;
- Propulsion engines are operating at low loads;
- Auxiliary engine loads are at their highest load of any mode as additional on-board equipment such as thrusters, air scavengers/blowers and additional generators are online in case an auxiliary engine/generator fails;
- Auxiliary boilers are on because the economisers are not functioning due to low propulsion engine loads; this may not apply to large diesel-electric vessels, which produce sufficient exhaust heat to power economisers at manoeuvring speeds; and
- Fuel consumption is very low for the propulsion system, is highest for the auxiliary engines and low for the auxiliary boilers.

Hotelling

During this mode, a ship is either docked at a berth (at-berth) or anchored (at-anchorage):

- Ship is not moving;
- Propulsion engines are off;
- Auxiliary engine loads can be high if the ship is self-discharging its cargo at-berth, as with self-discharging general cargo vessels, bulk liquids, auto carriers and RoRos or at-anchorage at a loading tanker buoy or during mid-stream operations;²⁰
- Auxiliary boilers are usually operated at-berth to keep the propulsion engine and fuel systems warm in case the ship is ordered to leave port on short notice, for crew amenities and, for certain types of tanker, for off-loading cargo through the use of steam-powered pumps at-berth or at-anchorage loading buoys; and
- Fuel consumption can be medium to high for auxiliary engines and can be medium to very high for boilers.

Figures 3.3 through 3.5 provide a simplified graphical representation of how the three power systems (propulsion system, auxiliary power system and auxiliary boilers) change in activity by operating mode. Note that equipment in blue means that it is off.

²⁰ Mid-stream operations: loading and unloading cargo containers at the container ship while at sea, with barges or dumb steel lighters performing the transfer, distribution or landing of containers to piers nearby.

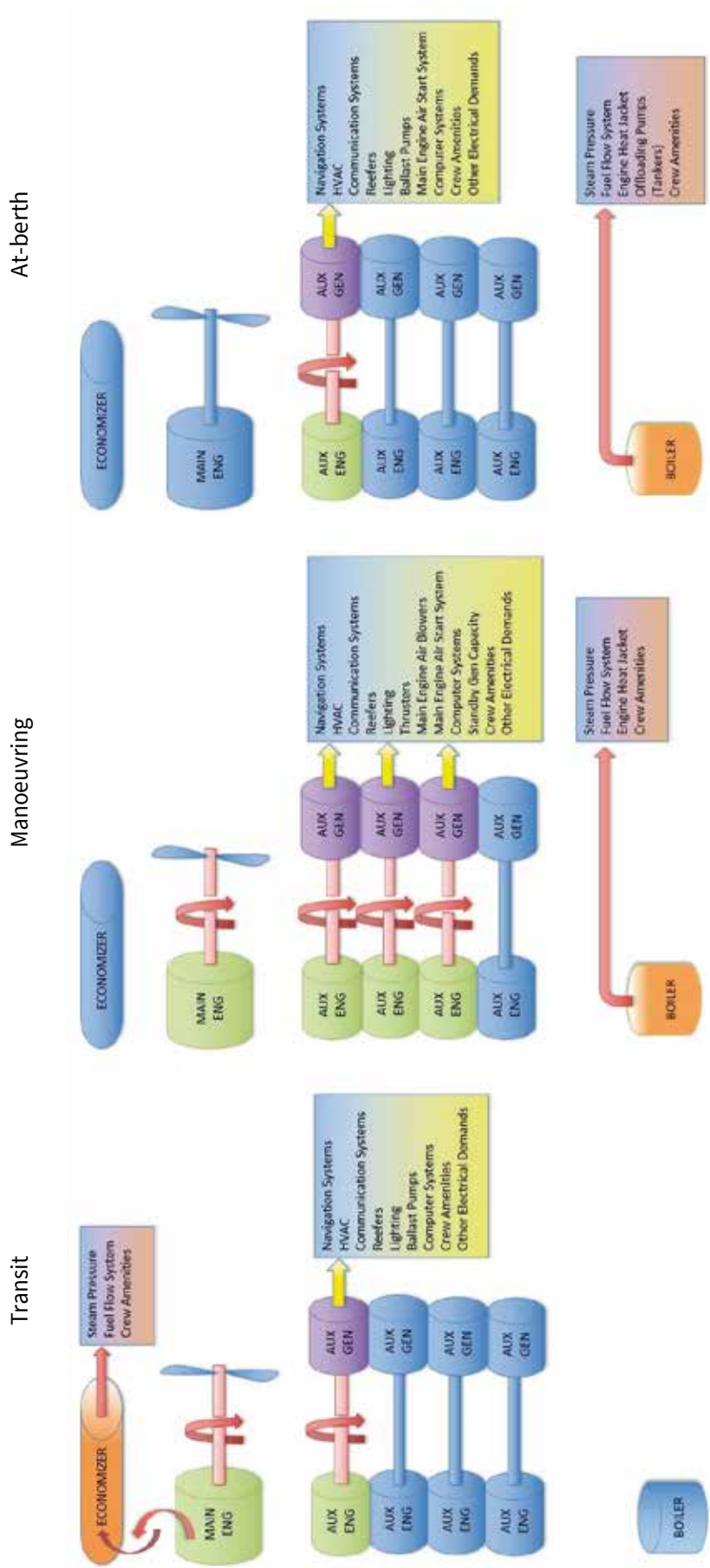


Figure 3.3: Direct drive/gear drive operational modes

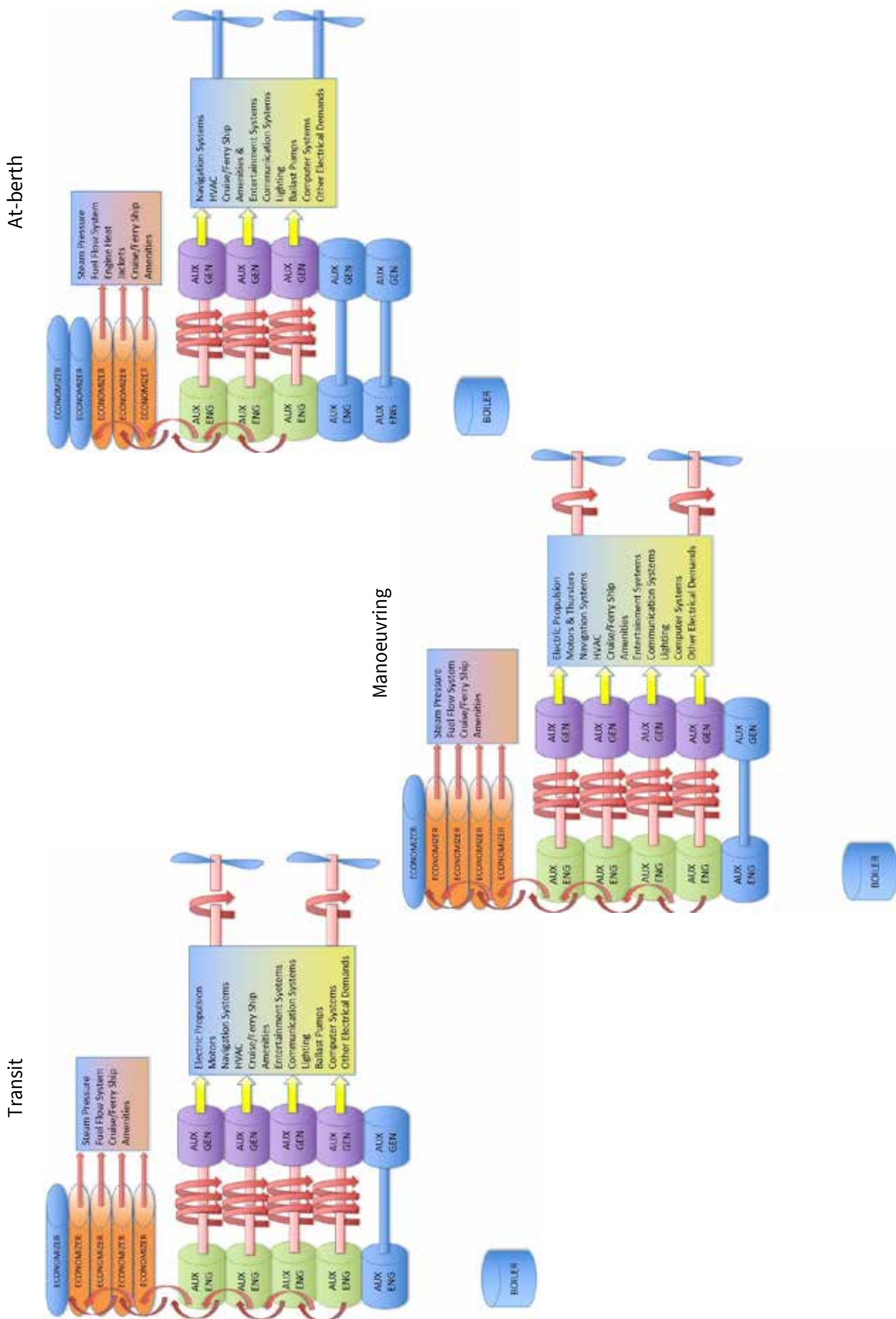


Figure 3.4: Diesel electric – operational modes (cruise/ferry)

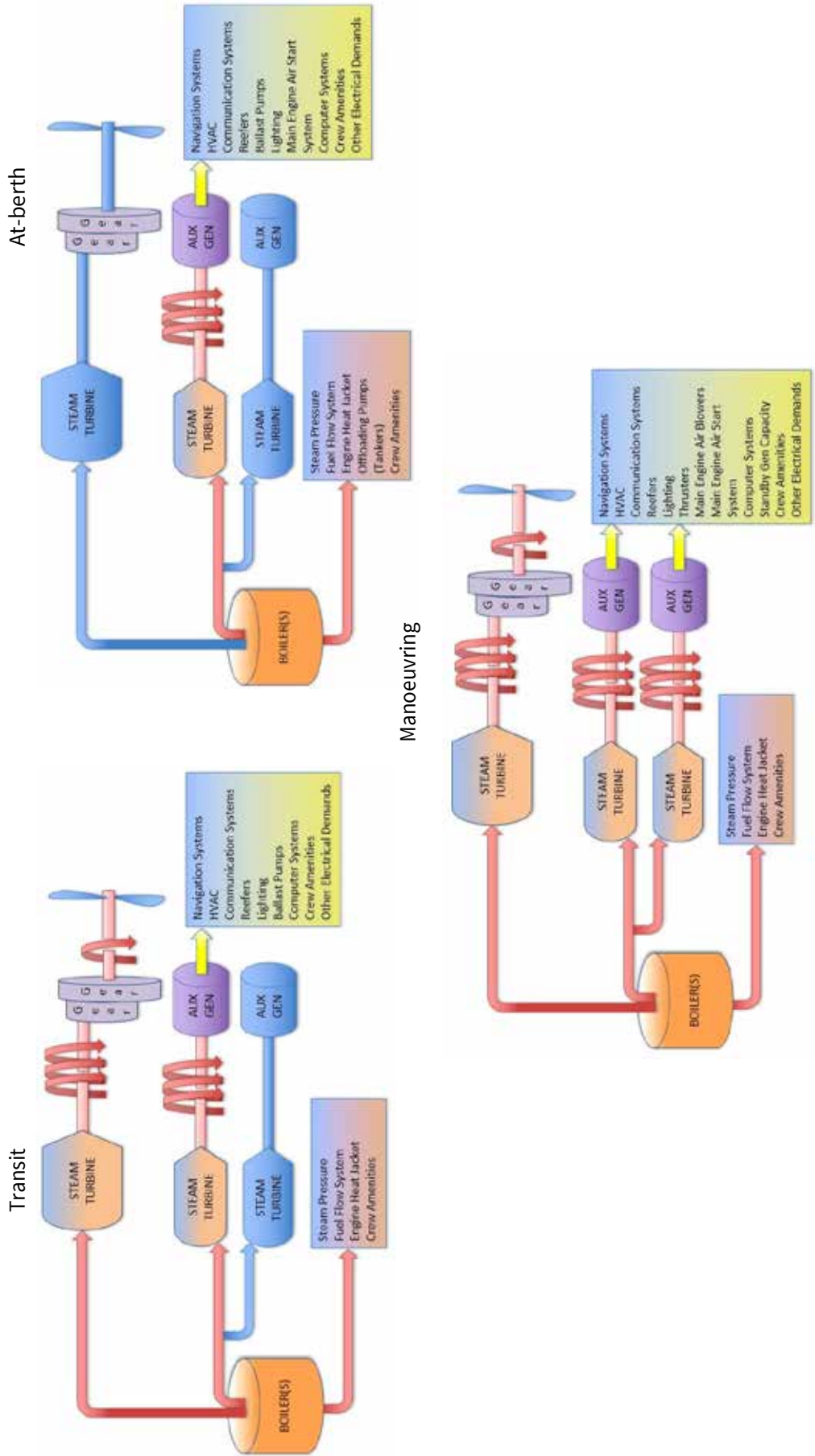


Figure 3.5: Steam ship – operational modes

Comprehensive emissions inventory approach

As discussed above, one can estimate seagoing vessel emissions using a scaled, screening, or comprehensive approach. Ships' emissions inventories lend themselves to both screening and comprehensive approaches because good information is usually available to ports on movement of ships within their domain. The comprehensive approach can be complex and it can take well over a year to complete an initial emissions inventory, since several data elements that are not readily available need to be collected. This subsection discusses the steps involved with the comprehensive emissions inventory approach. The following subsection describes the process for scaled or screening approaches.

In a comprehensive inventory, estimating emissions from seagoing vessels requires gathering as much information as possible on the vessels, their activity level and the operational modes within the geographical domain of the inventory. Estimating emissions from seagoing vessels requires the most data compared to the other mobile source categories. The types of data required are described below:

- **Vessel parameter data** – These data can be commonly found from sources such as the IHS database discussed above,²¹ which provides vessel characteristics such as propulsion type, main engine power, age of the vessel, speed and sometimes information on installed auxiliary engines and boilers. IHS data do not provide any operational data and data related to auxiliary equipment, boilers and other parameters is incomplete for a significant proportion of the world's fleet. Other vendors of similar data also do not provide operational data and while they may provide more complete ship-specific parameter data, they usually provide less coverage of the world fleet.
- **Activity data** – Ports can obtain ship activity data from a number of sources including: port pilots, marine exchanges, vessel traffic systems (VTS) and Automated Identification System (AIS) data. Information obtained from these sources includes: ship IMO number, date, time, location, berth/anchorage, previous and next ports and speed information. AIS datasets are a robust source of vessel movement data, but AIS data needs to be pre-processed before use, to address errors, time gaps, duplicates, missing activities and other anomalies. None of these activity data sources include information on a ship's individual system operation in a given location.
- **Operational data, by mode** – Modal operational data characterise the operational state of the ship as it moves through the geographical domain defined for the emissions inventory. This information includes energy states or loads of the ship's emissions sources, such as propulsion, auxiliary engines, boilers, steam plants, etc. This information is most commonly gathered from vessel chief engineers. Modal operational data will vary from port to port based on various factors. As an example, the auxiliary load of ship calling Hamburg in the autumn will have a lower at-berth auxiliary load than the same ship, with the same cargo mix, calling Shanghai in mid-summer. Differences in ambient temperature between the two locales in this case would affect energy loads required for both ship house-loads and to support reefers. Several North American ports have supplemented the IHS data with additional data collected through a vessel boarding program (VBP) for their inventories because operational data, such as auxiliary engine or boiler loads by mode, are not available in IHS database. Proxy operational data can also be sourced from published inventories of other ports.
- **Geographical domain data** – Once the emissions inventory's geographical domain is specified, information on location of ships travelling within that domain can be gathered from nautical charts and from surveys with port operations, port pilots, vessel traffic system operators and ship captains.

²¹ The IHS Maritime World Register of Ships is referenced here. This database has been found to be a reliable source of vessel parameter data with some qualifications discussed in the text. There are other sources of vessel parameter data available. Use of such other sources would need to be evaluated for reliability.

Emissions

In general, emissions are estimated as a function of vessel power demand or energy utilised expressed in kWh multiplied by an emission factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kWh). Emission factor adjustments (for low propulsion engine load, different fuel usage, or emissions controls) are then applied to the various activity and operational data.

Equations 1 and 2 shown below are the basic equations used to estimate emissions by operating mode and engine. As discussed previously, there are three vessel-operating modes: transit, manoeuvring and hotelling. For most container ships there are three emissions sources: main, auxiliary and boiler. So, for a vessel arrival you would need to undertake these calculations nine times (three sources times three modes).

Equation 1

$$E_i = \text{Energy}_i \times EF \times FCF \times CF$$

Where:

E_i =	emissions by operating mode i
Energy_i =	energy demand by mode i, calculated using Equation 2 below as the energy output of the engine(s) or boiler(s) over the period of time, kWh
EF =	emission factor, expressed in terms of g/kWh, depends on engine type, IMO NO _x standards and fuel used
FCF =	fuel correction factor, unitless
CF =	control factor(s) for emissions reduction technologies, unitless

Energy

The 'Energy' term of the equation is where most of the location-specific information is used. Energy is a function of the engine's maximum continuous rated (MCR) power expressed in kW, multiplied by a load factor (LF), which is unitless and which represents the percentage of maximum engine load on the propulsion engine during each operating mode, multiplied by the operating time for each mode that emissions are being estimated for. Energy by mode and engine is calculated using Equation 2.

Equation 2

$$E_i = \text{Load}_i \times \text{Activity}_i$$

Where:

Energy_i =	energy demand by mode i, kWh
Load_i =	maximum continuous rated (MCR) power times load factor (LF) for <i>propulsion engine power</i> , kW; reported operational load of the <i>auxiliary engine(s)</i> , by mode i, kW; or operational load of the <i>auxiliary boiler</i> , by mode i, kW
Activity_i =	activity for mode i, hours

Determining auxiliary engine and boiler operational loads is difficult because this information is not available commercially and is highly variable. In addition, in the worldwide fleet of seagoing vessels, there are a wide array of auxiliary engine system configurations, a lack of relatively complete data sets on installed equipment and numerous other factors that make determining auxiliary power requirements a challenge without input from vessel operators. It is recommended that this information be collected for the port specific seagoing vessels directly or that proxy data be collected or developed. Aggregate proxy data for auxiliary engines and boilers can be found in the annual emissions reports of POLA, POLB and PANYNJ; however, using these data may not reflect the actual operations at another port.

Propulsion engine MCR power

MCR power is defined as the manufacturer’s tested maximum engine power and is used to determine load by mode for propulsion engines. The international specification is to document MCR in kilowatts and it is related to the highest power available from a ship engine during average cargo and sea conditions. For this document, it is assumed that the IHS’s ‘Power’ value is the best proxy for MCR power. For diesel-electric configured ships, MCR is the combined electric propulsion motor(s) rating, in kW.

It should be noted that a number of ships have ‘de-rated’ their propulsion engine’s MCR due to the generally slower speeds at which ships are opting to travel the open ocean.²²

Propulsion engine load factor

The propulsion load factor is used to estimate how much of the propulsion engine(s)’ MCR is being used. The propulsion engine load factor is estimated using the Propeller Law, which shows that propulsion engine load varies with the cube of the ratio of actual speed to the ship’s maximum rated speed. Equation 3 illustrates propulsion engine load at a given speed.

Equation 3

$$LF = (Speed_{Actual} / Speed_{Maximum})^3$$

Where:

LF = load factor, unitless

Speed_{Actual} = actual speed, knots

Speed_{Maximum} = maximum speed, knots

For the purpose of estimating emissions, propulsion engine LF is capped at 1.0 so that there are no calculated propulsion engine load factors greater than 100%. This may occur when, for example, a ship is moving with a tide and with the wind and the wind and sea action moves the ship faster than the rated speed even though the propulsion engine is set for less than the rated speed. In such a case the calculated load would not accurately reflect the actual operating load on the engine. Operating a vessel’s propulsion engine at 100% or more of its MCR power is very costly from a fuel consumption and engine maintenance perspective, so most operators limit their maximum power to about 83% of MCR or less.

Activity

Activity is usually measured in hours of operation by mode. Activity in a mode is estimated by determining the time it takes to travel through the zone, by dividing the distance travelled in nautical miles (nm) while in operating mode i by the ship’s actual speed in knots, as illustrated by Equation 4.

Equation 4

$$Activity_i = D_i / Speed_i$$

Where:

Activity_i = activity, hours

D_i = distance travelled while in mode i, nautical miles

Speed_i = actual ship speed by mode i, knots

Actual speeds can be obtained by automated identification system (AIS) data, vessel traffic system (VTS) data, pilot data, or other available resources.

²² IMO 2015. Third IMO GHG Study 2014; International Maritime Organization (IMO) London, UK, April 2015.

Emission factors

Emission factors combined with energy consumption result in estimates of the various air pollutants and GHGs. For seagoing vessels, it is recommended to use emission factors provided in annex 6 of the Third IMO Greenhouse Gas Study 2014.²³ For the latest seagoing emission factors and methods, the annual emissions inventories for POLB and POLA are a good source.²⁴

Emission factors are developed using actual engine test data on various duty cycles. The most common duty cycles used are ISO 8178 cycles²⁵ (E2, E3 cycles for various types of propulsion engines, D2 for constant speed auxiliary engines, C1 for variable speed and load auxiliary engines).

Marine propulsion systems include:

- Diesel cycle fuel oil/marine distillate fuelled engines
- Steam powered (steamship) fuel oil/marine distillate fuelled engines
- Steam powered turbines (gas turbine) fuel oil/marine distillate fuelled
- Dual fuelled diesel cycled oil/marine distillate plus natural gas fuelled engines
- Otto cycle natural gas fuelled engines

Currently, diesel cycle engines are the most prevalent type of propulsion and auxiliary engines in the world fleet. IMO has established NO_x emissions standards for marine diesel engines.²⁶ For regulatory purposes, all diesel cycle fuel oil/marine distillate fuelled engines are divided into Tier 0 to Tier III as per the NO_x standards and by engine rated speed, in revolutions per minute or rpm, as listed below:

- Slow speed engines: less than 130 rpm
- Medium speed engines: between 130 and 2,000 rpm
- High speed engines: greater than or equal to 2,000 rpm

Tables 3.4 and 3.5 list the default air pollutant and GHG emission factors for sea-going propulsion and auxiliary engines, using 2.7% sulphur heavy fuel oil (HFO).²⁷

Table 3.4: Emission factors for propulsion and boiler engines using HFO with 2.7% sulphur content, g/kWh

Engine category	Model year range	NO _x	PM ₁₀	PM _{2.5}	SO ₂	HC	CO	CO ₂	N ₂ O	CH ₄
Slow speed main (Tier 0)	1999 and older	18.1	1.42	1.34	10.29	0.60	1.40	620	0.03	0.01
Slow speed main (Tier I)	2000 to 2010	17.0	1.42	1.34	10.29	0.60	1.40	620	0.03	0.01
Slow speed main (Tier II)	2011 to 2016	15.3	1.42	1.34	10.29	0.60	1.40	620	0.03	0.01
Slow speed main (Tier III)	2016 +	3.6	1.42	1.34	10.29	0.60	1.40	620	0.03	0.01
Medium speed main (Tier 0)	1999 and older	14.0	1.43	1.34	11.35	0.50	1.10	683	0.03	0.01
Medium speed main (Tier I)	2000 to 2010	13.0	1.43	1.34	11.35	0.50	1.10	683	0.03	0.01
Medium speed main (Tier II)	2011 to 2016	11.2	1.43	1.34	11.35	0.50	1.10	683	0.03	0.01
Medium speed main (Tier III)	2016 +	2.8	1.43	1.34	11.35	0.50	1.10	683	0.03	0.01
Gas turbine	All	6.1	0.06	0.06	16.10	0.10	0.20	970	0.08	0.00
Steam main engine and boiler	All	2.1	0.93	0.87	16.10	0.10	0.20	970	0.08	0.00

²³ IMO 2015. Third IMO GHG Study 2014; International Maritime Organization (IMO) London, UK, April 2015. See <https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf>

²⁴ See <https://www.polb.com/environment/air/emissions.asp> and https://www.portoflosangeles.org/environment/studies_reports.asp

²⁵ See <https://www.dieselnet.com/standards/cycles/iso8178.php>

²⁶ See <https://www.dieselnet.com/standards/inter/imo.php>

²⁷ IMO 2015. Third IMO GHG Study 2014, annex 6, table 22; International Maritime Organization (IMO) London, UK, April 2015.

Table 3.5: Emission factors for auxiliary engines using HFO with 2.7% sulphur content, g/kWh

Engine category	Model year range	NO _x	PM ₁₀	PM _{2.5}	SO ₂	HC	CO	CO ₂	N ₂ O	CH ₄
Medium speed auxiliary (Tier 0)	1999 and older	14.7	1.44	1.35	11.98	0.40	1.10	722	0.03	0.01
Medium speed auxiliary (Tier I)	2000 to 2010	13.0	1.44	1.35	11.98	0.40	1.10	722	0.03	0.01
Medium speed auxiliary (Tier II)	2011 to 2016	11.2	1.44	1.35	11.98	0.40	1.10	722	0.03	0.01
Medium speed auxiliary (Tier III)	2016 +	2.8	1.44	1.35	11.98	0.40	1.10	722	0.03	0.01
High speed auxiliary (Tier 0)	1999 and older	11.6	1.44	1.35	11.98	0.40	0.90	690	0.03	0.01
High speed auxiliary (Tier I)	2000 to 2010	10.4	1.44	1.35	11.98	0.40	0.90	690	0.03	0.01
High speed auxiliary (Tier II)	2011 to 2016	8.2	1.44	1.35	11.98	0.40	0.90	690	0.03	0.01
High speed auxiliary (Tier III)	2016 +	2.1	1.44	1.35	11.98	0.40	0.90	690	0.03	0.01

Ports may incorporate NO_x emissions data from each ship's IMO Engine International Air Pollution Prevention (EIAPP) Certificate for propulsion and auxiliary engines into the annual emissions inventories. For ships with a valid propulsion and/or auxiliary engine EIAPP, the engine's actual NO_x emissions value (g/kWh) as documented should be used in place of the general NO_x emission factor, which is the same as the applicable engine's IMO Tier NO_x standard. The expiration date of the International Air Pollution Prevention Certificate (IAPP) should be reviewed to ensure the EIAPP values are valid for the time period under study.

Fuel correction factors

Fuel correction factors (FCF) are used to adjust 'base' emission factors developed for a particular type of fuel, such as HFO and sulphur content during emissions testing to represent the actual fuel type and/or sulphur content used for the period of the emissions inventory. The use of fuel correction factors (FCF) will depend on the source of the emission factors used and the fuel being used by the fleet being inventoried. If the fuel used by vessels included in the emissions inventory is the same as the referenced fuel for the emission factors, then the FCF is 1.0. If the fuel used by vessels in the inventory within the geographical domain is a different quality than the emission factor fuel then fuel correction factors will be needed to adjust the emission factors. For example, Tables 3.4 and 3.5 above show emission factors for vessels using HFO with 2.7% sulphur content. Vessels in the inventory that use 2.7% HFO would use a FCF of 1.0. Vessels in the inventory using a fuel other than 2.7% HFO would use a FCF greater or less than 1.0. Comprehensive fuel correction factors for this purpose are provided in Annex 6 of the Third IMO Greenhouse Gas Study 2014.²⁸ Each year, the IMO Secretariat reports to the Marine Environmental Protection Committee (MEPC) the annual global average sulphur content of fuel oil and marine distillate fuels. This information source is recommended for determining in-use fuel sulphur content during the year of the emissions assessment when ship-specific data is not available.

Control factors

Control factors account for emissions reductions, such as from emissions control equipment installed by the manufacturer or other measures resulting from implementation of emissions reduction strategies. Control factors are specific to the emissions control equipment, the engines or boilers they are being applied to and the mode in which the ship is being operated. For more information on seagoing vessel control factors, please refer to IMO's Study of Emissions Controls and Energy Efficiency Measure for Ships in the Port Area.²⁹

²⁸ IMO 2015. Third IMO GHG Study 2014; International Maritime Organization (IMO) London, UK, April 2015. See <https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf> cited March 2018.

²⁹ IMO 2015. Study of Emission Control and Energy Efficiency measures for Ships in the Port Area; International Maritime Organization (IMO) London, UK, February 2015. See <https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/Port%20Area.pdf> cited March 2018.

Scaled inventory approach

For scaled inventories, data from published emissions assessments from other ports (also referred to as surrogate ports) are used. Care should be taken to identify 1) a port that is similar in size and cargo throughput which might include taking container-related emissions from one inventory and bulk operations from another inventory, 2) the port's equipment is subject to similar regulations and 3) geographical and operational domains, as these will define what emissions are being scaled.

Scaling is accomplished by taking the surrogate port's emissions by pollutant and by source category (or even at the equipment level) and dividing them by the associated cargo throughput of the surrogate port during the inventory period to get emissions per cargo throughput metrics. These metrics are then used to scale the emissions of the surrogate port to the target port by multiplying the metrics times the cargo throughput of the target port.

Screening inventory approach

For a screening inventory, the recommended approach is to utilise a combination of simplified assumptions, world fleet averages and data published in the latest comprehensive port inventories from other (comparable) ports. One would use simplified operational and activity assumptions and make assumption assignments as appropriate to speed, distances, time at berth, propulsion type, auxiliary power systems, boilers, modes, etc. and use world fleet averages for main engine and maximum rated ship speeds. Table 3.6 below provides the world fleet averages for MCR, maximum rated speed and sea-speed by the most common vessel classes.³⁰ The next step would be to obtain a count or estimate of the number and types of seagoing vessels that called during the time period associated with the emissions inventory. As a subsequent step, default averages for auxiliary engine and auxiliary boiler loads, by vessel class from the most recent published comprehensive emissions inventories would be utilised. For the final steps, estimate energy by vessel class; apply emission factors, fuel correction factors and control factors; and convert from grams to tonnes. A graphical representation of this approach is presented in Figure 3.6, after Table 3.6.

Table 3.6: Selected 2016 sub-class global counts, MCR and rated speeds

Ship class	Sub-class	StatCode5 designation	StatCode5 description	Capacity units	Capacity range	# Of ship	Propulsion MCR (kW)	Rated speed (knots)
Bulk carrier	Bulk dry	A21A2BC	Bulk carrier	dwt	0, 9,999	263	1,879	11.5
		A21A2BC	Bulk carrier	dwt	10,000, 34,999	2,399	6,116	13.9
		A21A2BC	Bulk carrier	dwt	35,000, 59,999	3,664	8,195	14.3
		A21A2BC	Bulk carrier	dwt	60,000, 99,999	3,316	9,889	14.4
		A21A2BC	Bulk carrier	dwt	100,000, 199,999	1,440	16,395	14.5
		A21A2BC	Bulk carrier	dwt	200,000, +	233	16,985	14.4
Chemical tanker	Chemical	A12A2TC	Chemical tanker	dwt	0, 4,999	701	970	11.2
		A12A2TC	Chemical tanker	dwt	5,000, 9,999	50	3,103	13.2
		A12A2TC	Chemical tanker	dwt	10,000, 19,999	46	4,923	13.9
		A12A2TC	Chemical tanker	dwt	20,000, +	32	8,516	14.9
		A12B2TR	Chemical/products tanker	dwt	0, 4,999	696	1,813	12.3
		A12B2TR	Chemical/products tanker	dwt	5,000, 9,999	899	3,192	12.9
		A12B2TR	Chemical/products tanker	dwt	10,000, 19,999	1,032	5,132	13.9
		A12B2TR	Chemical/products tanker	dwt	20,000, +	1,875	8,844	14.6

³⁰ Selected vessel class averages from IHS Markit Marine Data, 2016.

Ship class	Sub-class	StatCode5 designation	StatCode5 description	Capacity units	Capacity range		# Of ship	Propulsion MCR (kW)	Rated speed (knots)
Container	Container	A33A2CC	Container ship (fully cellular)	teu	0	999	1,099	5,583	15.9
		A33A2CC	Container ship (fully cellular)	teu	1,000	1,999	1,459	12,009	18.9
		A33A2CC	Container ship (fully cellular)	teu	2,000	2,999	741	21,228	21.3
		A33A2CC	Container ship (fully cellular)	teu	3,000	4,999	1,068	34,659	23.2
		A33A2CC	Container ship (fully cellular)	teu	5,000	7,999	624	52,656	24.7
		A33A2CC	Container ship (fully cellular)	teu	8,000	11,999	571	58,954	24.1
		A33A2CC	Container ship (fully cellular)	teu	12,000	14,499	184	65,682	24.0
General cargo	General cargo	A31A2GX	General cargo ship	dwt	0	4,999	11,285	1,008	10.9
		A31A2GX	General cargo ship	dwt	5,000	9,999	2,919	3,032	12.8
		A31A2GX	General cargo ship	dwt	10,000	+	1,700	6,356	14.6
Liquefied gas tanker	Liquefied gas	A11A2TN	LNG tanker	cbm	0	49,999	17	5,569	15.2
		A11A2TN	LNG tanker	cbm	50,000	199,999	392	29,306	19.3
		A11A2TN	LNG tanker	cbm	200,000	+	45	36,738	19.3
Oil tanker	Oil	A13A2TV	Crude oil tanker	dwt	0	4,999	42	1,240	11.5
		A13A2TV	Crude oil tanker	dwt	5,000	9,999	5	2,721	12.7
		A13A2TV	Crude oil tanker	dwt	10,000	19,999	9	4,977	13.3
		A13A2TV	Crude oil tanker	dwt	20,000	59,999	10	7,610	14.3
		A13A2TV	Crude oil tanker	dwt	60,000	79,999	60	10,791	14.7
		A13A2TV	Crude oil tanker	dwt	80,000	119,999	546	13,056	14.8
		A13A2TV	Crude oil tanker	dwt	120,000	199,999	435	17,776	15.3
		A13A2TV	Crude oil tanker	dwt	200,000	+	721	27,317	15.6
		A13A2TW	Crude/oil products tanker	dwt	0	4,999	34	1,914	12.0
		A13A2TW	Crude/oil products tanker	dwt	5,000	9,999	18	2,508	11.5
		A13A2TW	Crude/oil products tanker	dwt	10,000	19,999	16	6,738	13.9
		A13A2TW	Crude/oil products tanker	dwt	20,000	59,999	175	8,433	14.5
		A13A2TW	Crude/oil products tanker	dwt	60,000	79,999	170	11,392	14.7
		A13A2TW	Crude/oil products tanker	dwt	80,000	119,999	384	13,607	14.9
		A13A2TW	Crude/oil products tanker	dwt	120,000	+	60	16,916	15.2
		A13B2TP	Products tanker	dwt	0	4,999	2,860	1,276	11.2
		A13B2TP	Products tanker	dwt	5,000	9,999	704	2,672	11.9
		A13B2TP	Products tanker	dwt	10,000	19,999	204	4,335	12.9
		A13B2TP	Products tanker	dwt	20,000	59,999	490	8,619	14.7
A13B2TP	Products tanker	dwt	60,000	79,999	180	12,299	15.1		
A13B2TP	Products tanker	dwt	80,000	+	49	13,481	15.0		
Cruise	Passenger	A37A2PC	Passenger/cruise	gt	0	1,999	202	878	11.9
		A37A2PC	Passenger/cruise	gt	2,000	9,999	72	4,230	14.8
		A37A2PC	Passenger/cruise	gt	10,000	59,999	113	18,974	19.2
		A37A2PC	Passenger/cruise	gt	60,000	99,999	96	51,489	21.8
		A37A2PC	Passenger/cruise	gt	100,000	+	65	70,632	21.5
Ferry-RoPax	Passenger/Ro-Ro cargo	A36A2PR	Passenger/Ro-Ro ship (vehicles)	gt	0	1,999	1,784	1,496	12.9
		A36A2PR	Passenger/Ro-Ro ship (vehicles)	gt	2,000	+	1,219	14,896	21.1
Refrigerated cargo	Refrigerated cargo	A34A2GR	Refrigerated cargo ship	dwt	0	+	1,043	4,550	15.6
Ro-Ro	Ro-Ro cargo	A35A2RR	Ro-Ro cargo ship	dwt	0	4,999	298	3,592	14.3
		A35A2RR	Ro-Ro cargo ship	dwt	5,000	+	430	13,303	18.4
Vehicle	Ro-Ro cargo	A35B2RV	Vehicles carrier	vehicles	0	3,999	266	8,284	17.8
		A35B2RV	Vehicles carrier	vehicles	4,000	+	635	13,990	19.8

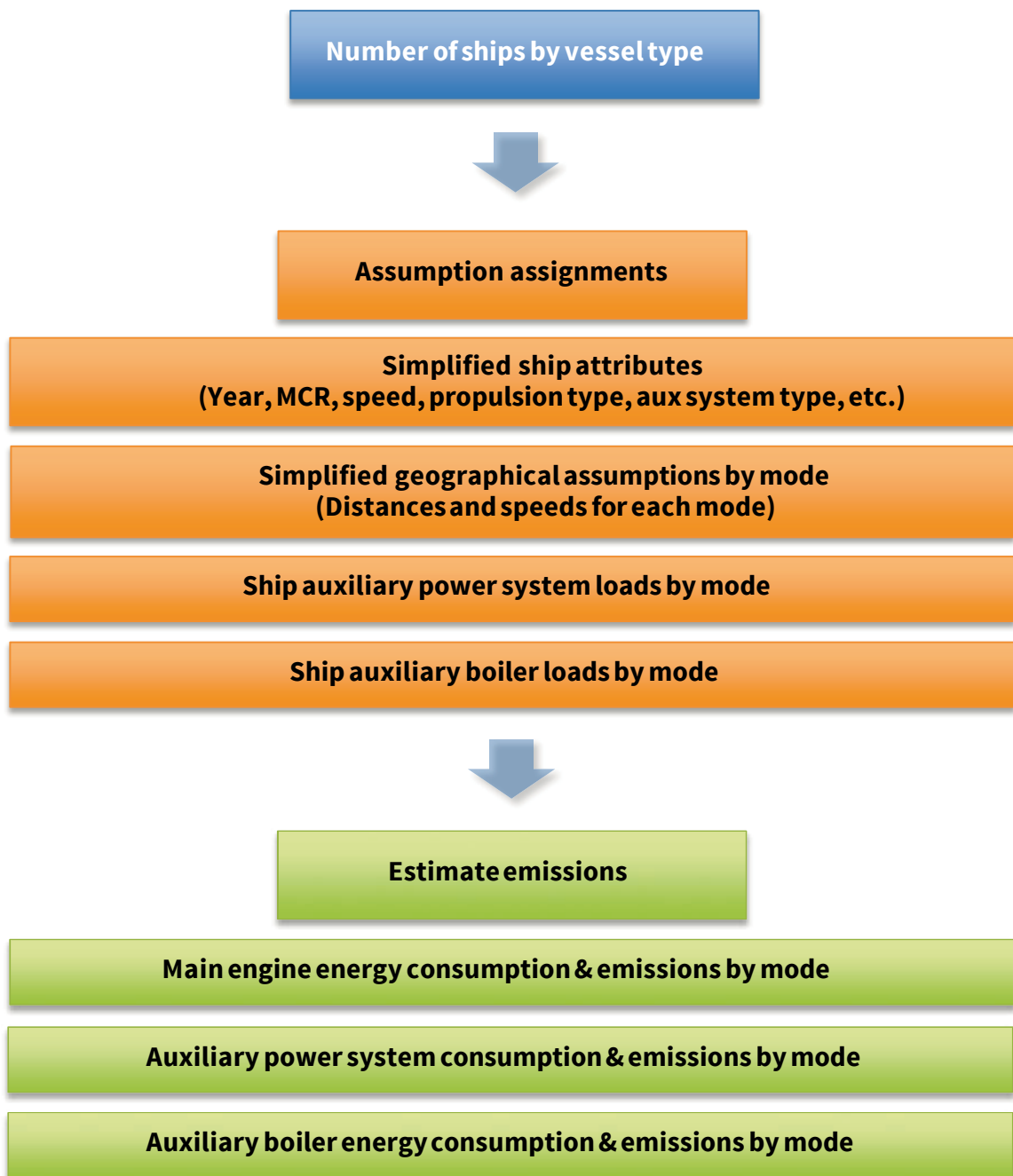


Figure 3.6: Recommended screening approach for estimating emissions from seagoing vessels

3.2.1.2 Domestic vessels

This section discusses methods that can be used to develop estimates of emissions from domestic vessels used in goods movement. Domestic vessels are divided into two categories: harbour craft and inland vessels that are not included in the seagoing emissions source category.

Harbour craft include a wide variety of vessel types and applications that tend to operate in and around a harbour or port, relatively close to shore or that are used specifically for assisting with port operations or local public transportation. Harbour craft differ from inland vessels in that they do tend to leave the port area for extended periods of time. The harbour craft source category includes the following vessel types:

- **Assist tugboats** – assist larger seagoing vessels during manoeuvring and docking
- **Towboats and push boats** – move barges and other floating objects

- **Local ferries** – carry passengers to specified locations near ports, harbours and cities
- **Excursion vessels** – used in commercial sightseeing
- **Crew boats** – ferry crew members between ships and shore
- **Work boats** – carry workers to offshore locations
- **Dredges** – used for deepening channels, land reclamation, restoring beaches and other related activities
- **Government vessels** – including police, fire and coast guard vessels
- **Commercial fishing vessels** – used in the commercial fishing industry
- **Pleasure craft** – usually privately owned small boats and yachts

On several continents, a significant amount of the movement of commercial goods and tourists is through inland waterways. Unlike harbour craft, inland vessels spend most of their time away from the port area transporting cargo or passengers from one destination to another using rivers, canals, tributaries and inland seas. The vessels used in these trades tend to be smaller and narrower than either seagoing vessels or harbour craft to efficiently navigate the rivers and canals of the inland waterway networks. A variety of methods exists to classify vessels used in inland waterway navigation including the following:

- According to the area of navigation
 - River (canal) boats
 - River-sea vessels
 - Lakes
- According to dedicated service
 - Commercial vessels, including
 - Cargo movement
 - Passenger movement
 - Pleasure craft
 - Government vessels
- According to installed machinery
 - Self-propelled
 - Non-self-propelled vessels

Like harbour craft, vessels used in inland waterways tend to have one or two propulsion engines and one or more auxiliary engines to generate power for on-board instrumentation and amenities. Most harbour craft often utilise distillate fuels available at the locations where they operate.

Depending upon location, the movement of goods via inland waterway may be a preferred alternative to overland transport. In terms of environmental impact, the energy consumption per tonne-kilometre per tonne of fuel consumed, for goods moved via inland waterways can be up to 76% less compared to goods moved by truck and 22% less compared to rail transport.³¹

³¹ See <https://www.docs.trb.org/prp/13-2200.pdf> cited March 2018.

Figure 3.7 provides an illustration of the major inland navigable networks worldwide.³²



Figure 3.7: *Global inland waterways*

Finally, there are cargo operations that are performed by large ocean tugs that travel in coastal waters between ports. The routes can range from local travel to long-distance travel. Seagoing tugs include large tug or tow barges, integrated tug-barges (ITB) and articulated tug-barges (ATB).

As with all mobile sources, estimating emissions from harbour craft and the vessels used on inland waterways requires gathering as much information as possible on the vessels and engines being modelled. Ideally, information would be collected on the population of the vessel fleet, the types and sizes of the vessels in use, the number and power rating of the engines in each vessel, the amount and types of fuel consumed and the activity by modes of operation that the vessels encounter in daily operation.

Harbour craft and inland vessels have propulsion and auxiliary engines. Harbour craft and inland vessels do not usually have boilers and use electric water heaters.

Emissions

Once the characteristics of the fleet are known, emissions from harbour craft and inland vessel engines can be estimated using the same general equation as seagoing vessels, as shown in Equation 5.

Equation 5

$$E_i = \text{Energy}_i \times EF \times FCF \times CF$$

Where:

E_i = emissions

Energy_i = energy demand by mode and engine i , kWh, calculated using Equation 6

EF = emission factor, expressed in terms of g/kWh, depends on engine type, emissions standards applicable in the region of operation and fuel type

FCF = fuel correction factor, unitless

CF = control factor(s) for emissions reduction technologies, unitless

³² See <https://www.wwinn.org> cited March 2018.

Energy

The ‘energy’ term of the equation is where most of the location-specific information is used. Energy is a function of the engine’s MRP expressed in kW, multiplied by a load factor that represents the load on the engine during each operating mode and is unitless, multiplied by the operating time for each mode that emissions are being estimated for. The ‘energy’ term of the equation is where most of the location-specific information is used. Energy by mode and engine is calculated using Equation 6.

Equation 6

$$Energy_i = MRP \times LF_i \times Activity_i$$

Where:

Energy_i = energy demand by mode and engine i, kWh

MRP = maximum rated power, kW or horsepower

LF_i = load factor for mode i (ratio of average load used during normal operations as compared to full load at maximum rated horsepower), unitless

Activity_i = hours of operation in mode i, hours

Equation 7

$$Activity = D / Speed_{Actual}$$

Where:

Activity = activity, hours

D = distance, nautical miles

Speed_{Actual} = actual ship speed, knots

Maximum rated power

Similar to seagoing vessels, MRP power is defined as the manufacturer’s rated engine power. For the purposes of this document, it is assumed that the IHS’s ‘power’ value is the MRP; if this value were not available, another data source would need to be found. A significant number of harbour craft and inland vessels do not have an IMO number and therefore are not included in the IHS database. Local data collection is a good source of MRP data for those vessels that call at the port that is developing the emissions inventory. Alternatively, other national vessel registration databases can provide engine data. Lastly, proxy data can be utilised from other published emissions inventories or applicable studies and reports.

Load factor

Engine load factor is used in emissions calculations to reflect the fact that, on average, engines are operated at power levels lower than their maximum power rating. Table 3.7 summarises the average engine load factors³³ that are recommended for the various harbour craft types for their propulsion and auxiliary engines. These load factors are based on various studies and surveys conducted by United States Environmental Protection Agency (US EPA) and the California Air Resources Board (CARB).

Activity

Activity is measured in hours of operation. The travel time in a zone is estimated by determining the time it takes to move through the zone. This is estimated by dividing the distance in nautical miles (nm) by the harbour craft and inland vessels’ actual speed in knots, as shown by Equation 7.

Actual speeds and distances can be obtained from AIS data providers, VTS data providers, vessel operators, or other sources.

³³ See https://www.portoflosangeles.org/pdf/2013_Air_Emissions_Inventory_Full_Report.pdf

Table 3.7: Harbour craft engine load factors

Harbour craft type	Auxiliary engines	Propulsion engines
Assist tug	0.43	0.31
Commercial fishing	0.43	0.27
Crew boat	0.32	0.38
Excursion	0.43	0.42
Ferry	0.43	0.42
Government	0.43	0.51
Ocean tug	0.43	0.68
Tugboat	0.43	0.31
Work boat	0.32	0.38

Emission factors

IMO regulation of marine engines is primarily applicable to ocean-going vessels. In many parts of the world, harbour craft and inland vessels engines are regulated by regional authorities such as in the EU³⁴ or national standards such as in US.³⁵ TransportPolicy.net collects emissions standards for various countries on the web.³⁶ Where possible, use emission factors that are recommended by the environmental regulatory agency in the country where the inventory is being conducted.

From a GHG perspective, although CH₄ and CO₂ are routinely measured during certification, special testing is required to measure N₂O and these data may be harder to obtain. However, N₂O, even with high global warming potential compared to CO₂, is a minor component of GHG emissions from harbour and inland vessels' engines, so any uncertainty around the emissions of this GHG should not significantly affect emissions totals.

Air pollutant and GHG emission factors published in other inventories from regulatory agencies or from other ports are another option for proxy emission factor data. Determining whether the engines in the inventory fleet were built to a specific national standard will also help determine the selection of emission factors. If it can be determined that an engine is built to a national standard, use the standards as emission factors. If it cannot be determined the engine is built to a national standard, one would need to look for factors for the equipment in other published sources.

Air pollutant and GHG emission factors are developed using energy or fuel consumed as the activity parameter. It is recommended that if there are guidelines published by the country where the inventory is being conducted, these guidelines be followed for the selection of emission factors. Where such guidelines are not available, use sources such as IPCC (for greenhouse gas pollutants only),³⁷ US EPA,³⁸ CARB,³⁹ EU and other published governmental resources.

Fuel correction factors

Fuel correction factors (FCF) are used to adjust 'base' emission factors that have been developed using a particular type and sulphur content fuel to represent actual fuel type and sulphur content used during the emissions inventory assessment year. The use of fuel correction factors will depend on the source of the emission factors used and the type of fuel used by the fleet being inventoried. If the fuel used is the same as the

³⁴ See <https://www.dieselnet.com/standards/eu/nonroad.php>

³⁵ See <https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-marine-vessels>

³⁶ See <https://www.transportpolicy.net/topic/emissions-standards/>

³⁷ IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 2: Stationary Combustion; Prepared by the National Greenhouse Gas Inventories Programme; Published: IGES, Japan. See https://www.ipccnggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

³⁸ See <https://www.epa.gov/ghgreporting/>

³⁹ See <https://www.arb.ca.gov/regact/2010/chc10/appc.pdf>

referenced fuel for the emission factors, then the FCF is 1.0. If the fuel used within the geographical domain is a different quality, then fuel correction factors will be needed to adjust the emission factors. It is recommended using the comprehensive emission factors provided in annex 6 of the Third IMO Greenhouse Gas Study 2014 for calculating emissions from domestic vessels. National fuel standards and/or national fuel types used for harbour craft and inland vessels can be used to determine default fuel types and sulphur content.

Control factors

Control factors are specific to the emissions control equipment, the engines or boilers they are being applied to and the mode in which the vessel is being operated. Several regulatory agencies around the world verify (or certify) the effectiveness of emissions reduction technologies for specific applications. Selected examples include:

- European Union Environmental Technology Verification (ETV)⁴⁰
- Danish Centre for Verification of Climate and Environmental Technologies⁴¹
- Nordic Environmental Technology Verification⁴²
- USEPA, ETV Program⁴³
- CARB ETV Program⁴⁴
- ETV Canada⁴⁵
- Japan Ministry of the Environment, ETV Program⁴⁶
- Philippines ETV⁴⁷

In addition, the information on seagoing vessel control factors can be used as a proxy for harbour craft and inland vessels.⁴⁸

3.2.1.3 Cargo handling equipment

Cargo handling equipment (CHE) includes equipment used to move cargo, such as cranes, container handlers, forklifts and yard tractors. Other types of equipment commonly included with cargo handling equipment in emissions inventories, although not directly used to move cargo, include sweepers, backhoes and other construction related equipment that may be used on the port's terminals. The following discussion refers to the three approaches to developing emissions inventories discussed in section 2: scaled, screening and comprehensive.

The cargo handling equipment emissions source category includes equipment that moves cargo such as general cargo, bulk cargo and containers to and from marine vessels, railcars and on-road trucks. Cargo handling equipment operates in most types of terminals, including container, break-bulk, auto/vehicle, dry bulk, liquid bulk and passenger. The majority of cargo handling equipment operating at marine terminals or rail yards is off-road equipment that is not designed to operate on public roadways. Engines fuelled by diesel, gasoline,

⁴⁰ See https://www.ec.europa.eu/environment/ecoap/etv_en cited March 2018.

⁴¹ See <https://www.etv-denmark.com/> cited March 2018.

⁴² See <https://www.etvnord.org/> cited March 2018.

⁴³ See <https://www.archive.epa.gov/nrmrl/archive-etv/web/html/> cited March 2018.

⁴⁴ See <https://www.arb.ca.gov/diesel/verdev/vt/cvt.htm> cited March 2018.

⁴⁵ See <https://www.etvcanada.ca/> cited March 2018.

⁴⁶ See <https://www.env.go.jp/policy/etv/en/> cited March 2018.

⁴⁷ See <https://www.denr.gov.ph/index.php/home/40-invitation-to-bid/363-central-office-package-1-establishment-of-emissions-factors-and-verification-of-environmental-technology.html> cited March 2018.

⁴⁸ See <https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf> cited March 2018.

propane, natural gas and electricity can power cargo handling equipment. The following are examples of common cargo handling equipment found in port terminals:

- Automated guided vehicles (AGVs)
- Bulldozers
- Electric pallet jacks
- Excavators
- Forklifts
- Loaders
- Man lifts
- Material handlers
- Rail-mounted gantry cranes (RMGs)
- Rail pushers
- Rubber-tyred gantry cranes (RTGs)
- Man lifts
- Material handlers
- Rail pushers
- Side handlers
- Skid steer loader
- Straddle carriers
- Top handlers/top picks
- Tractors
- Wharf or quay cranes
- Yard tractors

For a comprehensive activity-based emissions inventory, the following lists are examples of the data that might be collected for each piece of cargo handling equipment:

- Emissions source data:
 - Equipment type
 - Internal equipment identification number/name
 - Equipment make, model and country of origin
 - Equipment and engine manufacturer(s)
 - Engine make and model
 - Certification to any regional or national engine standards
 - Fuel type used and sulphur content, if applicable (diesel, gasoline, propane, natural gas, electric, etc.)
 - Rated power (e.g. kW or horsepower)
 - Emissions control devices or methods (other than standard for the model and year) such as diesel oxidation catalyst, particulate filter, anti-idling devices, etc.

- Activity data:
 - Annual hours of operation
 - Energy consumption (either fuel consumed per year or kWh from grid)
 - Average load factor while operating
- Emissions data
 - Emission factors appropriate to the types of engines in the inventory, grams pollutant/kWh or grams pollutant/litre fuel (or pounds pollutant/gallon fuel)
 - Control factors (per cent reduction offered by identified emissions control devices or methods)

To estimate emissions, not all of the source data listed above is directly needed. Items such as the internal identification number, manufacturer and model designations can be used in subsequent planning if equipment changes are considered as a means of reducing emissions.

For electric-powered equipment, the source data will mostly include kWh of recharging if the equipment utilises batteries, or total energy consumption for the equipment, if available. If recharging records and specific equipment energy consumption records are not available, the energy consumption is part of the overall energy consumption of the facility and rolled up in the electrical utility billing. The emission factors should reflect power plant emissions, preferably specific to the mix of power generation fuels used to provide power to the region being inventoried.

Comprehensive emissions calculations could be made for each piece of equipment or for the fleet of equipment as a whole. Estimates for each piece of equipment are preferable because that method results in emissions estimates that reflect actual usage and help identify potential candidates for emissions reduction efforts.

For both fuel-based and energy-based calculations, it is important to calculate the emissions from equipment using different fuels separately, because the emission factors are different for each fuel. In addition, fuels classified as biofuels (e.g. biodiesel and ethanol) should be calculated separately, even if the biofuel is a component of a fuel blend (such as a B20 blend of biodiesel and petroleum diesel).

For a scaled or screening inventory, data could be limited to terminal cargo throughputs and equipment counts by type. Other data elements, like annual hours of operation, assumed fleet make-up and energy consumption, could be based on data from published emissions inventories from other ports or other published literature. Actual cargo throughput figures from the target and proxy ports could be used to develop a ratio that could be applied to the published emissions of the proxy port to scale emissions for the target port.

Depending on the information collected, emissions can be estimated using fuel or energy figures.

Fuel-based emissions

If based on fuel consumption (tonnes per year), emissions are estimated by fuel type consumed using the Equation 8.

Equation 8

$$E = \text{Fuel Consumption} \times EF \times FCF \times CF$$

Where:

E =	emissions, grams/year
Fuel Consumption =	fuel consumed, litres
EF =	emission factor, grams of pollutant per gallon of fuel consumed, g/litre
FCF =	fuel correction factors are used to adjust from a base fuel associated with the EF and the fuel being used, dimensionless
CF =	control factor to reflect changes in emissions due to installation of emissions reduction technologies not originally reflected in the emission factors, dimensionless

Energy-based emissions

The energy-based emissions calculation methodology used to estimate cargo handling equipment emissions is consistent with previous emissions source categories. The basic equation used to estimate emissions per engine is shown in Equation 9.

Equation 9

$$E = \text{Energy} \times EF \times FCF \times CF$$

Where:

E =	emissions, grams/year
Energy =	energy demand per engine, kWh, calculated using Equation 10
EF =	emission factor, grams of pollutant per unit of work, g/kWh or g/hp-hr, depends on engine type, emissions standards applicable in the region of operation and fuel type
FCF =	fuel correction factors are used to adjust from a base fuel associated with the EF and the fuel being used, dimensionless
CF =	control factor to reflect changes in emissions due to installation of emissions reduction technologies not originally reflected in the emission factors, dimensionless

Energy

The 'energy' term of the equation is where most of the location-specific information is used. Energy by mode and engine is calculated using Equation 10:

Equation 10

$$E = MRP \times LF \times \text{Activity}$$

Where:

Energy =	energy demand, kWh
MRP =	maximum rated power, kW or horsepower
LF =	load factor (ratio of average load used during normal operations as compared to full load at maximum rated power), dimensionless
Activity =	hours of operation, hours

Maximum rated power

Similar to vessels, MRP power is defined as the manufacturer’s tested engine power. Local data collection is a good source of power data for equipment that operates at the port. Alternatively, other data sources, such as manufacturers’ websites or brochures, can provide engine power data. Lastly, proxy data can be utilised from other published emissions inventories or applicable studies and reports.

Engine load factor

Similar to harbour craft and inland vessels, cargo handling equipment engine load factors are used in emissions calculations to reflect the fact that, on average, engines are not used at their maximum power rating. As an example, CARB’s load factors are provided below, except for RTG cranes and yard tractors which are based on joint studies conducted by the Port of Los Angeles and Port of Long Beach in consultation with CARB (specifically, the yard tractor load factor⁴⁹ of 39% and the 20% load factor for RTG cranes).⁵⁰ Table 3.8 summarises the average engine load factors utilised in Port of Los Angeles and Port of Long Beach inventories for CHE emissions, which could be used as proxies for various types of cargo handling equipment.

Table 3.8: Cargo handling equipment engine load factors

Port equipment	Load factor
Rubber-tyred gantry crane	0.20
Crane	0.43
Excavator	0.55
Forklift	0.30
Top handler, side pick, reach stacker	0.59
Man lift, truck, other with off-road engine	0.51
Truck, other with on-road engine	0.51
Sweeper	0.68
Loader	0.55
Yard tractor, off-road engine	0.39
Yard tractor, on-road engine	0.39

Engine activity

Activity is measured in hours of operation. These data should be collected from the terminal equipment operators who routinely maintain records of hours logged by engine-hour. Where this is not possible, proxy data can be used from published port emissions inventories or assumptions can be developed based on local operating conditions.

Emission factors

Like harbour craft and inland vessels, cargo handling equipment engines are often subject to national or regional emissions standards for non-road mobile sources. Therefore, air pollutant emission factors for various sized engines expressed in terms of grams of pollutant per unit of work (g/kWh) are often available from state or national environmental protection or regulatory agencies or at TransportPolicy.net described above or DieselNet.⁵¹ During the certification process, engines are tested under varying speed and load combination to ensure that their emissions are below the allowable limits established by emissions standards.

⁴⁹ POLA and POLB 2008. *Yard Tractor Load Factor Study Addendum*, Port of Los Angeles and Port of Long Beach, December 2008.

⁵⁰ POLA and POLB 2009. *Rubber Tired Gantry Crane Load Factor Study*, Port of Los Angeles and Port of Long Beach, November 2009.

⁵¹ See <https://www.dieselnet.com/standards/>

From a GHG perspective, although CH₄ and CO₂ are routinely measured during certification, special testing is required to measure N₂O and these data may be harder to obtain. As noted previously, N₂O emissions contribute very little toward overall GHG emissions.

As a source of proxy pollutant data, emission factors published in other inventories or obtained from regulatory agencies or ports are an option. Determining whether the engines in the inventory fleet were built to a specific national standard will also help determine the selection of emission factors. If it can be determined that an engine is built to a national standard, use the standards as emission factors. If it cannot be determined the engine is built to a national standard, one would need to look for factors for the equipment in other published sources.

Similar to harbour craft, in general, air pollutant and GHG emission factors are developed by using energy or volume of fuel consumed used as the activity parameter. It is recommended that if there are guidelines published by the country where the inventory is being conducted, these guidelines be followed for the selection of emission factors. Where such guidelines are not available, use sources such as IPCC (for greenhouse gases), US EPA, EU and other published governmental resources.

Fuel correction factors

Fuel correction factors (FCF) are used to adjust 'base' emission factors that have been developed using a particular type and sulphur content of fuel to represent emissions from actual fuel type and sulphur content used for the assessment year. The use of fuel correction factors will depend on the source of the emission factors used and the type of fuel used by the fleet being inventoried. If the fuel used is the same as the referenced fuel for the emission factors, then the FCF is 1.0. If the fuel used within the geographical domain is a different quality, then fuel correction factors will be needed to adjust the emission factors. National fuel standards and/or national fuel types used for cargo handling equipment can be used to determine default fuel types and sulphur content.

Control factors

The same reference sources for control factors presented in section 3.2.1.2 (with the exception of the Third IMO GHG Study 2014) can be used for cargo handling equipment.

3.2.1.4 On-road heavy-duty vehicles

This section discusses methods that can be used to develop estimates of emissions from on-road heavy-duty vehicles or trucks (HDV or Truck). These vehicles, almost exclusively powered by diesel engines, classified in the US as Class 8 or heavy heavy-duty and with a Gross Vehicle Weight Rating (GVWR) greater than 14.97 tonnes, perform much of the movement of containerised cargo to ports for overseas export and from ports for local distribution. Trucks are the preferred method for moving cargo within relatively short distances compared to rail transport. For longer distance transportation, these trucks are also used to move containers (drayage) to off-terminal facilities where they are transferred to railcars. Although the heavy-duty truck fleet is predominately diesel powered, the percentage of trucks powered by compressed natural gas (CNG), liquefied natural gas (LNG), propane and electricity is increasing at least in some ports.

In estimating emissions from on-road heavy-duty vehicles in the port setting, several modes of operation are considered. During idling mode, emissions occur when the engine is running but the vehicle is not moving. During running mode, emissions occur when the engine is operating and the vehicle is in motion. Recently due to stringent emissions control for heavy-duty vehicles, engine manufacturers have started to use selective catalyst reduction technology. Since the temperature of a catalyst needs to reach a certain temperature before it can effectively reduce emissions, cold start emissions occur when an engine starts after lengthy shutoff. Cold start mode emissions are higher in magnitude than running emissions that occur when the engine has been running for a while and the catalyst is warm. Emissions from trucks can also be classified by area of operation: "on-terminal" when they idle waiting to pick up or drop off cargo within the bounds of a marine terminal or traverse the terminals with their loads; "on-port," when entering or exiting port property or travelling between terminals if they are located within the geographical confines of a port; and "regional," when travelling outside of port property on the public roadways as they pick up or deliver goods. These geographic distinctions tend to be made because the operational characteristics of the trucks differ by zone, as does the port's authority and ability to influence these operations.

Emissions

Estimating emissions from on-road heavy-duty vehicles requires knowledge of the fleet servicing the port and their operations. The basic estimation method is presented in Equation 11.

Equation 11

$$E_i = Pop \times EF \times ACT_i \times FCF \times CF$$

Where:

- E_i = emissions by mode i, grams/year
- Pop = count of heavy-duty vehicles
- EF = age distributed (discussed below) emission factor, g/kilometer (km) or g/mile for running mode; g/hour for idle mode; grams per start for cold start mode
- ACT_i = activity by mode i, km or mile for running mode, hours for idle mode, number of starts for cold start mode
- FCF = fuel correction factor
- CF = control factor

Population

In countries where emissions standards for on-road heavy-duty vehicles are implemented, an age-weighted distribution of the fleet calling at a port is important because the emissions from the vehicles will vary depending on their applicable engine emissions standard, which in turn depends on age (or model year). On-road motor vehicle emissions estimation models, such as the USEPA “MOVES,”⁵² California’s “EMFAC,”⁵³ and Europe’s “COPERT,”⁵⁴ include a default assumption of the heavy-duty vehicle age distribution that can be used for this purpose in the absence of port-specific information.

Alternatively, the model year distribution of the port truck fleet may potentially be determined by an examination of port tenants’ records of vehicle arrivals and departures if licence plate information is collected at the gate(s). In many cases this information is gathered for accounting purposes either manually or electronically; however, most modern terminals use optical character recognition systems (OCR) or radio frequency identification devices (RFID). Whether recorded manually or electronically, it is possible that the collected licence plate information can be linked to registration information of these vehicles through government motor vehicle departments, to determine the age or model year distribution of the vehicles that serviced the port.

Emission factors

On-road heavy-duty vehicles that use fossil fuels emit both air pollutants and GHG. The same regulatory models referenced above provide air pollutant and GHG emission factors based on applicable engine emissions standards and other variables. An age-weighted composite EF is calculated and used in the equation above. For countries that do not have regulatory engine emissions standards, non-governmental organisations, such as the International Council on Clean Transportation (ICCT),⁵⁵ can be useful sources of information.

As new vehicles become more fuel-efficient and older vehicles are replaced, the overall fleet will tend to emit lower levels of CO₂ on a per-mile or kilometre-basis.

⁵² See <https://www.epa.gov/moves> cited March 2018.

⁵³ See https://www.arb.ca.gov/msei/categories.htm#onroad_motor_vehicles cited March 2018.

⁵⁴ See <https://www.emisia.com/products/copert/copert-5> cited March 2018.

⁵⁵ See <https://www.theicct.org/heavy-duty-vehicles> cited March 2018.

Activity

Vehicle miles travelled (VMT) per vehicle trip while on terminal or on port roads within the defined geographical boundaries can be estimated by reviewing the physical layout of the terminal or port and estimating the average round trip distance between entry and exit gates. On-terminal activity includes idling or very low speed operation of trucks as they wait at gates or in queue and running which occurs as goods are picked up or dropped off. Therefore, in estimating on-terminal greenhouse gas emissions, the activity component of Equation 11 above would include hours of idle operation as well as VMT. Estimates of the hours of idle operation can be obtained through survey of terminal operators or by actual measurement of queue times at gates. Number of starts after certain vehicle rest (when engine is off) will probably be estimated based on surveys of truck operators. On public roads, short periods of idle, such as those experienced at traffic signals, are assumed to be integrated within the g/km emissions rates, obviating the need for separate assessment. Alternatively, fuel consumption rates and emission factors per unit volume of fuel can be used to develop emissions estimates.

The activity of on-road heavy-duty vehicles involved in the movement of goods to and from the ports may already be modelled by local, state or higher level governmental agencies as a part of their overall transportation plans. Agencies, such as the Federal Highway Administration (FHWA) in the US and local agencies such as the Southern California Association of Governments can be a valuable source of information as they periodically perform transportation analyses, including origin and destination surveys, that can be used to establish port-related activity levels. While ports tend to use these agencies' estimates for sake of consistency, it is not unusual for ports to work cooperatively with regulatory agencies to ensure that the most accurate information is used in establishing these estimates.

Fuel correction factors

Fuel correction factors (FCF) are used to adjust 'base' emission factors that have been developed using a particular type and sulphur content of fuel to represent emissions from actual fuel type and sulphur content used for the assessment year. The use of fuel correction factors will depend on the source of the emission factors used and the type of fuel used by the fleet being inventoried. If the fuel used is the same as the referenced fuel for the emission factors, then the FCF is 1.0. If the fuel used within the geographical domain is of a different quality and the emissions estimating model does not take this into account, then fuel correction factors will be needed to adjust the emission factors as needed. It is recommended, wherever possible, that fuel correction factors are taken from the same source(s) as the emission factors used for the inventory. National fuel standards and/or national fuel types used for on-road vehicles can be used to determine default fuel types and sulphur contents.

Control factors

The same reference sources for control factors presented in section 3.2.1.2 (with the exception of the Third IMO GHG Study 2014) can be used for heavy-duty vehicles.

Reefer containers

In addition to emissions from heavy-duty engines, emissions from refrigerated containers may be significant contributors to the port's emissions inventory. "Reefer" trucks are equipped with integral, transportation refrigeration units primarily powered by small diesel engines that work to keep cargo at optimal temperatures when external electrical power is unavailable. Transportation refrigeration units are considered non-road engines and the emissions rates expressed in grams of emissions per unit of work performed (g/kWh) are obtainable from engine manufacturers or government agencies in the form of certification data and emissions models such as EPA's "MOVES" and CARB's "OFFROAD."

In addition to the transportation refrigeration unit emissions, reefers utilise chemical refrigerants known to affect the atmosphere (for example, depletion of the ozone layer) and contribute to climate change. The type of refrigerant used is labelled on the units themselves. Refrigerants leaks are not usually reported in port emissions inventories since they are assumed to be low because the units are subject to frequent maintenance to ensure their continued operation.

3.2.1.5 Rail locomotives

This section discusses methods that can be used to develop estimates of emissions from locomotives used to move goods to and from ports via rail.

Locomotives used in port operations are routinely classified by size and/or usage as either line haul or switchers. Line haul locomotives tend to be larger and more powerful, and are used to move cargo over relatively long distances to ports or other destinations. In contrast, switching locomotives tend to be smaller, less powerful and perform relatively short distance rail movements, such as assembling and disassembling of trains at various locations or yards in and around the port, sorting of the cars of inbound cargo trains into contiguous “fragments” for subsequent delivery to terminals and the hauling of rail cargo within the port.

Locomotives can be diesel fuelled or electric powered. Most diesel-fuelled locomotives employ diesel electric systems, where diesel fuel is used to generate electricity, which provides the actual motive power. Therefore, unlike heavy-duty diesel trucks, engine load for diesel locomotives is not a direct function of vehicle speed. The activity of locomotives can be expressed in terms of “time in notch” or throttle position, which ranges from idle to one of eight different operating settings, each of which represents successively higher average engine load.

In many applications, external electrical energy sources are used to power locomotives rather than the internal combustion of diesel. These electric locomotives receive electricity from overhead lines or by means of third rail. Among the advantages of electrification of rail is the complete absence of pollutants emitted from the locomotives themselves, higher performance, lower maintenance and lower energy costs.

Similar to heavy-duty vehicles, locomotives have two general modes of operation: idling and moving. Estimating emissions from locomotives requires knowledge of the fleet servicing the port and their operations, similar to heavy-duty vehicles. The basic estimation method is presented in Equation 12.

Equation 12

$$E_i = Pop \times Energy_i \times EF \times FCF \times CF$$

Where:

- E_i = emissions by mode i, grams/year
- Pop = count of fleet of locomotives (age distributed if known)
- $Energy_i$ = energy consumed per locomotive by mode i, kWh or tonne-km
- EF = emission factor, g/kWh or g/kilometre (km) (age specific if known)
- FCF = fuel correction factor
- CF = control factor

Energy

There are four different approaches to estimating energy consumption related to locomotive activities: estimate the work performed in kWh, estimate the work performed in tonne-km, estimate the amount of fuel consumed, or obtain time-in-notch data.

If the estimator has modal data on the maximum rated power of the locomotive engines, load factors and hours of operations of locomotive engines operating in the port, Equation 13 can be used to estimate $Energy_i$ in kWh.

Equation 13

$$\mathbf{Energy}_i = \mathbf{Pop} \times \mathbf{MRP} \times \mathbf{LF}_i \times \mathbf{Act}_i$$

Where:

Energy _i =	energy consumed by mode i for each locomotive, kWh
Pop =	count of fleet of locomotives
MRP =	maximum rated power of locomotive engines, kW
LF _i =	engine load factor for mode i, unitless
Act _i =	hours of operation for mode i, hours

Alternatively, if the information on the total tonne-km of goods moved by rail is available, an estimate of total fuel consumption can be obtained by applying a locomotive fuel consumption factor expressed in terms of tonne-km per mass of fuel consumed. To estimate Energy_i based on tonne-km, train configurations and assumed weights of locomotives, carriages and cargo are used to develop the total mass of the train and then the total distance moved is applied using Equation 14.

Equation 14

$$\mathbf{Energy}_i = \mathbf{Pop}_i \times (\mathbf{Mass}_L + \mathbf{Mass}_C + \mathbf{Mass}_{CARGO}) \times \mathbf{D}_i$$

Where:

Energy _i =	energy consumed by train configuration i, tonnes-km
Pop _i =	population of trains by configuration i, count
Mass _L =	mass of locomotives per train configuration i, tonnes
Mass _C =	mass of rail carriages per train configuration i, tonnes
Mass _{CARGO} =	mass of cargo per train configuration i, tonnes
D _i =	distance travelled by train configuration i, km

It is important to differentiate between the figures noted above, which apply to the weight of the cargo alone, and other fuel consumption figures that are expressed in terms of gross weight, which includes the weight of the locomotives and railcars as well as the cargo. Alternatively, if only fuel consumption is known, then total energy consumed can be calculated using brake specific fuel consumption using Equation 15.

Equation 15

$$\mathbf{Energy}_i = \mathbf{Fuel\ Consumption}_i / \mathbf{BSFC}_i$$

Where:

Energy _i =	energy consumed by locomotive configuration i, kWh
Fuel Consumption _i =	mass of fuel consumed by locomotive configuration i, g fuel
BSFC _i =	brake specific fuel consumption by locomotive configuration i, g fuel/kWh

The most detailed information on locomotive operations is collected as they operate. Time-in-notch data is recorded by each locomotive's engine management systems or event recorder and may be obtained from rail operators. If these data can be obtained from rail operator, it is probably the best source of rail activity data. Time-in-notch data should be obtained from a representative selection of locomotives operating under conditions that represent the area being inventoried. The average percentage of time in each notch setting can be multiplied by the time period under consideration to estimate the total time in each notch setting.

As each notch is representative of a per cent of the full power available from the locomotive's engine, Energy per notch could be estimated using Equation 16 below. Summing all the notch-based energy (Energy_n) calculations would equal total energy consumed.

$$Energy_n = MRP \times LF_n \times Act_n$$

Where:

- Energy_n = energy consumed at notch n, kWh
- MRP = maximum rated power of locomotive engine, kW
- LF_n = load factor for notch n, unitless
- Act_n = time in notch n, hours

Maximum rated power (MRP)

Line haul locomotive engines have a higher maximum rated power per locomotive than switcher locomotives, due to their respective duty cycles. Locomotive engine maximum rated power can be collected from locomotives directly; maximum rated power may be different from country to country.

Engine load factor

Load factors can be generalised by line haul and switching activities, or specific throttle notch-based load factors can be used if data is available. Estimated load factors by notch are presented in Table 3.9.⁵⁶

Table 3.9: Estimated load factors by notch

Mode	LF	Mode	LF
Dynamic braking	0.021	Notch 4	0.343
Idle	0.004	Notch 5	0.481
Notch 1	0.05	Notch 6	0.643
Notch 2	0.114	Notch 7	0.866
Notch 3	0.235	Notch 8	1.025

Engine activity

Measures of engine activity will depend on the method used to estimate energy. Activity may be hours of operation by mode, fuel consumption, or distance travelled. These data can be collected for activities in the geographical and operational boundaries or proxy data can be used from other published reports.

Emission factors

The same models referenced above in the domestic vessel section provide emission factors based on the applicable engine standards. For countries that do not have regulatory engine emissions standards, non-governmental organisations such as the International Council on Clean Transportation (ICCT)⁵⁷ can be useful references.

Locomotives that burn fossil fuels emit both air pollutants and greenhouse gases. As new locomotives become more fuel efficient due to customer demand and the potential for future carbon emissions standards, the overall fleet tends to emit lower levels of air pollutants and greenhouse gases. The improvements gained in fuel economy within the locomotive fleet over time, although modest, may suggest that the average age of the fleet should also be considered rather than just the population. Locomotives of varying model years may also be subject to different emissions standards; this also supports the argument to track the age distribution, or the number of locomotives in each model year, of the port rail fleet.

⁵⁶ 40 CFR 1033.530, Table 3. Standard Notch Power Levels Expressed as a Percentage of Rated Power.

⁵⁷ See <https://www.theicct.org/heavy-duty-vehicles> cited March 2018.

Fuel correction factors

Fuel correction factors (FCF) are used to adjust ‘base’ emission factors that have been developed using a particular type and sulphur content of fuel to represent emissions from actual fuel type and sulphur content used for the assessment year. The use of fuel correction factors will depend on the source of the emission factors used and the type of fuel used by the fleet being inventoried. If the fuel used is the same as the referenced fuel for the emission factors, then the FCF is 1.0. If the fuel used within the geographical domain is a different quality, then fuel correction factors will be needed to adjust the emission factors. National fuel standards and/or national fuel types used for non-road equipment or marine vessels can be used to determine default fuel types and sulphur contents.

Control factors

The same reference sources for control factors presented in section 3.2.1.2 can be used for locomotives, with the exception of IMO 2015.

3.2.2 Electrical grid emissions

For the purpose of this report, electrical grid greenhouse gas emissions are associated with Scope 2 (port purchased) and Scope 3 (tenant purchased) and associated with the generation of energy used by a port, related to the movement of cargo. Examples of electrical grid-based energy sources include: terminal and road lighting, electric vehicle recharging, on-shore power supply for ships at-berth, terminal and port administration buildings.

Electrical grid emissions are solely used for GHG port assessments and not air pollutant assessments because air pollutants emitted by grid based sources are insignificant compared to other port related sources described above. However, for GHGs, power plant emissions are significant and should be accounted for, especially since GHGs are a global concern and location is unimportant. Electrical grid emissions typically account for significantly less emissions than mobile sources, unless there are port-related power plants, industrial and manufacturing facilities and other significant stationary sources on port property.

Electricity consumption at ports includes electricity used in the routine operation of the port and tenant administrative facilities (e.g. lighting, instrumentation, comfort cooling, computers, heating, air conditioning and ventilation); electrified cargo handling equipment (electric wharf cranes, electric rail-mounted gantries, electric rubber-tyred gantries, etc.); shore powering of vessels; and reefer plugs. Even though various types of electrified cargo handling equipment have zero air pollutant emissions, from a greenhouse gas perspective, greenhouse gas emissions attributed to their operation need to be estimated based on their use of electricity.

Although significant, GHG emissions from the consumption of electricity typically represent a small fraction of the port’s overall greenhouse gas emissions. Estimates of port-related electrical grid GHG emissions are calculated using Equation 17.

Equation 17

$$E = EF \times \text{Energy}$$

Where:

- E = emissions, grams/year
- EF = emission factor, g/kWh or g/MWh
- Energy = electrical energy consumed, kWh or MWh

Emission factors

The appropriate greenhouse gas emission factors depend upon the fuel used to generate the electricity supplied to facilities and equipment within the port’s geographical boundary (i.e. burning of coal or natural gas, or use of renewable sources such as solar, wind, nuclear or hydropower).

It is recommended greenhouse gas emission factors be obtained directly from the electricity provider, as these will be the most accurate. If these emission factors are not available or published by the electricity provider, then default factors can be used based on the country in which the port emissions inventory is being conducted. An alternative resource is the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 Energy, Chapter 2, Stationary Combustion⁵⁸ report.

Energy

With respect to the consumption of electricity, the energy component of the equation is the estimated or measured kilowatts or megawatts of electricity consumed per unit of time (per day or per year), which can be determined through the audit of electricity bills. Depending on the metering of the port-related sources, data may need to be collected directly from tenants if the meters and records are not available to the port authority.

3.3 Equipment, activity and emissions metrics

Simple reporting of total emissions does not tell the entire story of port-related emissions. It is helpful to present the emissions information in different contexts that may be more meaningful to the various readers. Presenting results using equipment, activity and emissions metrics can also help identify efficiencies or inefficiencies that underlie the emissions documented in an emissions inventory. Equipment, activity and emissions metrics combine other data streams, like activity and cargo throughput, which provides context to the energy consumption and air pollutant estimates included in an emissions inventory. Examples of uses of equipment, activity and emissions metrics include:

- Comparing emissions by source category:
 - ‘Containerships were responsible for 64% of the PM emissions in the Port in 2015.’
- Comparing Port emissions to regional emissions:
 - ‘The Port contributed 4.4% of Regional NO_x emissions.’
- Comparing emissions over time:
 - ‘Since 2005, PM10 emissions have been reduced 86%.’
- Evaluating equipment:
 - ‘In 2015, 12% of vessel calls were IMO Tier 0, 67% were Tier I, 17% were Tier II and 4% were No Tier.’
- Evaluating emissions performance:
 - ‘In 2015, the Port emitted 12 tonnes of NO_x per 10,000 TEUs handled.’

There are three broad categories of metrics commonly used by ports: equipment-based, activity-based and emissions-based. Selected examples of these three metric categories are presented in Table 3.10.

Table 3.10: *Examples of equipment, activity and emissions metrics*

Metric	Examples
Equipment-based	
equipment energy, or activity/ equipment count or activity	yard hustler MWh/yard hustler
	tiered yard hustler NO _x tonnes/yard hustler respective tier
	8000 teu containership calls/total containership calls
	IMO Tier 1 seagoing vessel calls/total seagoing vessel calls
	hours at-berth/call
	hours at-anchorage/call

⁵⁸ IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories; Prepared by the National Greenhouse Gas Inventories Programme, Volume 2 Energy, Chapter 2, Stationary Combustion; Published: IGES, Japan. See https://www.ipccnggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf cited March 2018.

Metric	Examples
equipment energy, or activity/ equipment count or activity (Cont.)	cranes/container
	wharf cranes/containership call
	locomotives/train departure
	natural gas-powered truck calls/total truck calls
	OPS seagoing vessel calls/total seagoing vessel calls
Activity-based	
cargo throughput/activity	teus/containership call
	teus/lift
	passengers/cruise ship call
	teus/train departure
	barrels of crude/oil tanker call
	assist tugs/oil tanker call
	tonnes/inland vessel call
	lifts/containership call
	teus/truck arrival or departure
	autos discharged/ro-ro call
empty teus/containership call	
Emissions-based	
emissions/time period	total PM tonnes/year
	total NO _x tonnes/year
	total CO ₂ e tonnes/year
	seagoing vessel PM tonnes/year
	cargo handling equipment NO _x tonnes/year
	heavy duty vehicle CO ₂ e tonnes/year
	bulk ship PM tonnes/year
	cargo handling equipment NO _x tonnes/year
	rubber-tyred gantry PM tonnes/year
	assist tug NO _x tonnes/year
grid-based CO ₂ e tonnes/year	
emissions/cargo throughput	total PM tonnes/tonne
	container-related NO _x tonnes/10,000 teus
	bulk liquid-related CO ₂ e tonnes/barrel
	containership PM tonnes/10,000 teus
	cargo handling equipment NO _x tonnes/tonne
	heavy duty vehicle CO ₂ e tonnes/10,000 teus
	cruise ship PM tonnes/passenger
	crane NO _x tonnes/10,000 teus
	grid-based CO ₂ e tonnes/tonne
	locomotive NO _x tonnes/10,000 teus
general cargo ship CO ₂ e tonnes/tonne of steel	

Metric	Examples
Emissions-based (Cont.)	
emissions/activity	heavy-duty vehicle PM tonnes/kilometre (km) containership NO _x tonnes/containership call locomotive CO ₂ e tonnes/train departure heavy-duty vehicle PM tonnes/transit cargo handling equipment NO _x tonnes/vessel call oil tanker ship CO ₂ e tonnes/anchorage call bulk ship PM tonnes/arrival cargo handling equipment NO _x tonnes/lift cruise ship PM tonnes/at-berth visit assist tug NO _x tonnes/ship call grid-based CO ₂ e tonnes/shorepower call
emissions/energy	cruise ship PM tonnes/MWh containership NO _x tonnes/MWh cargo handling equipment CO ₂ e tonnes/kWh heavy-duty vehicle PM tonnes/kWh assist tug NO _x tonnes/kWh oil tanker ship CO ₂ e tonnes/MWh total PM tonnes/MWh IMO Tier 2 bulk ships NO _x tonnes/MWh cruise ship at-berth PM tonnes/MWh at-berth total IMO Tier 2 seagoing vessels NO _x tonnes/MWh grid-based CO ₂ e tonnes/purchased MWh

Each port will need to determine which metrics are most appropriate based on the drivers for the port emissions assessment and what the key indicators are that need to be communicated to stakeholders and the public.

Equipment, activity and emissions metrics become most valuable indicators when they are compared year-over-year to the metrics from past emissions inventories. They help indicate where efficiencies and inefficiencies are occurring within cargo movement operations. They can be used to identify and resolve ‘bottlenecks’ and provide context to stakeholders on why emissions are changing over time. However, note that care must be taken to ensure that metric changes year-to-year are reflective of changes in operations, not due to changes in methods.

In addition to year-over-year comparisons, emissions metrics can also be useful for comparisons between ports that use similar methods of assessment. Again, care must be taken to ensure that comparisons between ports are reflective of differences in operations, not methodological differences.

3.4 Port emissions forecasts

Port emissions forecasts are used to estimate port-related emissions in future years. Emissions forecasts may consider cargo growth, future number of vessel calls, changes in vessel sizes, regulations that will reduce emissions, operational efficiency improvements and any emissions control strategies implemented by the port or its tenants. Ports and/or regulatory agencies primarily use a forecast to evaluate scenarios to inform decisions on emissions reduction targets. Baseline year emissions inventories provide the base data used in emissions forecasting.

When estimating future emissions, a range of scenarios should be considered, depending on the drivers and available data. A “high” scenario utilises assumptions related to cargo growth, regulations, efficiencies and other assumptions that produce a high emissions scenario or “worse case” scenario from an emissions perspective. For instance, a high emissions growth scenario could use conservative assumptions associated with existing emissions reduction regulations and emissions reduction strategies, mixed with high growth rate

in cargo and emissions source activity. In contrast, a “low” scenario utilises more optimistic assumptions to produce a low emissions scenario or “best case” scenario. A low emissions growth scenario could use more aggressive assumptions associated with existing emissions reduction regulations and emissions reduction strategies, mixed with a low growth rate in cargo and emissions source activity. A range of forecasts provides more contexts with regard to the uncertainties associated with various assumptions than a single-scenario forecast.

Forecasting scenarios should be conducted, at a minimum, at the emissions source category level and, as more information becomes available, by vessel/equipment types, engine types and other parameters. Vessels and equipment should be categorised by cargo type, so that expected growth rates are properly applied by associated cargo types. A comprehensive forecasting approach would group emissions sources by source category, cargo type, engine type and energy type, then apply expected growth rates, fleet turnover scenarios, fleet efficiency scenarios, operation efficiency scenarios, existing regulation scenarios and emissions reduction strategy scenarios. The results are forecasted emissions scenarios by source category, which can be aggregated as needed based on the drivers for the port emissions forecast. A high-level matrix showing forecasting considerations, by source category, is presented in Figure 3.8.

Another fundamental aspect of forecasting is consideration of various future energy efficiency scenarios. It might be tempting to undertake a forecast using future cargo growth rates applied to a baseline emissions inventory. However, the resulting forecast would then ‘lock’ the emissions sources’ fleet distribution, energy use and operational efficiencies (or inefficiencies) from the baseline year into the future, often resulting in significant overestimates of future emissions. Future improvements to energy efficiencies associated with enhanced procedures, fleet characteristics and sizes, and changes in operational profiles need to be considered along with cargo growth. This indicates that a port needs to consider how each of these parameters will change over time given the projections of cargo growth and the local regulatory and business environment.

When considering regulations that will reduce emissions in the future, it is important to understand the entry-into-force date of the regulation to determine when to apply the requirements. For example, the IMO global maritime sulphur cap will set the future fuel sulphur content to 0.5% sulphur globally for those areas outside a Sulphur Emission Control Area (SECA) and will start on 1 January 2020. Therefore, when forecasting, one can set control factors for both sulphur and particulate matter based on the new fuel sulphur requirements. For areas already in an SECA, there will be no further impact from the 2020 global fuel cap, as the fuel used in a SECA is already required to have 0.1% sulphur.

Another example of taking into account an existing regulation is the application of IMO Tier III for nitrogen ECAs. For the North American ECA, the regulation states that vessels with keel laid 1 January 2016 or newer have to meet IMO Tier III when inside the ECA geographical boundaries. There were over 1,200 keels laid prior to 1 January 2016 and not constructed as of October 2016 that are all ‘grandfathered’ or exempt from the Tier III standard.⁵⁹ In addition, the existing world fleet built prior to 1 January 2016 is also exempt from the Tier III standard.

Case study

The Port of Los Angeles and Port of Long Beach have conducted the most extensive emissions forecasts for any port(s). These emissions forecasts were undertaken as part of the San Pedro Bay Ports Clean Air Action Plan (CAAP) and its several updates. These forecasts include cargo growth rates by cargo type, future containership call- and size-distributions, incorporate all international, national and state regulations, and numerous scenarios related to emissions reduction strategies as part of the CAAP. Figures 3.9 through 3.11 are from the 2010 SPBP CAAP Update document⁶⁰ and illustrate high (2007 forecasted emissions) and low (2009 forecasted emissions) forecasts for diesel particulate matter (DPM), NO_x and SO_x. These figures also show the 2014 and 2023 target levels set in the CAAP, relative to a 2005 baseline, that the ports have committed to reach and stay below.

⁵⁹ SPBP 2017. *San Pedro Bay Ports Clean Action Plan 2017, DRAFT – Bay Wide Ocean-going Vessel International Maritime Organization Tier Forecast 2015-2050*; San Pedro Bay Ports, July 2017. See <https://www.cleanairactionplan.org/documents/vessel-forecast-draft.pdf>

⁶⁰ See <https://www.cleanairactionplan.org/documents/2010-final-clean-air-action-plan-update.pdf> cited March 2018.



Figure 3.8: Comprehensive port emissions forecasting elements matrix, by emissions source category

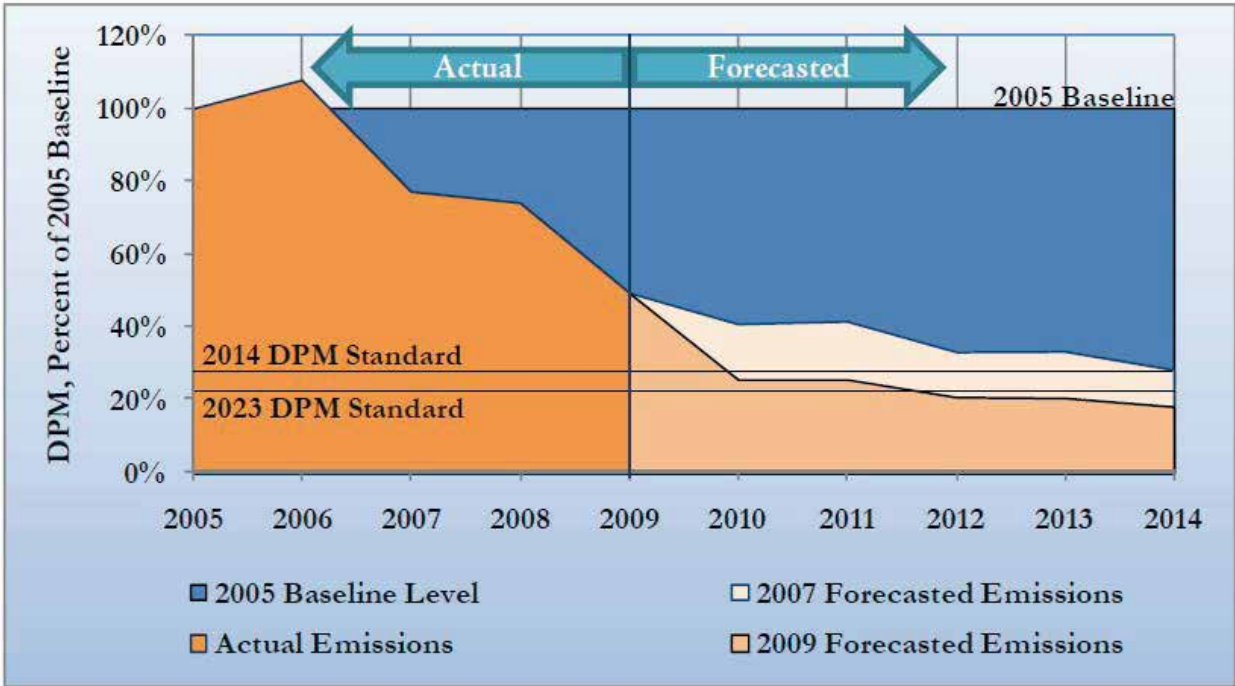


Figure 3.9: 2010 SPBP CAAP update diesel particulate matter forecast

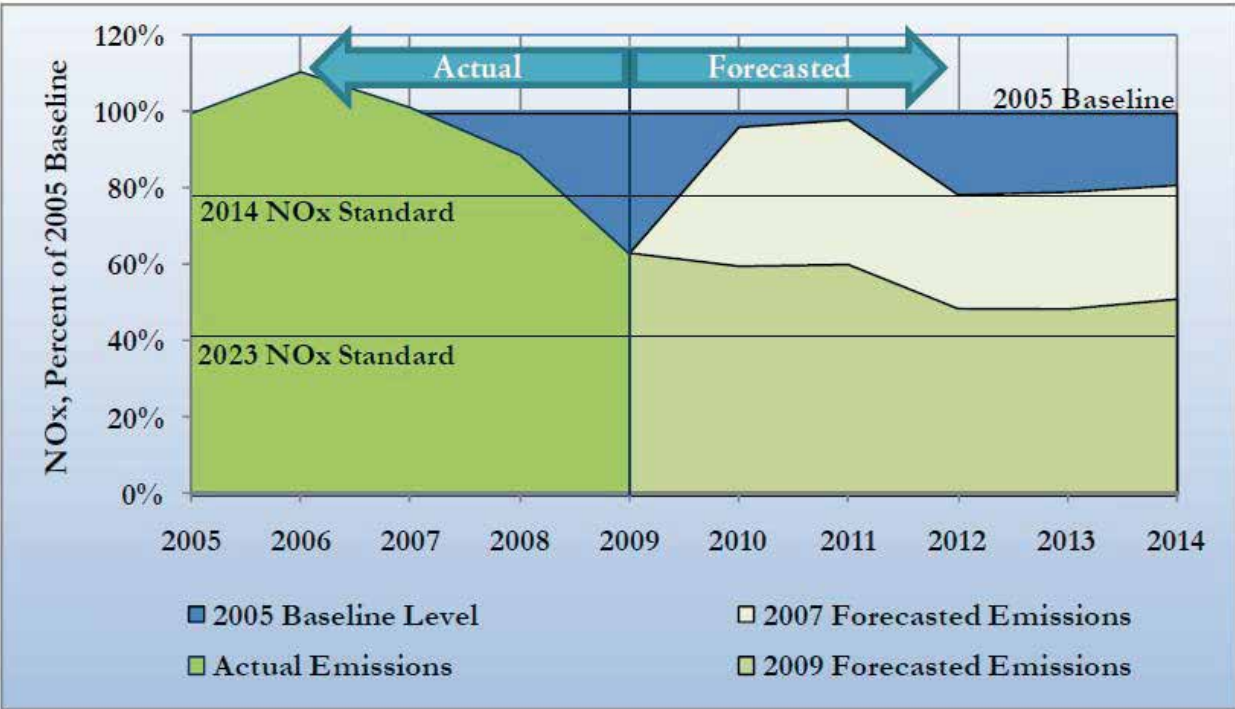


Figure 3.10: 2010 SPBP CAAP update NO_x forecast

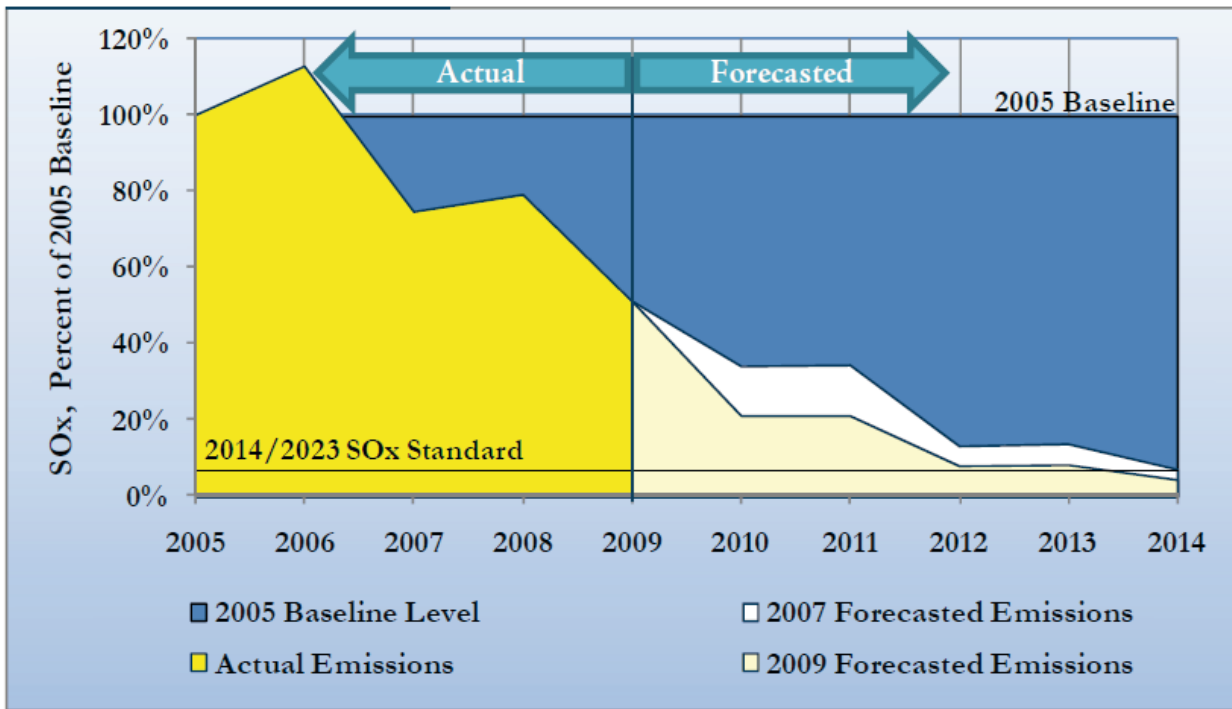


Figure 3.11: 2010 SPBP CAAP update SO_x forecast

As published in the Port of Los Angeles’ Inventory of Air Emissions – 2014,⁶¹ the actual emissions tracked closely with low forecasts for each pollutant compared to 2005, as presented in Figures 3.12 through 3.14.

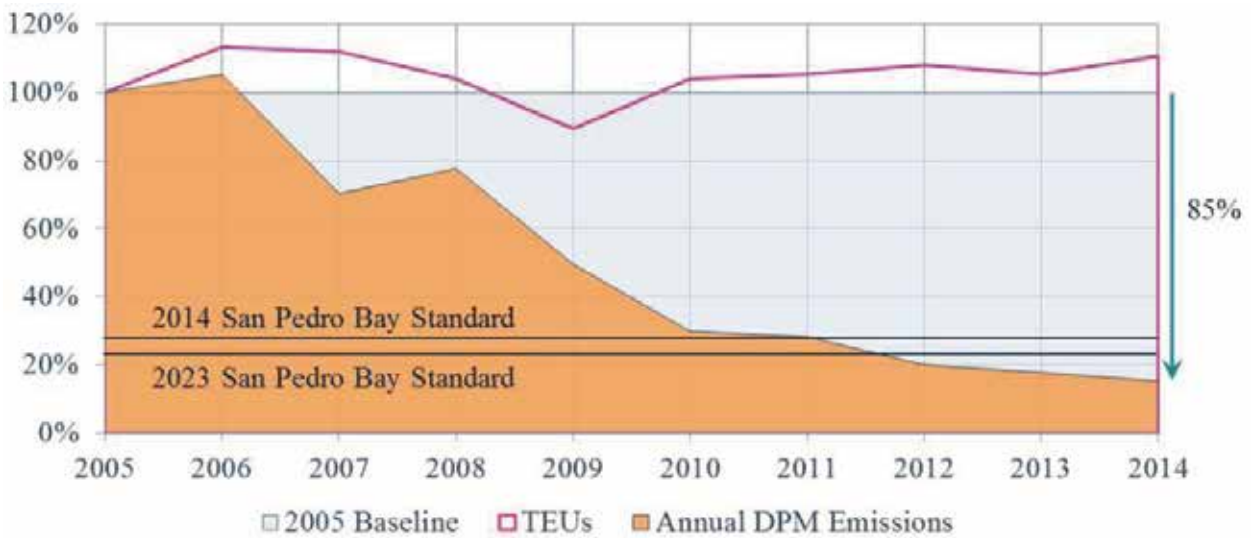


Figure 3.12: 2005-2014 POLA diesel particulate matter emissions reductions

⁶¹ See https://www.portoflosangeles.org/pdf/2014_Air_Emissions_Inventory_Full_Report.pdf cited March 2018.



Figure 3.13: 2005-2014 POLA NO_x emissions reductions

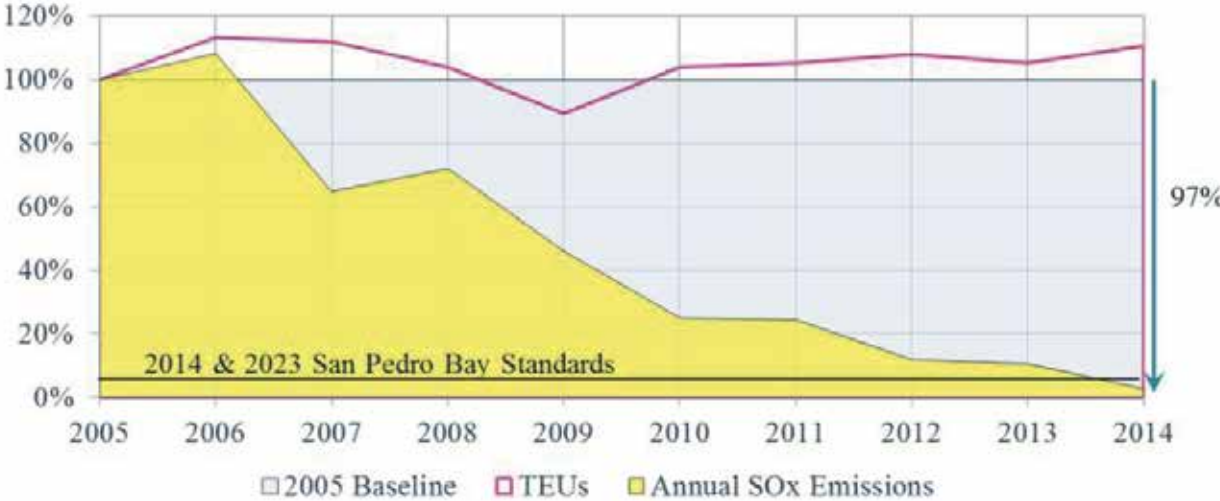


Figure 3.14: 2005-2014 POLA SO_x emissions reductions

4 Evaluation of results

4.1 Evaluating results of a port emissions assessment

After completing the emissions inventory calculations, evaluation of the results is the next step in understanding operational and emissions patterns of port-related emissions sources, identifying opportunities to reduce emissions and quantifying the expected benefits from emissions reduction strategies. Each emissions source category should be reported individually, breaking major source categories into sub-categories where appropriate. In addition, it is important to report emissions by operational mode, as some emissions reduction strategies may only be effective for certain modes of operation. Understanding fleet characteristics for each source sub-category is important to determine whether there are significant numbers of older, dirtier emissions sources. Reporting on characteristics such as population, energy consumption and emissions are important to understand how sources are operating and contributing to emissions. Through this type of analysis, cost-effective emissions reduction options can be identified.

For example, the Port of Los Angeles conducted an inventory analysis focused on cargo handling equipment to better understand fleet make up, energy consumption and emissions contributions to determine if there were any further cost-effective emissions reduction measures on which to focus additional reduction efforts. First, all of the units of CHE equipment included in the emissions assessment were grouped by engine type: non-road diesel, on-road diesel, propane, other and electric, as presented in Figure 4.1.

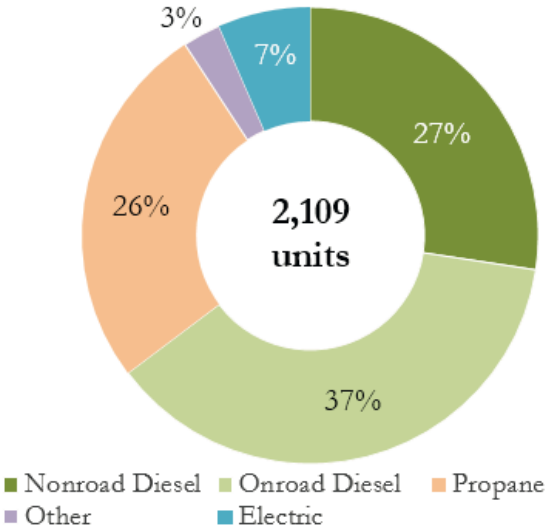


Figure 4.1: 2015 POLA cargo handling equipment counts, by engine type

It became clear that most of the port’s cargo handling equipment is made up of diesel and propane-powered engines, with diesel-powered engines making up 64% of the equipment population.

Further, energy consumption, in gigawatt-hours (GWh), for all engine types (excluding electric-powered equipment) was evaluated, as presented in Figure 4.2.

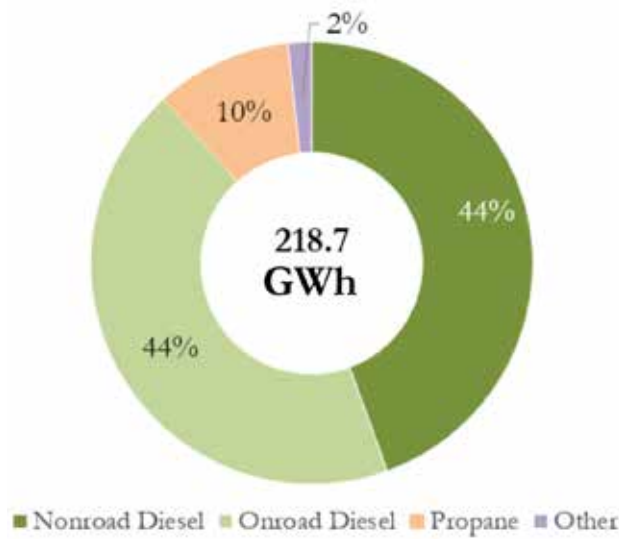


Figure 4.2: 2015 POLA cargo handling equipment energy consumption, by engine type

While 64% of the equipment is diesel-powered, that same equipment was responsible for 88% of the work (in kWh) in 2015, while propane-powered equipment contributed 10% of the total work. Diesel-powered equipment dominates the cargo handling work at POLA. However, work is split evenly at 44% between on-road diesel and non-road diesel engines, due to emissions reduction strategies and regulations mandating the introduction of cleaner on-road diesel engine equipment into cargo handling operations. Note, in California on-road diesel engines are subject to more stringent emissions standards compared to non-road diesel engines built in the same year.

Additionally, NO_x emissions contributions were evaluated by engine type, as presented in Figure 4.3.

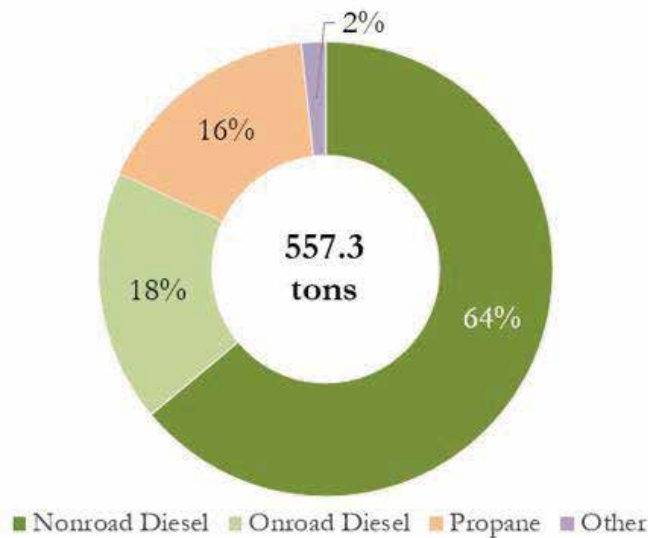


Figure 4.3: 2015 POLA cargo handling equipment NO_x emissions, by engine type

While non-road and on-road diesel engines each covered 44% of the work in 2015, their NO_x emissions contributions were significantly different. Non-road diesel engines contributed 64% of NO_x emissions compared with 18% from on-road diesel engines for the same amount of work. Therefore, it became apparent that additional reduction strategies should be considered for the remaining non-road equipment or it should be replaced by on-road equipment wherever possible. Also noted was the fact that propane engines contributed 16% of the total NO_x emissions while doing 10% of the work, showing that they are not the cleanest option for NO_x and should be considered candidates for reduction strategies similar to those being considered for replacement of similar diesel equipment.

Looking further at just diesel and propane powered CHE, the port evaluated non-road diesel energy consumption and emissions by non-road engine NO_x emissions standards implemented over years in phases, as presented in Figures 4.4 and 4.5. In the US, there are five engine tiers for non-road engines. The higher the engine tier, the lower the NO_x emissions. The engine tiers are designated as EPA Tier 0 (T0), Tier 1 (T1), Tier 2 (T2), Tier 3 (T3), Tier 4 interim (T4 int) and final Tier 4 (T4 fin). Energy consumption and NO_x emissions for non-road CHE by engine type and tier are shown in Figures 4.4 and 4.5.

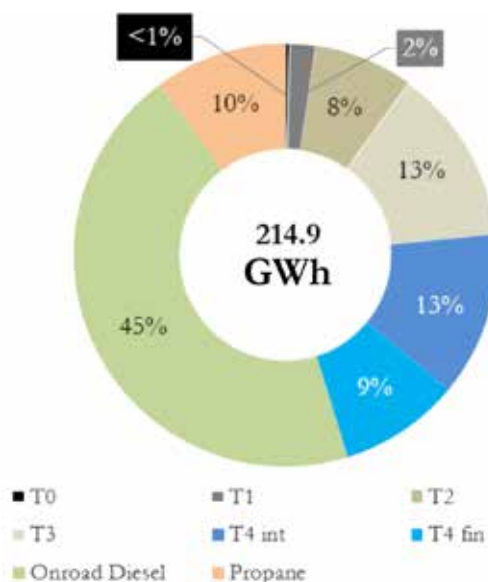


Figure 4.4: 2015 POLA cargo handling equipment energy consumption, by engine type & US EPA non-road diesel engine tier

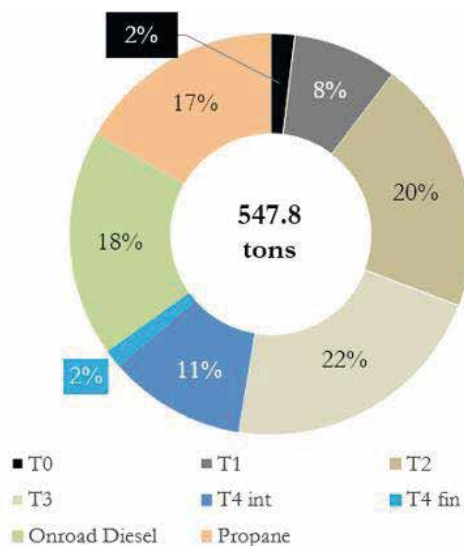


Figure 4.5: 2015 POLA cargo handling equipment NO_x emissions, by engine type & US EPA non-road diesel engine tier

Note that while the non-road T0, T1 and T2 engines used a combined total of less than 11% (Figure 4.4) of the total energy consumption in 2015, their NO_x emissions contribution was significantly higher at 30% (Figure 4.5). For example, T0 engines, using less than 1% of the total energy for the group, accounted for 2% of NO_x emissions, the same mass of emissions as T4 fin engines, which used 9% of the total energy. Similarly, T1 engines used 2% of the total group energy while emitting 8% of the total group's NO_x emissions. The same trend of lower energy consumption with higher emissions contributions can be seen in T2 and T3 non-road engines. The result of this type of analysis clearly demonstrates the need to target additional emissions reduction strategies on T0-T3 non-road engines.

4.2 Comparing the results of a port emissions assessment

Two types of comparisons are commonly made with port emissions assessments: comparing the same port on a year-over-year basis and comparing two different ports.

Year-over-year

Comparing emissions from the same port year-over-year shows how well the port is progressing from an emissions standpoint for the entire port as well as by emissions source categories. The preferred approach for undertaking year-over-year comparisons when there have been changes in methodology is to recalculate the previous year’s emissions using the activity and operational data from the previous year, applying the methods that are being used for the current year. This is a relatively sophisticated approach that requires a considerable amount of prior planning to achieve success. An alternative approach is to develop correction factors to adjust for method and factor changes between emissions assessments.

Comparing port emissions assessments on a year-over-year basis can provide context to help visualise the underlying reasons why emissions are changing, including the introduction of cleaner equipment through fleet turnover and other temporal factors, including changes in the economics of global trade. As an example, using the 2015 POLA cargo handling equipment analysis from Figure 4.2, Figure 4.6 presents the energy consumption in GWh for the same engine types from 2005 to 2015.

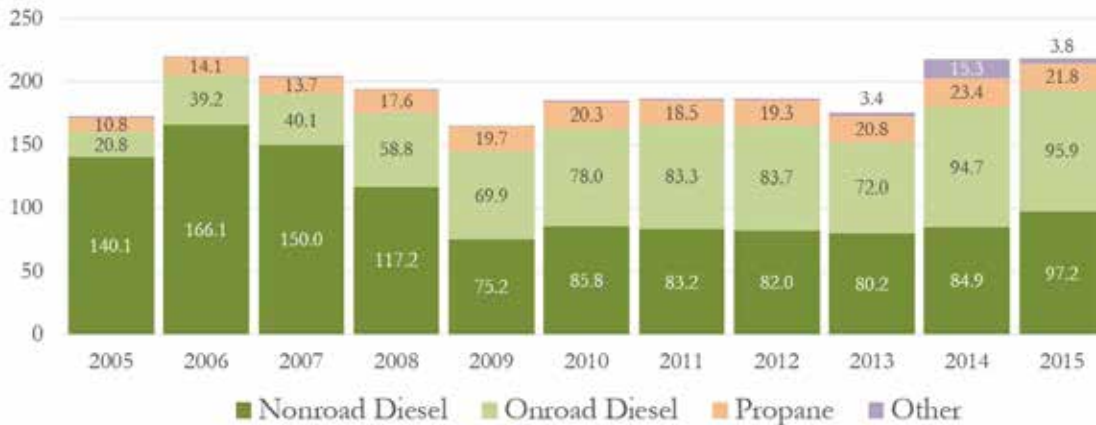


Figure 4.6: 2005-2015 POLA cargo handling equipment energy consumption, by engine type, GWh

Until 2009, higher-emitting non-road diesel engines dominated the work performed by cargo handling equipment at the port. Focusing on just non-road diesel engines, due to their emissions contribution to the group as presented in Figure 4.5 above, the effect of fleet turnover on the distribution of energy consumption (in GWh) by tier is illustrated in Figure 4.7 below.

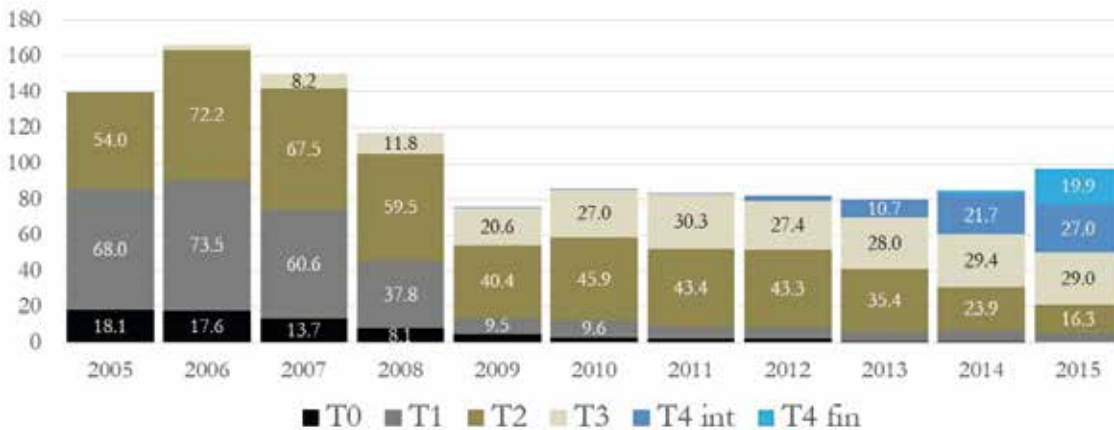


Figure 4.7: 2005-2015 POLA cargo handling equipment energy consumption, by US EPA non-road diesel engine tier, GWh

Note that values of less than 8 GWh are not displayed. The figure illustrates the dramatic turnover from older, high-emitting low-tier engines to newer, lower-emitting higher-tier engines. This turnover resulted from actions taken at the terminal, port and state levels. The figure also shows that, since 2012, interim Tier 4 (T4 int) and final Tier 4 (T4 fin) engines have increased energy consumption. This increase, which along with reductions in energy usage among the Tier 0 and Tier 1 engines, has resulted in significant overall emissions reductions since 2005, as shown in Figure 4.8.

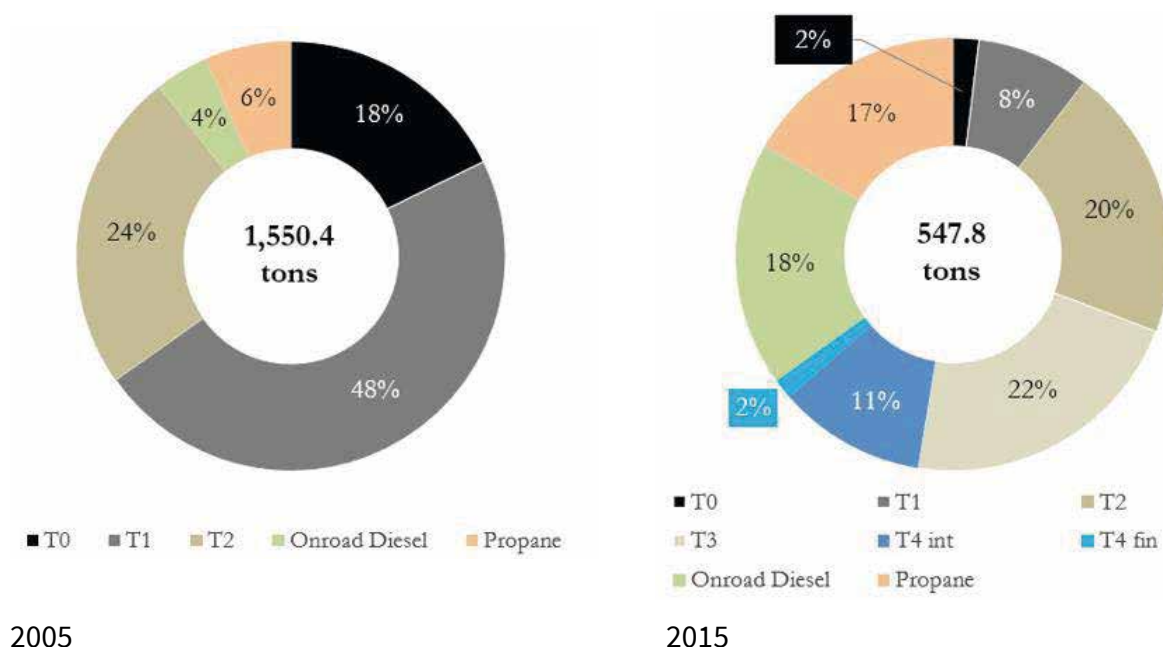


Figure 4.8: 2005 vs 2015 POLA cargo handling equipment NO_x emissions, by engine type & US EPA non-road diesel engine tier, tons

The centre of each doughnut indicates total emissions for the group. Each section of the doughnut represents the percentage contribution by individual tier. By comparing the two doughnuts, one can see that there has been a dramatic reduction in total emissions between 2005 and 2015, and that the individual contribution by tiers has shifted dramatically as well, reflecting fleet turnover.

Comparing two different ports

It is tempting to compare one port to another or multiple ports to each other. From a comparability perspective, this is highly problematic since each emissions inventory is tailored to a port, based on port-specific drivers, level of detail, geographical and operational boundaries, data quality, methods used, years inventoried and numerous other factors. Since an emissions inventory is the foundation for emissions metrics and emissions forecasts, it is not advisable to compare published port emissions inventories without fully considering and documenting the differences between each of the inventories.

5 Resources

As noted above, the field of port emissions assessment is both diverse and evolving as more and more ports engage in addressing and reducing air pollutant and greenhouse gas emissions. This section provides a list of resources that were used to develop this Guide and that can assist those conducting an assessment. Resources have been divided into ports that have conducted port emissions assessments and published reports that informed this Guide.

Ports conducting emissions assessments

A diverse selection of port emissions assessments over the past two decades has advanced the understanding and refined the approaches to quantifying emissions, developing metrics and conducting forecasts. The following list contains published port emissions assessments, which have details related to the approach, domains, emissions sources and methods used. This list is not comprehensive and there are several other ports working on port emissions assessments that have not been published.

- IAPH, Carbon Footprinting for Ports, Guidance Document, World Ports Climate Initiative, 2010.⁶² This guidance document was developed under the carbon footprinting project under WPCI, led by the Port of Los Angeles and co-developed with ports of Amsterdam, Antwerp, Houston, Long Beach, New York and New Jersey, Oakland, Oslo, Rotterdam, Seattle and the Finnish Port Association. The IAPH guidance document focuses only on carbon-related emissions and covers all port-related emissions sources. The guidance document was developed in a collaborative approach under the WPCI Carbon Footprinting Working Group, by ports seeking to establish common approaches and methods to estimating carbon emissions from port-related sources.
- **Port of Los Angeles**⁶³ – annual emissions inventories, department carbon inventories, expanded inventories, forecasts, etc.
- **Port of Long Beach**⁶⁴ – annual emissions inventories, department carbon inventories, forecasts, etc.
- **Port of New York & New Jersey**⁶⁵ – annual emissions inventories
- **Puget Sound Maritime Air Forum**⁶⁶ – periodic multiport emissions inventories
- **Port Everglades**⁶⁷ – baseline emissions inventory
- **Port of Vancouver**⁶⁸ – periodic emissions inventories
- **Port of Oakland**⁶⁹ – periodic emissions inventories

⁶² See https://www.wpci.iaphworldports.org/data/docs/carbonfootprinting/PV_DRAFT_WPCI_Carbon_Footprinting_Guidance_Doc-June-30-2010_scg.pdf cited March 2018.

⁶³ See https://www.portoflosangeles.org/environment/studies_reports.asp cited March 2018.

⁶⁴ See <https://www.polb.com/environment/air/emissions.asp> cited March 2018.

⁶⁵ See <https://www.panynj.gov/about/port-initiatives.html> cited March 2018.

⁶⁶ See <https://www.pugetsoundmaritimeairforum.org/> cited March 2018.

⁶⁷ See <https://www.porteverglades.net/environment/air-quality/> cited March 2018.

⁶⁸ See <https://www.portvancouver.com/environment/air-energy-climate-action/clean-air-strategy/> cited March 2018.

⁶⁹ See <https://www.portofoakland.com/community/environmental-stewardship/maritime-air-quality-improvement-plan/> cited March 2018.

Published reports

The following list contains published reports that have informed preparation of this Guide. This is not a complete list but contains much of the material referenced herein.

- Daniel Mueller, Stefanie Uibel, et al., 2011. *Ships, Ports and Particulate Air Pollution – An Analysis of Recent Studies*; J Occup Med Toxicol. 2011; 6: 31. Published online 2011 Dec 5. doi: 10.1186/1745-6673-6-31.
- Sebastian Oeder, Tamara Kanashova, et al., 2015. *Particulate Matter from Both Heavy Fuel Oil and Diesel Fuel Shipping Emissions Show Strong Biological Effects on Human Lung Cells at Realistic and Comparable In Vitro Exposure Conditions*; PLoS One. 2015; 10(6): e0126536.
- IMO 2015a. *Third IMO GHG Study 2014*; International Maritime Organization (IMO) London, UK, April 2015.
- IMO 2015b. *Study of Emission Control and Energy Efficiency measures for Ships in the Port Area*; International Maritime Organization (IMO) London, UK, February 2015.⁷⁰
- IPCC 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 2: Stationary Combustion*; Prepared by the National Greenhouse Gas Inventories Programme; Published: IGES, Japan.⁷¹
- IPCC 2007. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.⁷²
- POLA and POLB 2008. *San Pedro Bay Ports Yard Tractor Load Factor Study Addendum*; Port of Los Angeles and Port of Long Beach, December 2008.
- POLA and POLB 2009. *Rubber Tired Gantry Crane Load Factor Study*; Port of Los Angeles and Port of Long Beach, November 2009.
- SPBP 2017a. *San Pedro Bay Ports Clean Action Plan 2017, DRAFT – Bay Wide Ocean-going Vessel International Maritime Organization Tier Forecast 2015-2050*; San Pedro Bay Ports, July 2017.⁷³
- SPBP 2017b. *San Pedro Bay Ports Clean Action Plan 2017, Final Clean Air Action Plan Update*; San Pedro Bay Ports, November 2017.⁷⁴
- WRI and WBCSD 2004. *GHG Protocol Corporate Accounting and Reporting Standard. Revised Edition*; World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), 2004.⁷⁵
- WRI 2014a. *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*; World Resources Institute (WRI), 2014.⁷⁶
- WRI 2014b. *GHG Protocol Mitigation Goal Standard. An Accounting Standard for National and Subnational Greenhouse Gas Reduction Goals*; World Resources Institute (WRI), 2014.⁷⁷

⁷⁰ See <https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/Port%20Area.pdf>

⁷¹ See https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

⁷² See https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

⁷³ See <https://www.cleanairactionplan.org/documents/vessel-forecast-draft.pdf>

⁷⁴ See <https://www.cleanairactionplan.org/documents/2017-final-clean-air-action-plan-update.pdf>

⁷⁵ See <https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf>

⁷⁶ See https://ghgprotocol.org/sites/default/files/standards/GHGP_GPC_0.pdf

⁷⁷ See <https://ghgprotocol.org/mitigation-goal-standard>

Additional resources

1 **EMEP/EEA Air Pollution Emission Inventory Guidebook (2016 edition)**

<https://www.eea.europa.eu/publications/emep-eea-guidebook-2016>

- Each emissions source has a specific code (the so-called ‘NFR’) to harmonise the emissions inventory reporting.
- Scroll down the general webpage to get the specific guidance for different emissions sources, e.g. for non-road mobile machinery: <https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-4-non-road-1/view> or railways: <https://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-3-c-railways-2016/view>
- The Guidebook is mandatory for all EU Member States and for the Parties to the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Trans boundary Air Pollution (LRTAP).

2 **Emission factor database**

http://efdb.apps.eea.europa.eu/?source=%7B%22query%22%3A%7B%22match_all%22%3A%7B%7D%7D%2C%22display_type%22%3A%22tabular%22%7D

- Structured by NFR code, see for instance for railways: http://efdb.apps.eea.europa.eu/?source=%7B%22query%22%3A%7B%22bool%22%3A%7B%22must%22%3A%5B%7B%22term%22%3A%7B%22code%22%3A%221.A.3.c%20Railways%22%7D%7D%5D%7D%7D%2C%22display_type%22%3A%22tabular%22%7D

3 **UNECE Convention on Long Range Transboundary Air Pollution (LRTAP)**

<https://www.unece.org/env/lrtap/welcome.html>

- For guidance on emissions reporting, including guidance on the reporting of emissions projections, under the Convention see: <https://www.unece.org/environmental-policy/conventions/envlrtapwelcome/guidance-documents-and-other-methodological-materials/emissions-reporting.html>

4 **Centre on Emission Inventories and Projections (CEIP)**

<http://www.ceip.at/>

- **Latest reported emissions inventories by parties to the LRTAP Convention**
http://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting/2018_submissions/
- **Reporting of gridded emissions data** (in geographic coordinate system:
http://www.ceip.at/ms/ceip_home1/ceip_home/new_emep-grid/)

5 **Reported emissions inventories by EU Member States and Parties to the LRTAP Convention**

- On the European Environment Agency’s (EEA) Central Data Repository: <http://cdr.eionet.europa.eu/>
- Example of emissions inventory of the Netherlands: <http://cdr.eionet.europa.eu/nl/un/clrtap/>

6 **IAPH WPCI Onshore Power Supply**

<http://wpci.iaphworldports.org/onshore-power-supply/library/>

- Contains guidance and examples of cold ironing in different ports.

7 **European Commission report on the implementation and compliance with the sulphur standards for marine fuels**

http://ec.europa.eu/environment/air/pdf/report_sulphur_directive.pdf

- Section 7.3 of the report: In accordance with Article 19 of Directive 2003/96/EC on taxation of energy products and electricity, Member States can be authorised to apply a reduced rate of taxation on electricity provided to ships at berth which can encourage shipowners to invest in the necessary onboard equipment to use electricity from the land grid instead of from marine fuels. A number of Member States have already made use of this authorisation: e.g. Germany, Sweden and Denmark (respective Council Implementing Decisions: 2014/722/EU of 14 October 2014, 2014/725/EU of 14 October 2014 and (EU) 2015/993 of 19 June 2015).

8 Overview of EU source control legislation

<http://ec.europa.eu/environment/air/reduction/legislation.htm>

- The relevant EU source-based air pollution control legislative acts are identified here:
[http://ec.europa.eu/environment/air/pdf/Union source legislation overview 4 October 2017.xlsx](http://ec.europa.eu/environment/air/pdf/Union_source_legislation_overview_4_October_2017.xlsx)

9 EU study on differentiated port infrastructure charging to promote environmentally friendly maritime transport

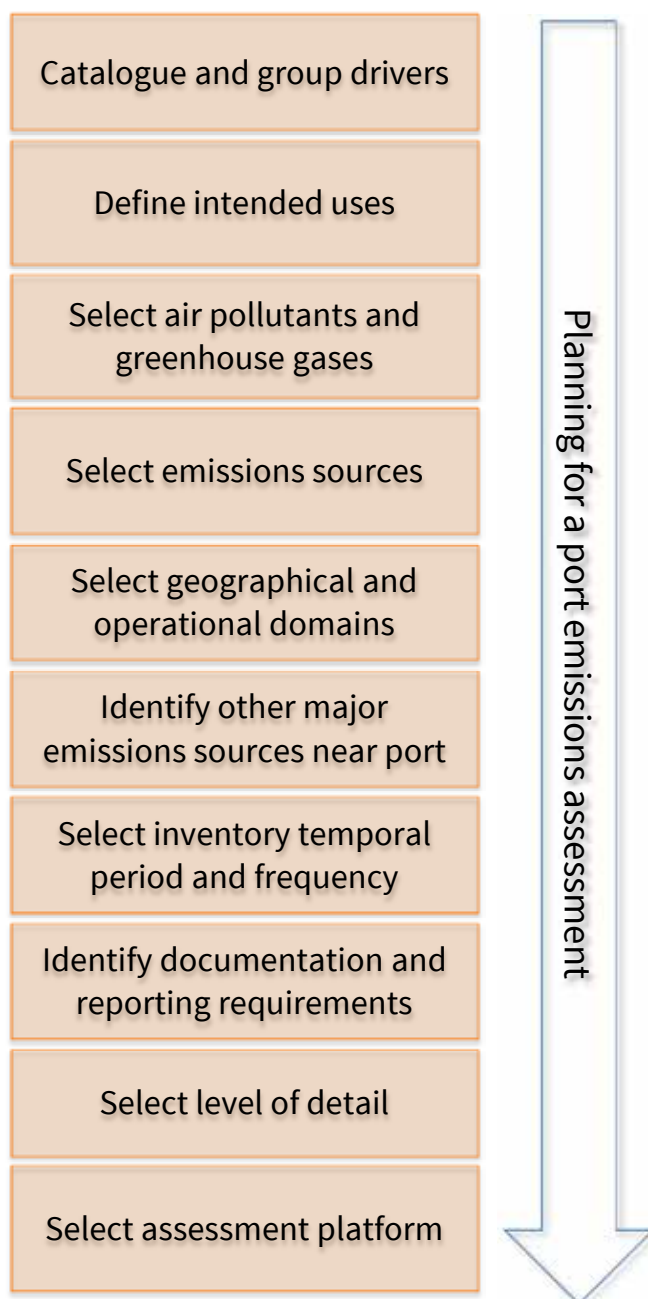
- Differentiated port infrastructure charges to promote environmentally friendly maritime transport activities and sustainable transportation.
Final report: <https://ec.europa.eu/transport/sites/transport/files/2017-06-differentiated-port-infrastructure-charges-report.pdf>
Executive summary: <https://ec.europa.eu/transport/sites/transport/files/2017-06-differentiated-port-infrastructure-charges-exec-summary.pdf>

10 Organization for Economic Co-Operation (OECD) study on reduction of GHG emissions from ships

<https://www.itf-oecd.org/reducing-shipping-ghg-emissions>

Annex 1

Port emissions assessment planning checklist



Planning steps for a port emissions assessment

Catalogue and group drivers

- High drivers List: _____
- Medium drivers List: _____
- Low drivers List: _____

Define intended uses

- Internal
- External
- Environmental regulatory agency
 - Compliance purposes

Select air pollutants and greenhouse gases

Air pollutants:

- Oxides of nitrogen (NO_x)
- Particulate matter (PM)
 - PM <10-microns (PM10) and
 - PM fines <2.5-microns (PM2.5)
 - Diesel PM (DPM)
- Oxides of sulphur (SO_x)
- Volatile organic compounds (VOCs)
- Carbon monoxide (CO)

Greenhouse gases/climate change pollutants:

- Carbon dioxide (CO₂)
- Nitrous oxide (N₂O)
- Methane (CH₄)
- Carbon dioxide equivalents (CO₂e)

Select emissions sources

- Seagoing vessels
- Domestic vessels
- Cargo handling equipment
- Heavy-duty vehicles
- Locomotives
- Light-duty vehicles
- Others
- Electrical grid
- Administrative offices

Select geographical and operational domains

- Geographical Describe: _____
- Operational Describe: _____
- GHG domain Describe: _____

Identify other major emissions sources near port

- Major non-port sources in geographical domain List: _____

Select inventory temporal period and frequency

- Inventory year List: _____
- Assessment frequency (optional) List: _____

Identify documentation and reporting requirements

- Documentation and reporting requirements List: _____

Select level of detail

- Scaled Sources: _____
- Screening Sources: _____
- Comprehensive Sources: _____

Select assessment platform

- Spreadsheets Name: _____
- Desktop database software Name: _____
- Server-based multi-user RDBMS Name: _____
- Off-the-shelf tool Name: _____



MORE INFORMATION?

GloMEEP Project Coordination Unit
International Maritime Organization

4 Albert Embankment,
London SE1 7SR, United Kingdom

<http://glomeep.imo.org>