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Port of Yangpu emissions inventory report using the goPEIT model

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Introduction and background

Ports are hubs of international trade, where ships gather to load and unload cargo, gantry cranes and forklifts work around the clock to move cargo around the port grounds, and trucks and locomotives deliver cargo for shipping or pick up cargo bound for inland destinations. All this equipment consumes energy and can emit air and climate pollutants, causing public health concerns for nearby communities. China is the largest trading nation on the planet and is home to seven of the 10 world-leading container ports by cargo capacity (United Nations Conference on Trade and Development, 2021). These ports are all located in highly populated areas (Mao & Rutherford, 2018). In order to understand the environmental and climate impacts of port activities, design port-level clean air programs and national-level policies to reduce them, and then evaluate the effectiveness of these measures, a port emissions inventory is a simple yet powerful tool (Agrawal et al., 2022). However, most Chinese ports lack the data or resources required to conduct port emissions inventories themselves, and only a handful of scholars have published emissions inventories for Chinese ports as part of their research. These studies, performed for the ports of Shenzhen, Shanghai, Tianjin, and Qingdao, focus primarily on ships and have inconsistent definitions of the boundary of port emissions inventories (Liang, Liao, Yan, Zheng, & Xu, 2016; Sun, Tian, Malekian, & Li, 2018; Yang et al., 2021; Zhou et al., 2020).

To enable as many ports as possible to perform emissions inventories, the ICCT collaborated with Transport Canada in 2016 to expand its country-specific port emissions inventory tool (PEIT) into a free online application that can be used by ports around the globe. The global online Port Emissions Inventory Tool (goPEIT)[1] allows users to calculate air and climate pollutant emissions from oceangoing vessels (OGVs), harbor craft, cargo handling equipment (CHE), on-road vehicles, locomotives, and administrative facilities within a defined port boundary. Recently, the ICCT finished a major maintenance update on goPEIT, including an updated ship characteristic database and applicability to years beyond 2015. To demonstrate the functionality of the goPEIT tool, we undertook a study to determine the 2019 emissions inventory for

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1 goPEIT can be accessed here: https://gopeit.org/. Access is granted on an individual basis upon request.

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Port of Yangpu. A step-by-step user guide illustrating how goPEIT was applied and its underlying assumptions is provided in the appendix.

The Port of Yangpu was selected for our emissions inventory for two reasons. First, the designation of Port of Yangpu as a Hainan Free Trade Port in 2020 is expected to result in a dramatic increase in ship traffic in the coming years (China Transportation News Network, 2022). Determining the port's baseline emissions profile and possible trajectory of future emissions through the use of the goPEIT tool can assist the port in making environmentally responsible development plans. Second, we see great potential for Port of Yangpu to become a pilot zero-emission port by 2050. Under the existing Domestic Emission Control Area (DECA) policy framework, Hainan has the nation's most stringent marine fuel sulfur limits on all visiting ships and the most advanced marine engine standards for all China-flagged visiting ships since 2022 (Mao, 2016). Port electrification would achieve even larger climate benefits as Hainan has committed to decarbonizing its grid and achieving the concentration level for fine particulate matter ($PM_{2.5}$) recommended by the World Health Organization of 5 $\mu g/m^3$ by 2035 (Cui, He, Huang, & Wang, 2021). Additionally, after being designated as a National Ecological Civilization Pilot Zone in 2019 and with the rollout of China's 2030 carbon-peaking target (Mao & Meng, 2022), Hainan has ramped up its efforts to establish or expand "Near-Zero Emission Zone" projects on the island (National Development and Reform Commission, 2022). Among the candidate zones that bear great demonstrative potential, ports stand out as they are emission hot spots with a clearly defined administrative boundary and regulatory authority.

In the following sections, we first introduce how we collect data for inputs into goPEIT and provide a brief overview of how goPEIT translates those inputs into emissions inventory results. We then define each emission source group and present their emission results. Finally, we discuss how this emissions inventory could help the port and its regulators to make informed decisions on environmentally responsible development plans for the next decade.

Data and methods

We developed a quantitative port emissions inventory using the number of vessels, vehicles, and equipment operating in a defined port area, along with data on their operational activity combined with appropriate emission factors obtained from reliable sources including the International Maritime Organization (IMO) and the U.S. Environmental Protection Agency (Table 1). In goPEIT, a generic port boundary is defined in Figure 1, and the general method for calculating emissions is described in Equation 1.

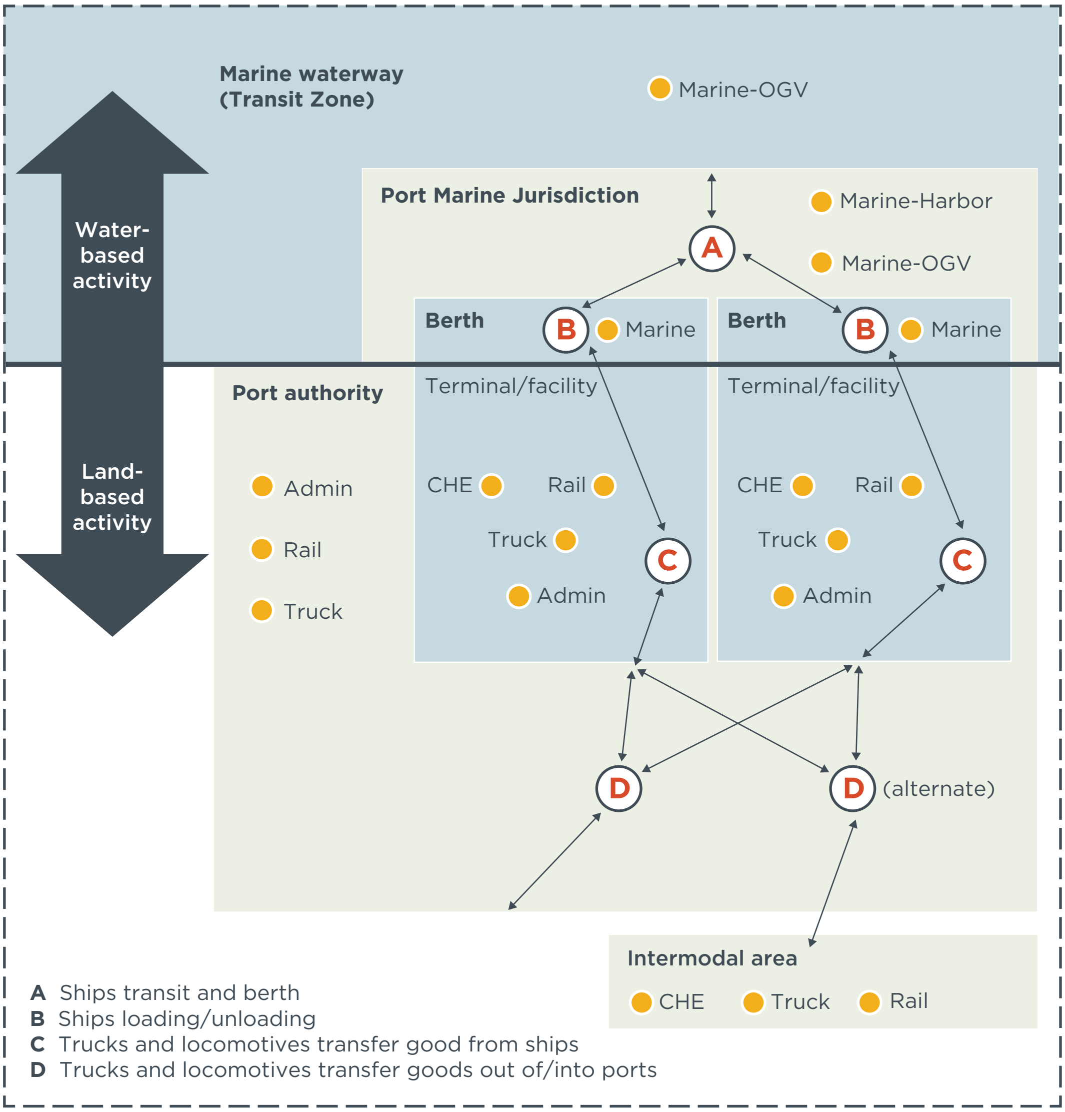

Figure 1. Generic diagram of a port boundary (adapted from SNC-Lavalin Inc., Environment & Water, 2013)

$$Emissions = Activity \times Emission\ Factor \qquad \text{(Equation 1)}$$

In this equation, *Activity* can take different forms but usually includes hours of engine use and/or distance traveled. Five broad emission source groups are included in goPEIT: vessels, which include oceangoing vessels and harbor craft, cargo handling equipment, on-road vehicles, locomotives, and administrative facilities, which include buildings and compound lighting. *Emission Factor* is dependent on three broad inputs: fuel characteristics, engine characteristics, and emission control policies. In the current version, goPEIT can only be used to estimate direct emissions within the port boundary, but upstream emissions from fuel production and transportation, as well as emissions from grid-connected electricity, will be included in future updates. Emission control policies considered by default are regulations under the Emission Control Areas designated by the IMO. For specific regional policies, such as the fuel sulfur limits applicable to all ships visiting Hainan ports, the applicable emission factors are entered in the user-defined value section within goPEIT.

The quality of input data is paramount for the quality of port emission inventories. To reduce the difficulty of data collection for terminal and port operators, goPEIT contains a ship characteristics database and a series of default values that can be used to approximate emissions (Table 1). The following subsections describe how data was collected, our assumptions, and the default values provided by goPEIT that were used to generate an emissions inventory for Port of Yangpu in 2019.

Table 1. List of goPEIT built-in data inputs

Inputs	Usage	Sources
Ship characteristics (e.g., engine power, ship speed, etc.)	To estimate emissions from OGVs and harbor craft	IHS maritime ship database, updated periodically.[a] IMO number is needed to enable internal matching to get ship characteristics.
Greenhouse gas (GHG) emission factors for various equipment and fuel type combinations	To estimate GHG emissions from various sources	OGV and harbor craft: Fourth IMO GHG study (Faber et al., 2020) Other sources: Environment Canada National Inventory Report 1990-2010 (Environment Canada, 2012). Details can be found in the appendix.
Criteria air pollutant emission factors for various equipment and fuel type combinations	To estimate criteria air pollutant emissions from various sources	OGV and harbor craft: Fourth IMO GHG study (Faber et al., 2020) CHE: U.S. EPA NONROAD 2008 Model (U.S. EPA, 2009c) Locomotive: U.S. EPA locomotive emission factors (U.S. EPA, 2009a) On-road vehicle: EPA MOVES 2010b Model (U.S. EPA, 2009b) Admin: mainly from U.S. EPA regulations Details can be found in the appendix.
Duty cycles for vessels, on-road vehicles, and locomotives	To enable activity-based calculation of emission estimates for different activity modes	OGV and harbor craft: IMO 4th GHG study (Faber et al., 2020) On-road vehicle: EPA MOVES 2010b Model (U.S. EPA, 2009b), this can be re-defined by the user Locomotive: Canada national average duty-cycle, this can be re-defined by the user. Details can be found in the appendix.

[a] IHS Markit merged into S&P Global in 2022.

General information about Port of Yangpu

Port of Yangpu is located on the northwest coastline of Hainan Province, facing the west entry point of Qiongzhou Strait (Figure 2). According to statistics released in the China Ports Yearbook (2020), the Port of Yangpu mainly handles three types of cargo: dry bulk (such as iron and ore), liquid bulk (such as crude oil and liquified natural gas) and containers. In 2019, the port's annual cargo throughput was approximately 50 million tonnes. There are two container terminals within the port boundary. Guotou Terminal is equipped with eight berths with a designed annual throughput capacity of 660,000 twenty-foot equivalent units (TEUs) servicing mostly domestic routes. Xiaochantan Terminal is relatively larger with a designed annual throughput capacity of 1.6 million TEUs servicing both international and domestic routes. In 2019, Port of Yangpu handled 700,000 TEUs in total, and the port plans to increase its volume to 5 million TEUs by 2025.[2] At present, there are no railways operating on the port grounds. The basic information on the port was collected from publicly available sources including the port's website, news coverage and China Ports Yearbook, as well as internally communicated information from port visits and interviews with people who have knowledge of the port. If the port authority were to perform the port emissions inventory, which should be the default usage scenario for goPEIT, this information should be easily available.

2 This information is from internal communication with the Vehicle Emissions Control Center, which conducted an internal emissions inventory study for Port of Shenzhen in 2015.

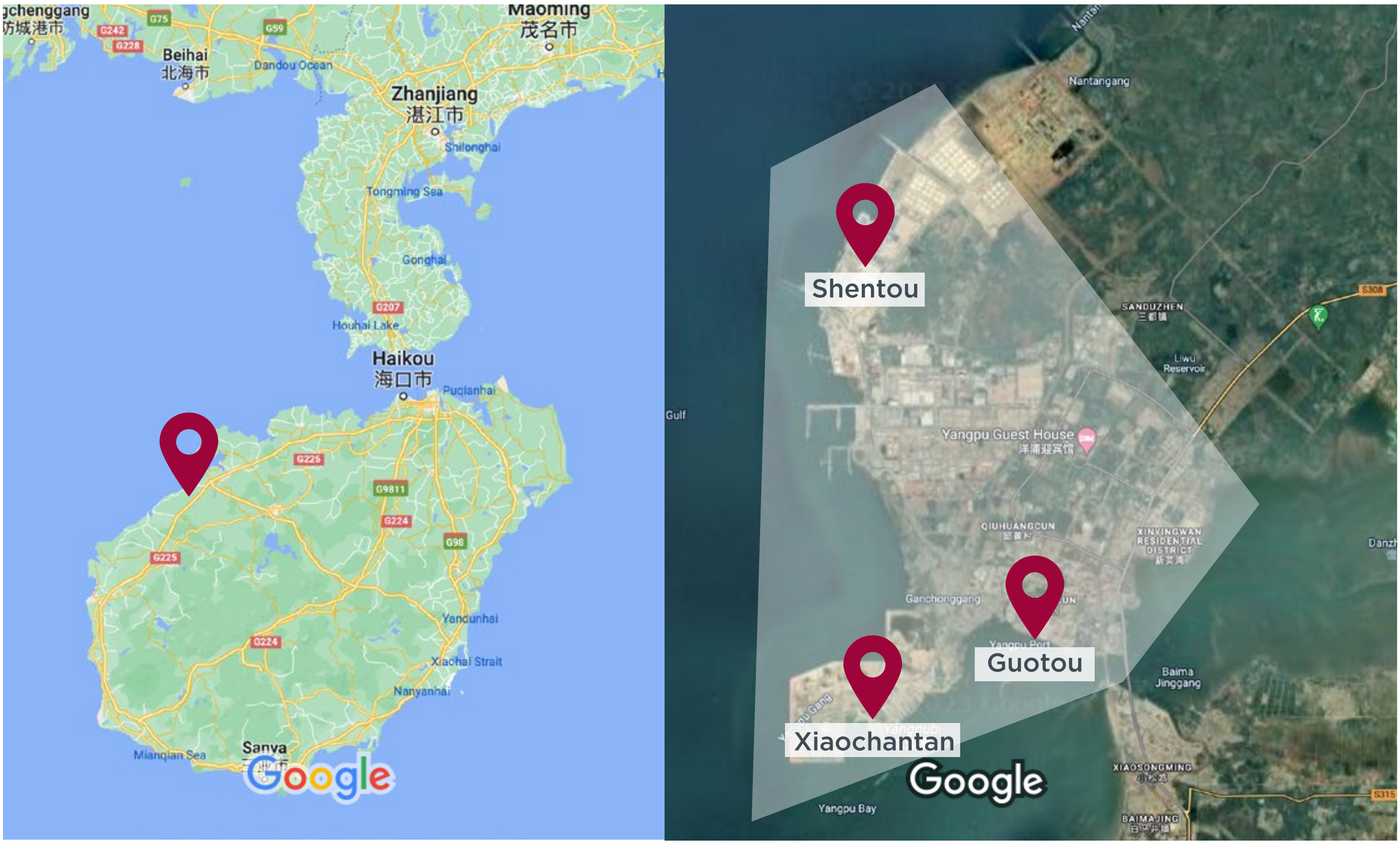

Figure 2. Location of Port of Yangpu and the port boundary for this study. The Guotou and Xiaochantan terminals are container terminals and Shentou is a crude oil terminal.

Vessels

We used Automatic Identification System (AIS) data to identify ships that called on the Port of Yangpu to load and unload cargo (oceangoing vessels) and ships that were operating within the port's boundary (harbor craft) in 2019 and estimated their activity levels within the port boundary. The port boundary includes water and land areas (Figure 2), so vessel activities include time cruising, at anchor, and at berth. According to real-time vessel traffic patterns around the port boundary,[3] the cruising distance of a vessel was approximately 1.5 nautical miles. Since goPEIT contains a ship characteristics database that only pertains to those registered with IMO numbers,[4] the domestic fleet, including coastal and river vessels, are excluded from this study, yet their emissions might not be negligible (Mao & Rutherford, 2018). If the port authority were to perform the port emissions inventory, fleet and activity information should be readily available to them so that AIS data is not required. Users of goPEIT who wish to include the port's domestic fleet can enter details of the ships as well as their fuel consumption data in the harbor craft category of goPEIT to account for their emissions.

Cargo handling equipment

The list of cargo handling equipment for Port of Yangpu shown in Table 2 was obtained from China Ports Network (www.chinaport.com, n.d.). Through personal communication with the Vehicle Emission Control Center, which paid an official visit to Port of Yangpu in 2020, we learned that as of 2019 all equipment used diesel fuel. Due to data limitations, we used the port's annual container and cargo throughput

3 This is viewable on a real-time basis via marinetraffic.com.
4 The number is a unique identifier for international vessels.

data to linearly infer fuel consumption for cargo-handling equipment based on the 2010 emissions inventory for cargo handling equipment in Port of Shanghai (Tan, Liu, Shen, & Fang, 2013). We estimated that cargo handling equipment in Port of Yangpu burned 2,710 tonnes of regular diesel in 2019. This information should be available to the port authority if they were to perform the emissions inventory. To estimate emissions from cargo handling equipment, goPEIT uses the U.S. EPA NONROAD 2008 emissions model. This model includes default emission factors for each specific piece of equipment by size and age, which were developed assuming the average annual hours of operation of the U.S. fleet statistics data in the model.

Table 2. List of cargo handling equipment in Port of Yangpu

Equipment type	Equipment count	Equipment capacity
Gantry cranes	14	40 tonnes
Rubber tire cranes	11	25 tonnes
Tractors/loaders	65	---[a]
Forklifts	16	---
Chassis stackers	10	---
Reach stackers	6	45 tonnes
Total	**122**	**---**

[a] This data is not available.

On-road vehicles

Similar to cargo handling equipment, we found little information regarding on-road vehicles active in the Port of Yangpu in the public domain. As a result, we used the emissions inventory report of Port of Shenzhen in 2013[5] to estimate the average number of TEUs carried by a container truck per visit and the average amount of cargo carried by a commercial heavy truck per visit. These values were applied to the annual TEU and cargo throughput of Port of Yangpu in 2019 to infer total number of visits by these trucks. We focused on commercial trucks only, as they are the most active vehicles on the port grounds, although goPEIT can estimate emissions from port-owned vehicles if data is available. To determine the trucks' activity level, we measured the port's terminal ground area, collected the vehicle speed limit at the port (30 km/h), and assumed the goPEIT default vehicle duty cycle. To estimate on-road vehicle emissions, goPEIT uses the U.S. EPA MOVES 2010 model. This model includes default vehicle emission factors generated from national U.S. vehicle populations and annual accumulated mileage values by age and vehicle class. However, a user can define a unique vehicle fleet profile that pertains to the country's specific situation. Table 3 lists what we used as inputs into goPEIT. This information should be readily available to a port authority performing a port emissions inventory.

Table 3. Inputs of on-road vehicles in Port of Yangpu 2019 into goPEIT

Vehicle type	Visits	Distance traveled in port (km)	Average time spent on port ground (hours)
Container truck	214,000	5	0.5
Heavy commercial truck	836,000	5	1.5

5 Data is from internal communication with the Vehicle Emissions Control Center, which conducted an internal emissions inventory study for Port of Shenzhen in 2015.

Results

This section details the results of our port emissions inventory for Port of Yangpu in 2019 using the goPEIT tool. Given data limitations, this port emissions inventory includes emissions from three source groups: vessels, cargo handling equipment, and on-road vehicles. The output from goPEIT for select pollutants is summarized in Table 4.

Table 4. goPEIT output for 2019 port emissions inventory for Port of Yangpu (selected pollutants)

Source group[a]	Criteria air pollutants[b] (tonnes)						Greenhouse gases[c] (tonnes)			Fuel (tonnes)
	SO_X	$PM_{2.5}$	NO_X	CO	BC[d]	VOC	CO_2	CH_4	N_2O	
Vessels	69.1	14.4	231	12.1	2.89	8.78	23,300	0.535	3.06	7,460
Cargo handling equipment	0.0792	6.42	85.8	32.9	---	7.96	8,620	0.477	3.5	2,710
On-road vehicles	0.252	7.96	127	44.4	---	13.6	27,900	1.38	0.105	8,480
Total	**69.4**	**28.8**	**444**	**89.4**	**2.89**	**30.3**	**59,800**	**2.39**	**6.67**	**18,700**

[a] If relevant data is available, goPEIT can estimate emissions from two additional sources: administrative buildings and locomotives.

[b] goPEIT also reports PM_{10} and NMVOC emissions.

[c] By default, goPEIT reports direct GHG emissions on the port ground, meaning electricity-associated emissions are not included. goPEIT will be able to estimate life cycle GHG emissions in the next update.

[d] goPEIT only reports BC emissions for vessels but will be able to report that for all source groups in the next update.

In 2019, vessels, cargo handling equipment, and on-road vehicles consumed over 18,700 tonnes of diesel fuel of varying grades, with vessels and on-road vehicles contributing the majority (88%) of consumption. These two source groups were also responsible for the majority of CO_2 emissions. For SO_X and $PM_{2.5}$ emissions, however, vessels stood out as marine fuels are much dirtier than those used in cargo handling equipment or on-road vehicles in terms of sulfur content. NO_X emissions from vessels were also higher than from on-road vehicles as the NO_X emission standards for marine engines are less stringent than those for on-road vehicles. The next subsections present the detailed results for each source group.

Vessels

Using AIS data and the ship characteristics database in goPEIT, we were able to identify 499 unique oceangoing vessels and 18 harbor craft active in Port of Yangpu in 2019. Their features and activity levels are summarized in Table 5 and Table 6.

Table 5. Features of vessels active in Port of Yangpu in 2019

Ship type		Ship count	Average deadweight tonnage	Average year of built	Average main engine power/kW
OGV	**Chemical tanker**	167	11,800	2010	3,370
	Bulk carrier	143	28,600	2004	5,060
	Oil tanker	91	22,000	2009	4,590
	Container ship	51	27,800[a]	2005	17,200
	General cargo ship	35	2,930	2008	1,030
	Offshore	12	48,000	2015	17,200
Harbor craft	**Ferry**	1	40	2017	1,100
	Service[b]	16	588	2004	5,430
	Fishing	1	---[c]	2014	900

[a] For container ships, the average TEU is 2,100.
[b] 11 of the 16 vessels are tugboats.
[c] Data is not available.

The dominant ship types in Port of Yangpu in 2019 were chemical tankers and bulk carriers, which is consistent with the top cargo handled by the port that year. According to the 2020 Port Yearbook, the top cargo types moved through Port of

Yangpu were crude oil, liquified natural gas, and coal. Only 51 container ships visited the port in 2019, the largest of which can carry 8,800 TEUs at a time. This was likely due to the port's berth-capacity limit. According to the World Port Index 2019 (National Geospatial-Intelligence Agency, 2019), Port of Yangpu's harbor depth is 13 meters, which is required to handle container ships of 5,000 TEUs and higher. In order to reach the port's goal of moving 5 million TEUs by 2025,[6] which is a 6-fold increase from its current level, the port will need to build deeper berths to be able to handle larger container ships.

Table 6. Activity levels of oceangoing vessels active in Port of Yangpu in 2019

Ship type	Time spent at berth[a]/hours	Time spent at anchorage[b]/hours	Average cruising speed/knots	Total distance travelled/km
Bulk carrier	12,000	12,000	5.8	5,500
Chemical tanker	4,500	5,200	5.6	5,400
Container	3,200	2,100	5.6	4,000
General cargo	4,900	8,900	5.5	3,900
Oil tanker	2,600	3,600	5.6	2,800
Offshore	120	240	8.8	300

[a] Time spent at berth is defined as AIS signals with zero speed over ground.
[b] Time spent at anchorage is defined as AIS points with 0-1 knot speed over ground.

The most active ship types in terms of annual distance traveled within the Port of Yangpu in 2019 were bulk carriers and chemical tankers, consistent with the primary cargo types handled by the port of that year. All oceangoing vessels travel at similar speeds within the port, possibly due to a speed limit and the constraint of traffic flow as ships are restricted to designated routes when nearing a port. The offshore vessels travel faster since they service designated offshore oil rigs with a different route than those used for normal cargo-carrying vessels. To estimate fuel consumption and the associated emissions, goPEIT uses input on each ship's time spent at berth and anchorage, as well as the average distance a ship must travel within the port boundary before it starts to berth, which we measure as approximately 1.5 nautical miles, and the average ship cruising speed, which we approximate as 6 knots. For harbor craft, goPEIT uses input on fuel consumption directly instead of activity data. The estimated fuel consumption of harbor craft identified for Port of Yangpu in 2019 is listed in Table 7.

Table 7. Estimated activity and fuel consumption for harbor craft at Port of Yangpu in 2019

Ship class	Total time spent in port/hours	Total fuel consumption/tonnes
Ferry	269	9.57
Service	354	17.4
Fishing	15	0.555
Total	**638**	**27.6**

With the above inputs, goPEIT directly outputs total emissions for eight criteria air pollutants and three GHGs for the entire source group of vessels. Users of goPEIT have the option to output detailed calculation results for each piece of equipment, which can be aggregated to the desired granularity. We present the results aggregated for each ship type in Table 8. Consistent with their activity levels, chemical tankers, bulk carriers, oil tankers, and containers contributed the majority of ship emissions in Port of Yangpu in 2019. Container ships stood out for their criteria air pollutant emissions, even though they were significantly lower in vessel count and total hours spent in port

6 This information was acquired from internal communication with the Vehicle Emissions Control Center, which conducted a survey at Port of Yangpu in 2020.

in 2019 compared with bulk carriers, chemical tankers, and oil tankers. This is possibly because container ships have larger engines and spend more time slow steaming at low engine loads in port, during which diesel engines are much less efficient and much more polluting. For all oceangoing vessels, the majority of emissions were emitted while at berth loading and unloading cargo (34%) and at anchorage waiting for a berth (64%). However, if the study region included a bigger area of water around the port, cruising vessels would have a larger share of emissions.

Table 8. Detailed emissions for each vessel class from goPEIT for Port of Yangpu in 2019

Ship class		Criteria air pollutants[a]/kg						Greenhouse gases/kg		
		SO_x	$PM_{2.5}$	NO_x	CO	BC	VOC	CO_2	CH_4	N_2O
OGV	**Chemical tanker**	20,300	3,560	50,700	2,800	749	1,930	6,740,000	45.1	812
	Bulk carrier	18,500	4,180	69,300	3,470	792	2,560	5,900,000	61.1	831
	Oil tanker	13,200	2,350	37,100	2,060	519	1,420	4,910,000	33.3	581
	Container ship	16,400	4,060	61,900	3,180	758	2,410	5,130,000	57.4	706
	General cargo ship	531	193	9,790	415	56.2	317	460,000	7.77	96.4
	Offshore	45.8	18.1	1,050	123	6.68	68.9	72,900	328	13.7
Harbor craft	**Ferry**	13.1	8.58	577	27.9	3.13	20.7	30,700	0.517	5.48
	Service	45.2	20.8	1,060	52.9	8.56	45.2	55,600	1.04	11.6
	Fishing	0.76	0.498	33.6	1.62	0.18	1.2	1,780	0.03	0.556
Total		**69,100**	**14,400**	**231,000**	**12,100**	**2,890**	**8,780**	**23,300,000**	**535**	**3,060**

[a] goPEIT also reports emissions for NH_3 and PM_{10}.

Cargo handling equipment

Although we had limited data on the equipment details and activity levels for cargo handling equipment in Port of Yangpu in 2019, their fuel consumption should reflect the annual cargo throughput of the port. We present the detailed emission results below in Table 9, although it should be interpreted with caution since default values of the U.S. EPA NONROAD 2008 emissions model were used, which might not be representative of the equipment and how it was used in Port of Yangpu. That said, the total emissions of this source group should be reliable, as they were directly linked with fuel consumption.

Table 9. Detailed emission results of cargo handling equipment for Port of Yangpu in 2019

Equipment type	Fuel consumption /tonnes	Criteria air pollutants[a]/kg					Greenhouse gases/kg		
		SO_x	$PM_{2.5}$	NO_x	CO	VOC	CO_2	CH_4	N_2O
Reach stackers	1,420	41.4	3,970	45,100	14,800	5,360	4,500,000	250	1,830
Gantry cranes	440	12.9	499	16,200	3,760	556	1,400,000	77.6	569
Rubber tire cranes	399	11.7	863	9,580	8,500	855	1,270,000	70.2	515
Tractors/loaders	271	7.92	436	9,340	2,480	636	862,000	47.7	350
Forklifts	99.7	2.91	392	2,890	2,130	304	317,000	17.6	129
Chassis stackers	84.3	2.46	264	2,610	1,190	250	268,000	14.8	109
Total	**2,710**	**79.3**	**6,420**	**85,700**	**32,900**	**7,960**	**8,620,000**	**478**	**3,500**

On-road vehicles

Similar to cargo handling equipment, we had limited data on the equipment details and activity levels of on-road vehicles in Port of Yangpu in 2019. Their emissions should also reflect their fuel consumption, which should reflect cargo throughput of the port. The results are presented in Table 10 by each activity mode. Trucks spent a significant amount of time slowly moving on the port's grounds, so their diesel engines operated less efficiently and emitted more criteria air pollutants and greenhouse gases. However, the split between creep, idle, and transit modes reflects the default duty cycle assumed for trucks moving on port grounds used by the U.S. EPA MOVES 2010 model, which might be different from how trucks were operating in the Port of Yangpu in 2019. The results likely underestimate emissions from on-road vehicles in the port for two reasons. First, we did not account for emissions from port-owned vehicles. Second, in 2019 most heavy-duty vehicles were compliant with China III and IV emission standards for heavy-duty engines, which were less stringent than emission factors used by default in goPEIT.

Table 10. Estimated emissions from trucks at Yangpu Port in 2019

Activity mode	Fuel consumption /tonnes	Criteria air pollutants/kg					Greenhouse gases/kg		
		SO_x	$PM_{2.5}$	NO_x	CO	VOC	CO_2	CH_4	N_2O
Creep	5,030	149	4,780	75,800	27,600	8,430	16,500,000	890	61.3
Transit	2,110	62.6	1,820	29,100	8,950	2,150	6,930,000	211	13.5
Idle	1,340	39.8	1,360	22,400	7,870	3,020	4,410,000	279	30.6
Total	8,480	252	7,960	127,000	44,400	13,600	27,900,000	1,380	105

Discussion and conclusions

In this study, we demonstrated the functionality of goPEIT by performing an annual emissions inventory for Port of Yangpu in 2019. We collected inputs for three major port source groups: vessels, cargo handling equipment, and on-road vehicles. We found that collectively they emitted 69.4 tonnes of SO_X, 28.8 tonnes of $PM_{2.5}$, 444 tonnes of NO_X, and 60,000 tonnes of CO_2 emissions in 2019. Among the three source groups, vessels were the largest contributor of criteria air pollutants (>99% SO_X, 56% $PM_{2.5}$, and 49% NO_X) while on-road vehicles were the largest contributor of GHGs (48%).

At-berth activities from oceangoing vessels contributed 19%–34% of total emissions from vessels, depending on the pollutant. If vessels can use shore power while berthing at the Port of Yangpu, these direct emissions will be eliminated. This is anticipated under the DECA regulations. In addition, emissions from vessels at anchorage could be reduced by optimizing port operations to coordinate ship arrivals so that they spend as little time as possible waiting for a berth. Emissions from harbor craft can be reduced or eliminated by replacing them with battery- or hydrogen-powered ships. For example, in 2021, Lianyungang Port put into use China's first battery-driven tugboat, which is 35.5 meters long with a total battery capacity of about 5,000 kWh (Woldship network, 2021). Electrifying cargo handling equipment is already underway in China. By 2015, the Port of Shenzhen had replaced 70% of diesel consumption from cargo handling equipment with grid-connected electricity.[7] Electrification is also the most promising way to eliminate emissions from on-road vehicles, although hydrogen fuel cells could likely play a role in certain applications (Basma & Rodríguez, 2022). The remaining emissions from cruising vessels can gradually be reduced as the entire shipping industry moves towards decarbonization. Ports can attract cleaner vessels by providing financial incentives, investing in zero-emission fuel bunkering facilities, and committing to green shipping corridors with other port partners.

Port emissions inventories can provide the baseline emissions profiles of a port to diagnose where emissions originate from and to shed light on what control policies could help to reduce those emissions. Annual emissions inventories can also help ports to monitor the progress of clean air programs and evaluate their effectiveness. With goPEIT, these efforts can be integrated with a port's daily management for free and

7 Data collected via internal communication with the Vehicle Emissions Control Center.

without excessive training. If all ports in China use goPEIT, they can report emissions inventories to environmental regulators which can be compared against each other and aggregated to the national level. With goPEIT's designed data access privileges for different types of users, regulators can perform their supervision duties without compromising data confidentiality of port users. In this update, we also adapted goPEIT to a desktop application so that all data can be stored locally, which is another way to ensure data security.

In this study, our primary goal was to demonstrate the functionality of goPEIT. With limited access to data, we were still able to produce a port emissions inventory with goPEIT's default values of characteristics of port equipment activity and emission factors. Port operators would be able to provide port-specific, user-defined emission factor values and duty cycle assumptions of certain emission sources to replace the built-in default values in goPEIT. In this case, the results would more accurately capture the different contributions from each source group. The use of goPEIT can enable as many ports as possible to perform port emissions inventories and allow environmental regulators to design policies to help ports reduce their environmental and climate impacts. The ICCT plans to conduct regular updates of goPEIT to use the most relevant emission factors and consider policy updates for each port source group.

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Appendix: Global Online Port Emissions Inventory Tool user guide

Introduction

The global online Port Emission Inventory Tool (goPEIT) is a free, web-based tool that can calculate air pollution and greenhouse gas emissions associated with port activities. The tool helps users calculate these emissions from oceangoing vessels, harbor craft, cargo handling equipment, on-road vehicles, rail, and administrative facilities within a port or terminal. The ICCT and its contractors developed goPEIT, which is derived from Transport Canada's desktop-based Port Emissions Inventory Tool (PEIT). This guidance covers the methodology of goPEIT, which is largely based on the handbook developed for Transport Canada's PEIT (SNC-Lavalin Inc., Environment & Water, 2013). Video tutorials of goPEIT are available for approved users of goPEIT.

Ports are hotspots of emissions from waterborne transport due to highly concentrated ship traffic, busy cargo handling, and frequent goods movement. Co-located with densely populated communities, port emissions pose a threat to human health and the surrounding ecosystem. As a major energy consumption cluster, a port's carbon footprint could be comparable to a large coal power plant (Transport & Environment, 2022). An emissions inventory is a fundamental yet powerful tool to understand baseline emissions, determine priorities, and evaluate the effectiveness of control measures for ports that want to mitigate their environmental and climate impact. Although many ports have conducted port emissions inventories, few have published detailed reports, and even fewer have done so on a continuous basis.[8] As the scope and method vary for most port emissions inventories, a port-by-port comparison is almost impossible. The U.S. Environmental Protection Agency has published guidelines to generate port emissions inventories for mobile sources that recognize the heterogeneity of port emissions inventories given purpose, scope, data availability, and restraints on resources (United States Environmental Protection Agency, 2022). The purpose of goPEIT is to enable all ports to do port emissions inventories and standardize emissions reporting for convenient access for port regulators.

The goPEIT tool is designed with three tiers of user access. Tier I, or the private user tier, is granted to a terminal operator or a port that has access to all its inputs and outputs; Tier II, the regulator tier, is granted to a terminal or port's regulatory authority that has access to outputs only if access to inputs are not authorized; Tier III, the admin tier, is reserved for the ICCT, which manages the tool free of charge to all users. The tier system allows ports to perform emissions inventories and comply with regulatory report obligations without releasing business-sensitive data.

The scope and functionality of goPEIT is suggested by its full name, global online Ports Emissions Inventory Tool:

- **Global**. Any port can use goPEIT to do port emissions inventories. This is enabled by a wealth of embedded data and default assumptions that are essential for emissions inventories but are sometimes not available to the users. These include:
  - **A ship characteristics database** containing over 10,000 records of individual ships. A user only needs to provide a ship's unique identification number (IMO number or MMSI number) to get the characteristics of the ship required for an emissions estimation.
  - **A ship's default energy consumption profile**, consistent with that used in IMO's 4th Greenhouse Gas Study (Faber et al., 2020). A user only needs to provide a ship's in-port activities (hours and speed) to estimate energy consumption.

8 Notable exceptions include Port of Los Angeles and Port of Long Beach.

    - **A set of default emission factors** consistent with that used in IMO's 4th Greenhouse Gas Study (Faber et al., 2020). Emissions of five criteria pollutants (SO_X, NO_X, PM, CO, VOC, BC) and four greenhouse gases (CO_2, CH_4, N_2O) are calculated automatically.

- **Online.** Any user with a browser connected to the internet can use goPEIT, with no installation required. All inputs and outputs are stored securely in a cloud server. Because it is online, multiple users can log in at the same time to log inputs in different sections, which enables collaboration and improves efficiency.
- **Ports.** The scope of a port emissions inventory is usually defined as the jurisdiction of a port, although it can be specifically defined by the user. Normally, a port's jurisdiction includes a land area and a water area.
    - On the water side, emissions come from vessels. However, goPEIT does not calculate emissions from vessels conducting an innocent passage, meaning only vessels calling on the port for a stop would be accounted for. We include two broad categories of vessels in goPEIT:
        - Oceangoing vessels: These are vessels registered with a unique ID number with the IMO. Please note that goPEIT does not calculate emissions from the domestic fleet due to limited data availability. However, it's possible to obtain a rough estimate of these emissions using the "harbor craft" data.
        - Harbor craft: These are vessels transiting within or near the port boundary, including tugboats, ferries, commercial fishing boats, barges, and pilot boats. Domestic fleets can be treated as "harbor craft" for the purpose of emission estimations if input data is available.
    - On the land side, emissions come from mobile and stationary sources performing port logistics. The following emissions sources are included in goPEIT:
        - Cargo handling equipment: This is mobile or stationary equipment used to load and unload cargo from vessels, like container loaders, gantry cranes, and forklifts.
        - On-road vehicles: These are mainly commercial heavy-duty trucks moving containers in and out of the port boundary. Some port-owned light-duty and heavy-duty vehicles providing transit services can also be included.
        - Rail/locomotives: For ports that have port-owned or commercial locomotives moving cargo in and out of the port boundary, goPEIT can estimate the associated emissions.
        - Administrative buildings: These are stationary emission sources that sometimes are located within the port boundary; goPEIT does not estimate emissions from processing facilities.

- **Emissions inventory**. Emissions from five criteria pollutants (SO_X, NO_X, PM, CO, VOC, BC) and four greenhouse gases (CO_2, CH_4, N_2O) can be estimated using goPEIT. Methods for emission estimation can be found in detail in the Emissions Calculation section. The emission estimation results are shown in the "Report" page and can be downloaded for presentation (summary table) and further analysis (detailed results). For Tier II users, the emission results in the "Report" page are available for download only in the summary format.
- **Tool**. The goPEIT tool is designed to eliminate the most common barriers preventing ports from performing emissions inventories, which include a lack of funding, technical capacity, and data availability. The accuracy and granularity of the output depend mainly on the inputs. The ICCT will maintain the tool and update default assumptions to align with best practices for performing port emissions inventories. This is an initial assessment tool to help ports get a sense of the scale of the problem of emissions and locate the major sources so that emission reduction initiatives can be designed accordingly.

User interface

Log in page

» The website for goPEIT is gopeit.org. A username and password are needed to log into the system. A user is required to contact the ICCT to be granted an account with the appropriate access tier.

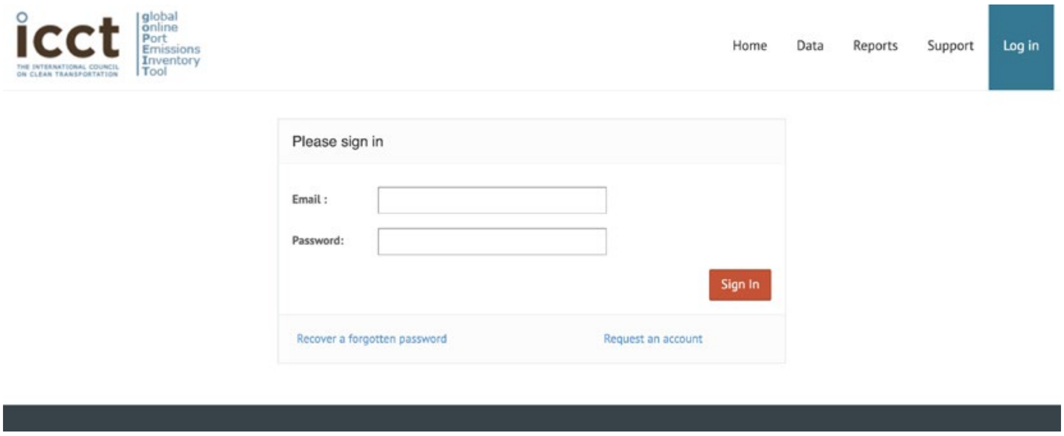


Figure A1. goPEIT login page

A user is advised that:

» ICCT will assign a username matching the email address of the user requesting access, together with a random password created by ICCT. The user will be able to change the password once logged in. ICCT will no longer have access to the user's new password.

» If a password is forgotten, a user can use the "Recover a forgotten password" function (Figure A1) to retrieve that. Alternatively, a user can contact ICCT to obtain a new password.

» If a username (email address) is forgotten, the user needs to contact ICCT to retrieve or make changes.

» When creating a user account, the following information is also assigned:

  » The user access tier.

  » The ports and associated terminals the user will create emissions inventories for. A user can be a port manager having access to data for multiple terminals who can choose to do emissions inventories for one or multiple terminals or for the entire port.

  » Whether the port is located in a designated Emission Control Area.

Home page
Once logged in, the user will be taken to the home page of goPEIT where basic information regarding the tool is shown.

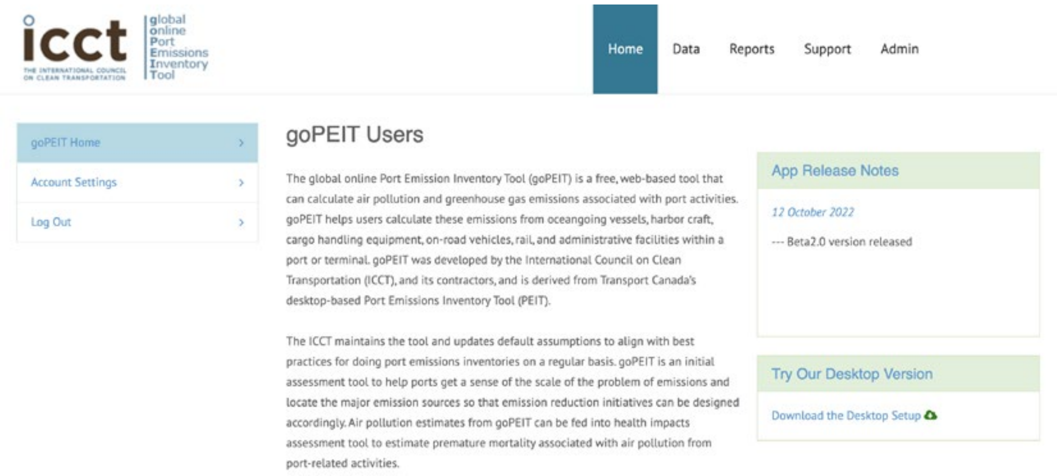


Figure A2. goPEIT home page

The main functions of goPEIT are accessed through the banner on the home page:

» The “Data” function is for data inputs.

» The “Reports” function is for outputs.

» The “Support” function is to provide assistance with using the tool.

Depending on the access tier of a user, the “Data” function may or may not be visible.

Data page
Under the Data tab, a user should navigate to the left-hand side and provide necessary inputs for various emissions source categories. The user is not required to provide inputs for all these categories in order to generate an emissions inventory. It is recommended to include, at a minimum, inputs for the “Harbor Craft,” “Oceangoing Vessels,” and “Cargo Handling Equipment” categories for a port emissions inventory as they are usually the largest contributors to a port’s total emissions.

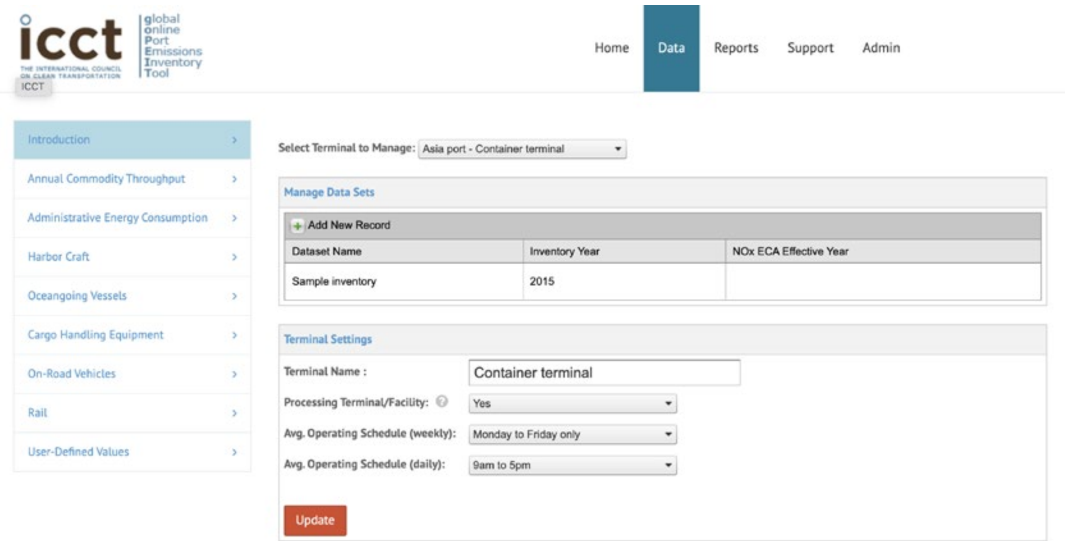


Figure A3. goPEIT Data page

The Introduction tab is the first step to complete before filling in any of the emission source categories. Here a user can select a terminal or port for the emissions inventory and a master data set needs to be created. One such data set corresponds to a specific inventory year and this data set will include all the input data for the following source categories. The terminal settings table is optional, which means that the information provided is not used for emission calculation.

Annual Commodity Throughput

Completion of this section is optional. A user can provide basic information on the types of cargo the terminal or port handles and the associated volume. This information can be used to calculate a port's emission intensity in tonnes of emissions per tonnes of throughput and can be compared with other ports of different scales.

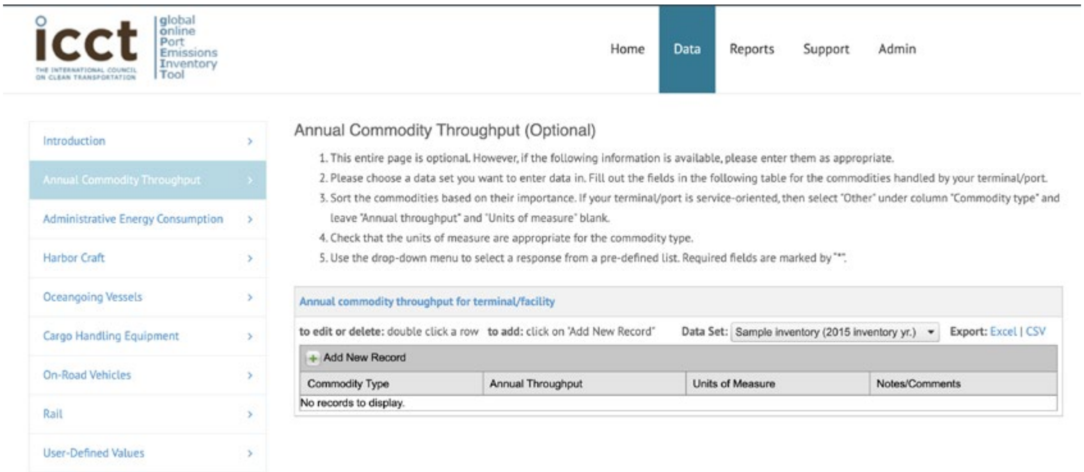


Figure A4. goPEIT Data page, Annual Commodity Throughput tab

Administrative Energy Consumption

This section encompasses the stationary emission sources of the port. This could include office buildings and compound lighting. For an annual port emissions inventory, only the total energy consumption is needed for different types of fuel or electricity used to power these sources. The units for different fuel types are predefined in order to make use of fuel-specific emission factors embedded in the tool. The user is advised to enter the correct amount of fuel to match the predefined unit if they collect the data in other units.

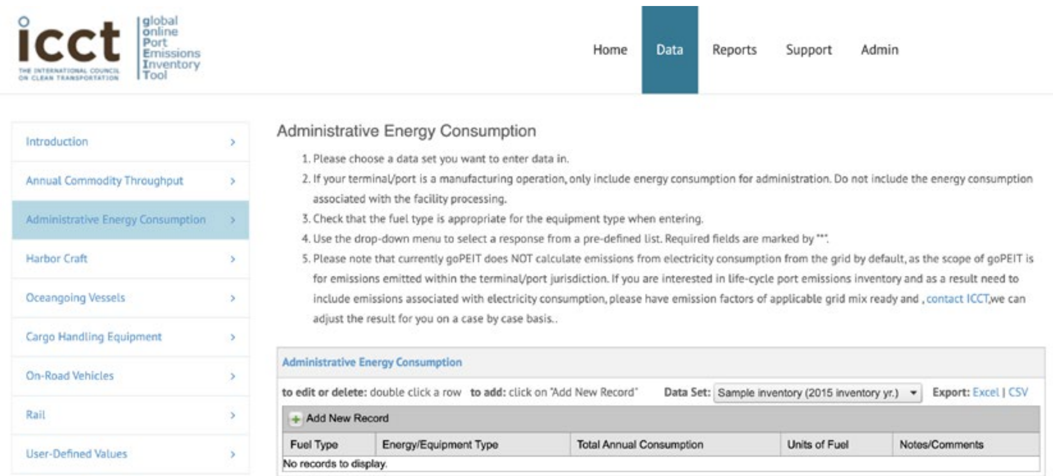


Figure A5. goPEIT Data page, Administrative Energy Consumption tab

Harbor Craft

The definition of a harbor craft can be different in different locations. The California Air Resources Board's definition of commercial harbor craft includes, but is not limited to, ferries, tugboats, crew and supply vessels, work boats, fishing boats, barges, and dredge vessels (California Air Resources Board, 2022). It is up to the user's discretion what to include in this category, but it is recommended to include as many vessel types as possible for a port's first emissions inventory. Once the user has a better idea of which vessel types contribute the majority of emissions, the types that have minor contributions can be left out of the inventory in future years.

In this section, a user needs to provide two types of information:

» Fuel consumption of the entire harbor craft fleet, by fuel type. This is the main source of data to estimate emissions from harbor craft, so data quality is key.

» Individual harbor craft information and intensity of usage. The information in this table is secondary to the emissions calculation, so a user is not required to enter information on each individual harbor craft. It is recommended, however, to enter grouped information for each type of harbor craft. For example, all tugboats can be entered into the table in one row, with a rough estimate of their overall characteristics and intensity of usage.

If a user has fuel consumption data on domestic shipping traffic within the port, it is possible to add that information in the Harbor Craft tab in order to include the vessels in the emission inventory.

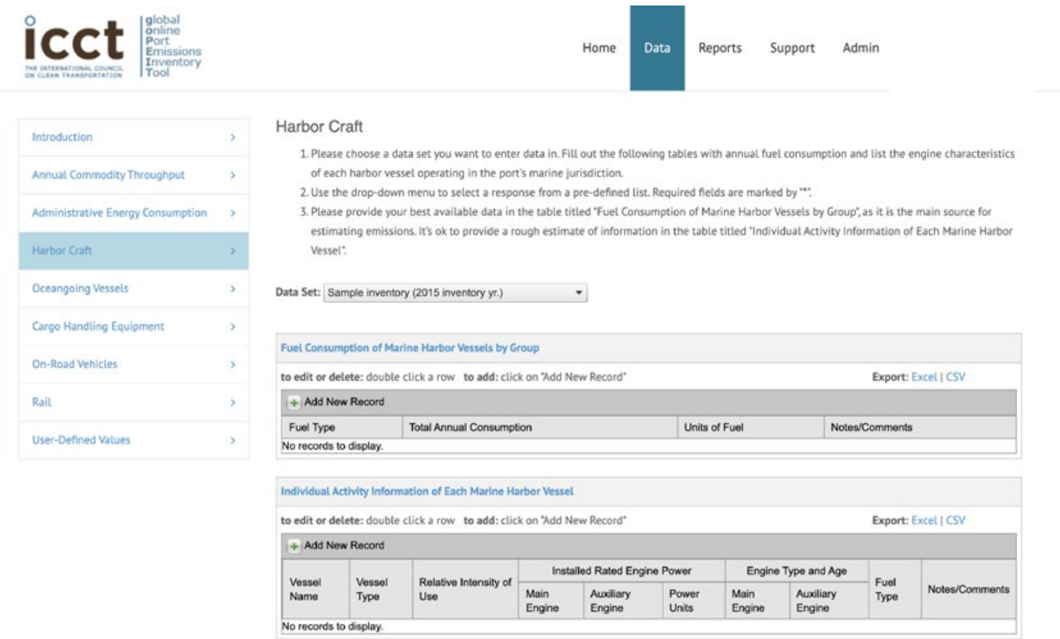


Figure A6. goPEIT Data page, Harbor Craft tab

Oceangoing Vessels

Oceangoing vessels represent the largest source of emissions in a port emissions inventory. However, ports often do not have access to the necessary information from all visiting vessels to be able to estimate their emissions within the port. A user only needs to provide the following information in goPEIT to enable the calculation of emissions for these vessels:

» Ship ID: This can be the ship's IMO number, MMSI number or name, but an IMO or MMSI number is preferred.

- Ship's activity within the port's boundary: goPEIT provides two granularity levels of calculation based on data availability.
  - In the basic option, ships have three operational phases in the port: normal cruising within the port boundary, anchored at a designated spot to wait for a berthing spot, and at berth to load/unload cargo. A user needs to enter the distance and speed a vessel traveled during this period, as well as time spent when anchoring and berthing, although these values can be a rough estimate. The energy consumption profile and emission factors are different for each phase, although goPEIT will perform the emissons calculation automatically with the embedded parameters.
  - In the detailed option, ships have five operational phases in the port: normal cruising within the port boundary, reduced-speed zone, maneuvering into the anchor spot, anchor, and berth. A user needs to enter the distance and speed of the vessel in the cruise, reduced speed, and maneuver phases, as well as the time spent anchoring and at berth to be able to use the detailed option.

A goPEIT template allows users to fill in information for each vessel visit in a given inventory year. After uploading the information, the system will attempt to match the user-provided ships with the internal ship characteristics database. If there is a mismatch, the record is routed to the error table, which can be downloaded and reviewed by the user. If there appears to be a mistake in the records, the user can revise and re-upload those vessels. In cases where the entered vessel does not exist in the internal database, and goPEIT cannot calculate emissions for that particular vessel, we recommend taking the following actions:

- Exclude emissions of that vessel from the inventory, or
- Estimate the fuel consumption of the vessel visits separately and include that information on the Harbor Craft page.

A user can also choose to include the Harbor Craft emission calculation on the Oceangoing Vessel tab if they are registered with IMO numbers.

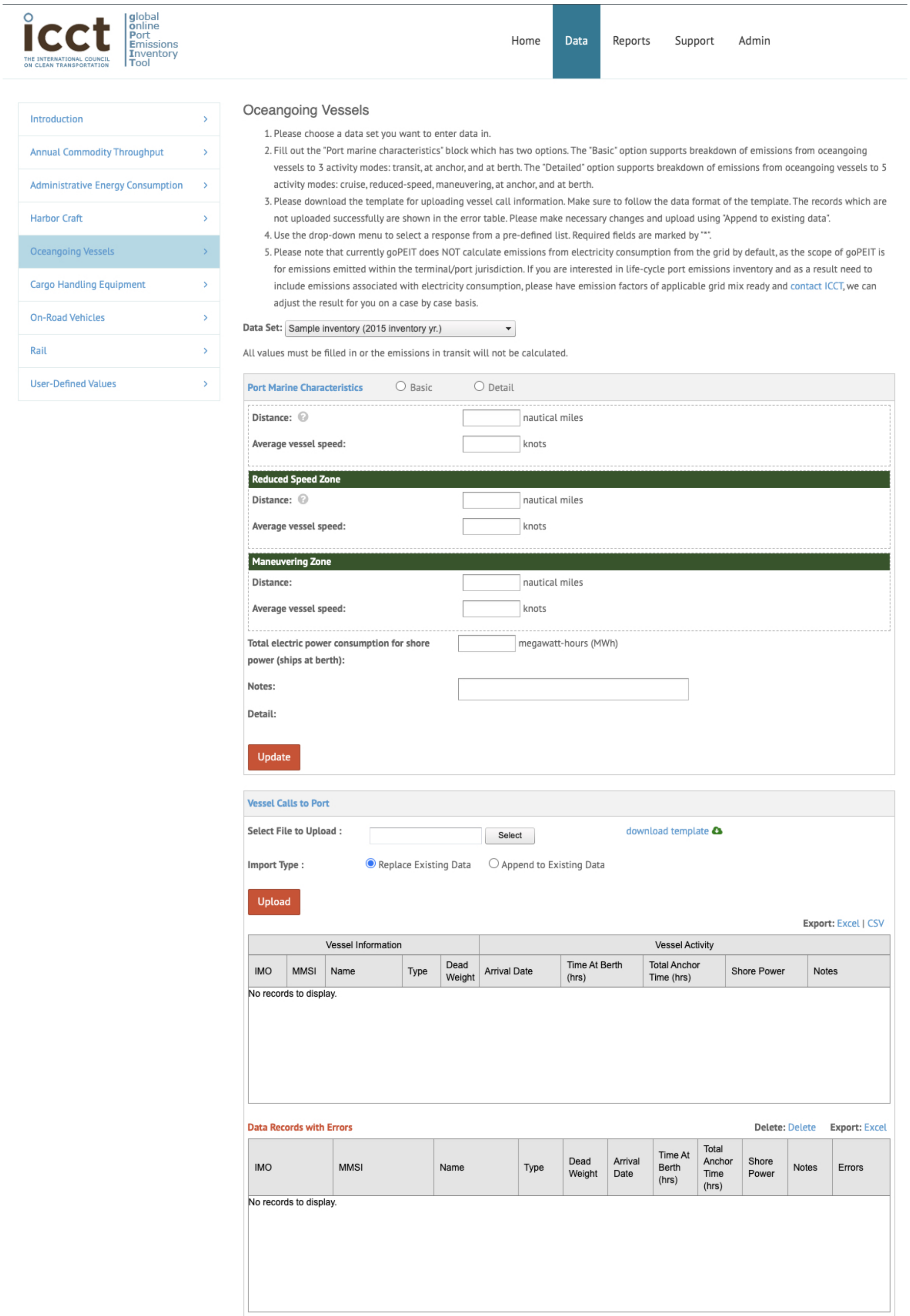


Figure A7. goPEIT Data page, Oceangoing Vessel tab

Cargo handling equipment

Cargo handling equipment is used to load and unload cargo from vessels, move the cargo around the port grounds, and stack it for trucks to transport them to final destinations. To estimate activity-based emissions from this equipment, goPEIT uses the US EPA NONROAD 2008 emissions model (U.S. EPA, 2009c). The model builds in emission factors for each specific piece of equipment by size (kW) and age, assuming the average annual hours of operation from the U.S. fleet statistics data. Information required as goPEIT inputs include total fuel consumption for each type of fuel used by the equipment, and each individual piece of cargo handling equipment (similar units can be grouped together) with basic engine and activity data like engine power, hours of use and fuel type. If these data are not readily available, estimates will need to be entered so that goPEIT can estimate emissions.

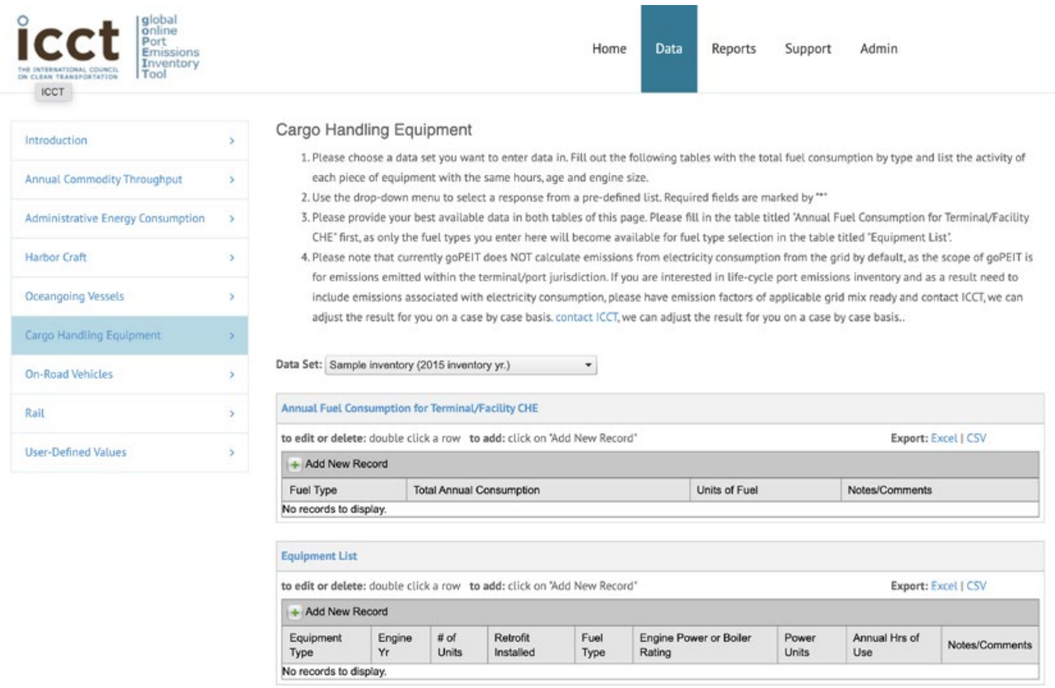


Figure A8. goPEIT Data page, Cargo Handling Equipment tab

On-road vehicles

There are two broad categories of on-road vehicles considered in a port emissions inventory by goPEIT. The first one is terminal- or facility-owned on-road vehicles used to transport staff and cargo within the terminal or facility boundary. The second category is external on-road vehicles, mostly commercial trucks, used to move cargo to their destination or from their origination. Every time a truck enters and leaves a port boundary and a terminal or facility boundary, its visit information is manually or automatically reported and collected. Therefore, a truck's technical information and the time spent at the facility should be readily available for most goPEIT users. For ports that use data loggers for trucks active in the port boundary, their activities in normal transit, creep or idle could be differentiated directly. If not, the user needs to provide a best estimate of transit and idle time for trucks on their facility. Emissions for on-road vehicles in goPEIT are differentiated between two major activity modes: in transit and in creep or idle. All vehicle emission factors were sourced from the U.S. EPA MOVES 2010b model (U.S. EPA, 2009b) assuming the national U.S. vehicle populations and annual accumulated mileage values by age and vehicle class (Figure A10). However, the user can revise this information by entering vehicle age profile pertaining to their own situation.

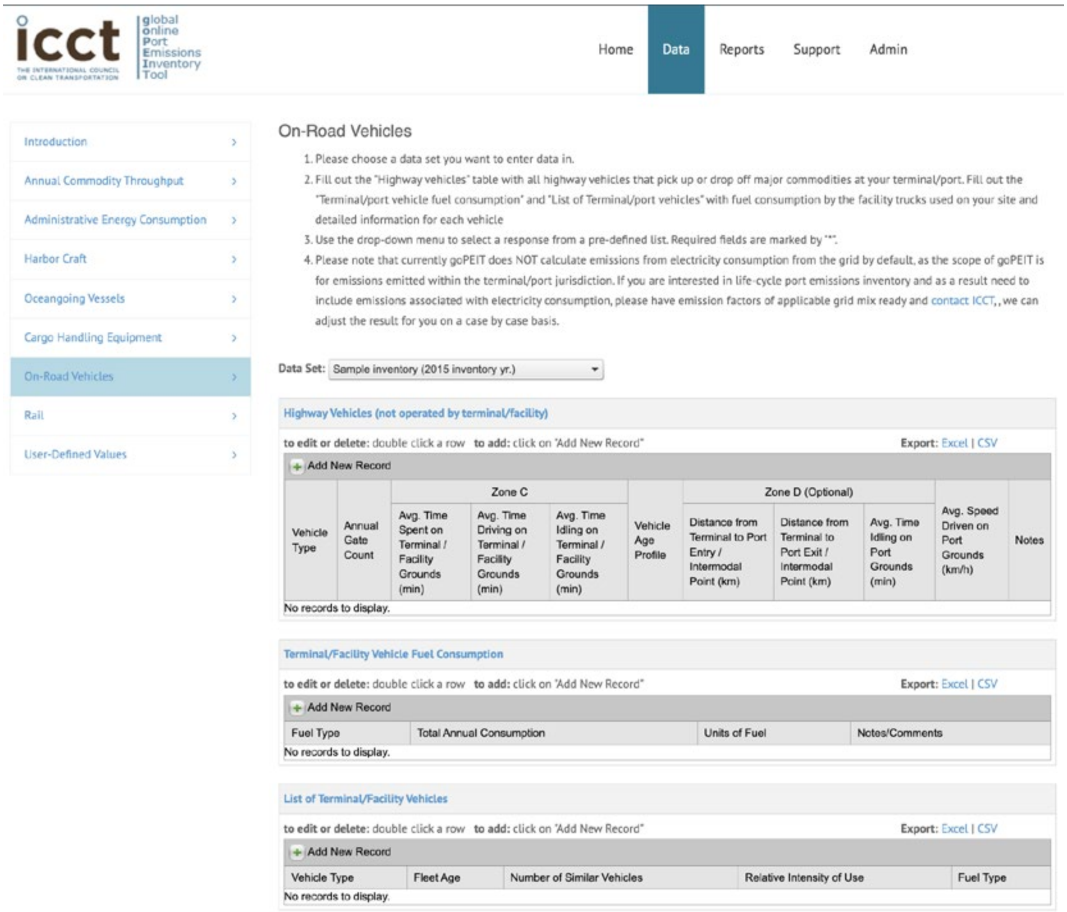


Figure A9. goPEIT Data page, On-road vehicles tab

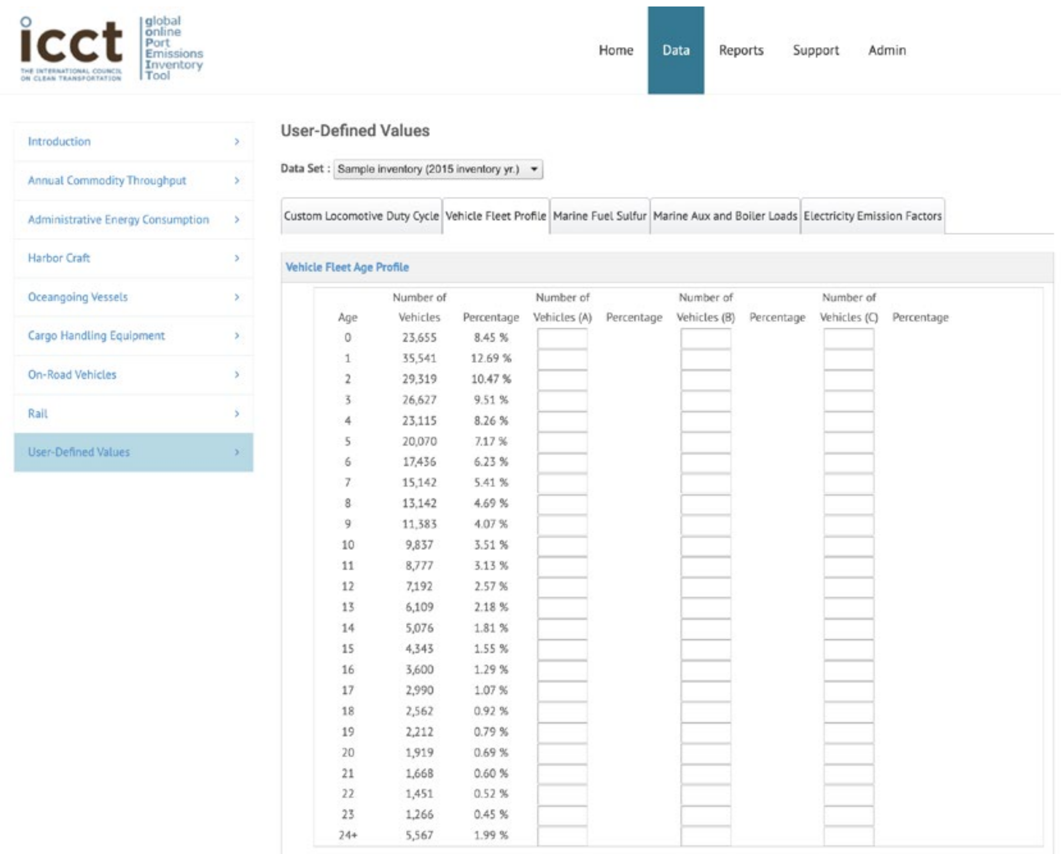


Figure A10. User-defined value page for vehicle fleet profile assumption

Rail/locomotive

Estimates of emissions from both facility-owned and external locomotives can be calculated in goPEIT. Emission factors are determined dynamically with duty cycles. The user is able to define locomotive duty cycles pertaining to their own situation if data is available. Otherwise, the default duty cycle, which can be found in Figure A12, is assumed. Emission rates are generated from emissions tests completed by the U.S. EPA for older-model locomotives and from additional studies for newer locomotives. For terminal/facility-owned locomotives, total fuel consumption can be entered and goPEIT will automatically adjust activity modes to apply activity-based emission factors to be consistent with fuel consumption data.

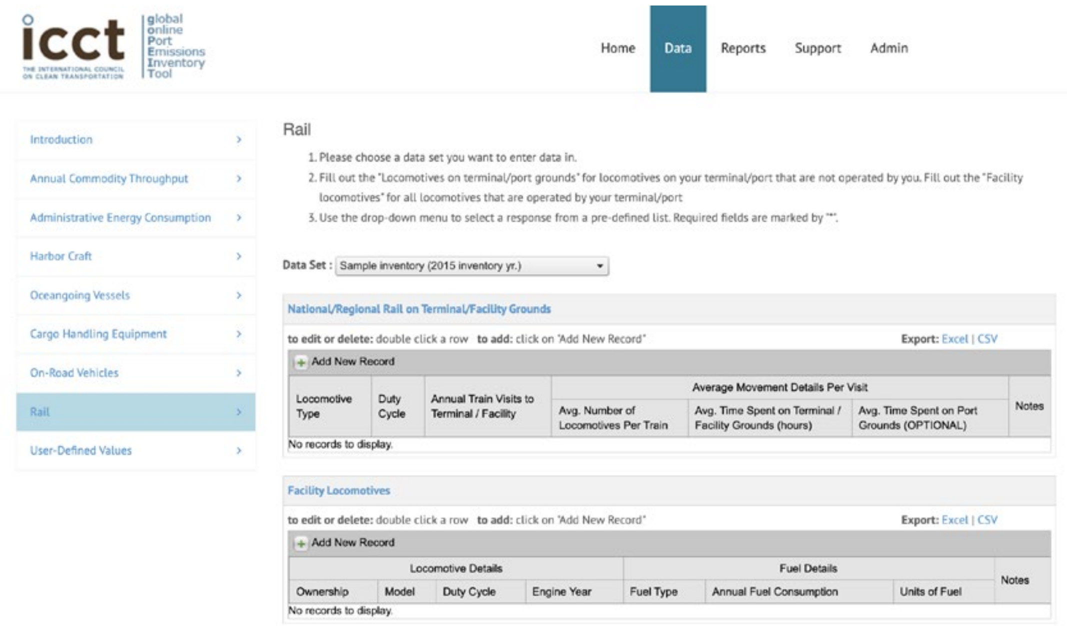


Figure A11. goPEIT Data page, Rail/locomotive tab

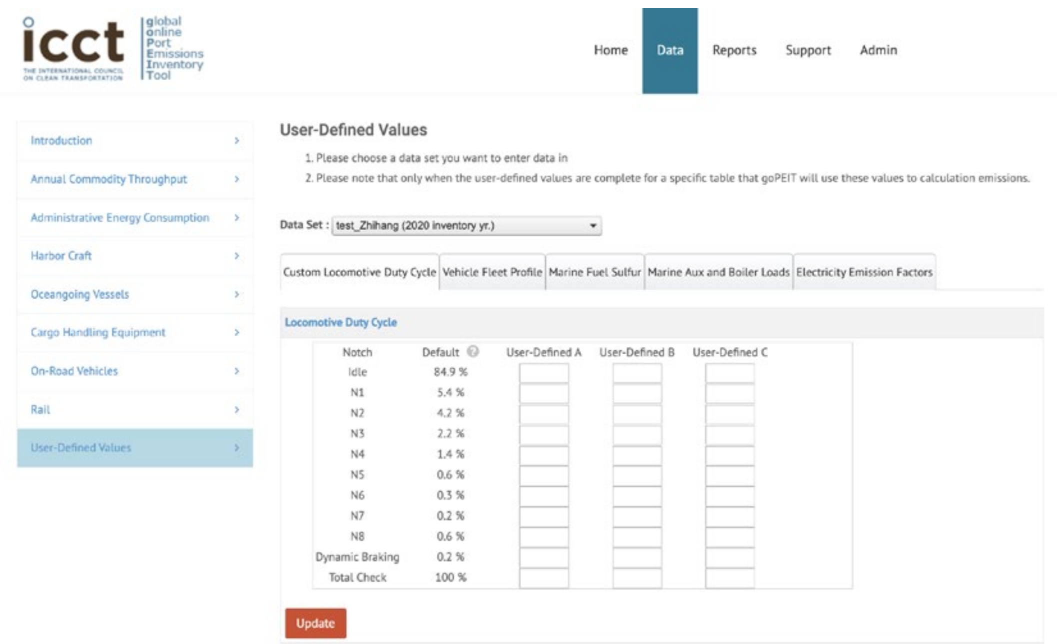
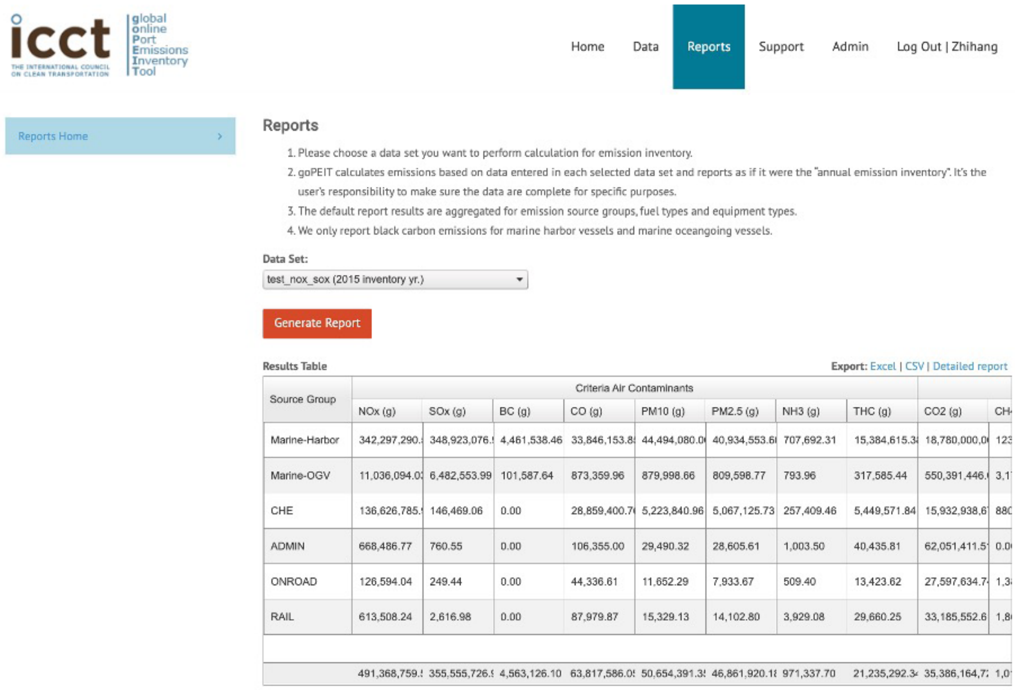


Figure A12. User-defined value page for locomotive duty cycle definition

Report page

On the report page, emissions estimation results are presented for each source group in terms of fuel consumption and each criteria air pollutant and climate pollutant. The results can be downloaded to be used externally. Alternatively, users can download a detailed disaggregated version of the inventory for each piece of equipment active on the port boundary. If multiple engines are on a piece of equipment, emissions of each engine are reported. The user can aggregate the results to any desired level of detail.



Source Group	Criteria Air Contaminants									
	NOx (g)	SOx (g)	BC (g)	CO (g)	PM10 (g)	PM2.5 (g)	NH3 (g)	THC (g)	CO2 (g)	CH
Marine-Harbor	342,297,290.	348,923,076.	4,461,538.46	33,846,153.8	44,494,080.0	40,934,553.6	707,692.31	15,384,615.3	18,780,000,0	123
Marine-OGV	11,036,094.0	6,482,553.99	101,587.64	873,359.96	879,998.66	809,598.77	793.96	317,585.44	550,391,446.	3,1
CHE	136,626,785.	146,469.06	0.00	28,859,400.7	5,223,840.96	5,067,125.73	257,409.46	5,449,571.84	15,932,938,6	880
ADMIN	668,486.77	760.55	0.00	106,355.00	29,490.32	28,605.61	1,003.50	40,435.81	62,051,411.5	0.0
ONROAD	126,594.04	249.44	0.00	44,336.61	11,652.29	7,933.67	509.40	13,423.62	27,597,634.7	1,3
RAIL	613,508.24	2,616.98	0.00	87,979.87	15,329.13	14,102.80	3,929.08	29,660.25	33,185,552.6	1,8
	491,368,759.	355,555,726.	4,563,126.10	63,817,586.0	50,654,391.3	46,861,920.1	971,337.70	21,235,292.3	35,386,164,7	1,0

Figure A13. goPEIT report page

Support page

Currently, the support page includes tutorial videos in English and Chinese, with a glossary of terms used throughout the tool. The ICCT will periodically update this section to include more helpful information. A complete user manual with basic FAQs will be provided soon.

Figure A14. goPEIT support page

Emissions calculations

Table A1 provides a list of equations for estimating emissions for each source group in goPEIT. Tables A2 through A4 provide the default emission factors for different equipment and fuel type combinations used in goPEIT.

Table A1. Emission estimation methodology for different source groups in goPEIT

Methodology	Source categories
Activity-based approach: E=P*LF*T*EF Where: E=Emissions (g) P=Power (kW) LF=Load Factor (%) T=Time (hour) EF=Emission Factor (g/kWh)	Oceangoing vessels Cargo handling equipment Rail/locomotives
Activity-based approach other: US EPA MOVES model	On-road vehicles
Fuel consumption-based approach: E=F*T*EF Where: E=Emissions (g) F=Fuel consumption rate (tonne/hour) T=Time (hour) EF= Emission Factor (g/tonne)	Harbor vessels Administrative building

Table A2. Emission factors (selected) for marine engines (g/kWh)

Engine type	Fuel type	NO_x[b]	CO	SO_x	$PM_{2.5}$	CO_2	CH_4	N_2O	BC	VOC
A4	HFO[a]	13.0	0.540	9.91	1.34	607	0.0100	0.0360	0.120	0.400
A4	MGO[a]	13.0	0.540	0.253	0.173	593	0.0100	0.0400	0.0600	0.400
A4-LNG[c]	LNG	1.30	1.30	0.00253	0.0192	429	5.50	0.0200	0.00253	0.500
M2	HFO	17.4	0.592	9.47	1.38	580	0.0112	0.0317	0.0391	0.671
M2	MGO	17.4	0.592	0.240	0.185	563	0.0112	0.0307	0.00795	0.671
M2-LNG[c]	LNG	1.33	1.43	0.00255	0.0199	433	2.80	0.0204	0.00252	0.559
M4	HFO	12.8	0.592	10.0	1.39	613	0.0112	0.0347	0.145	0.559
M4	MGO	12.8	0.592	0.255	0.183	597	0.0112	0.0307	0.0830	0.559
M4-LNG[c]	LNG	1.33	1.43	0.00269	0.0199	457	6.15	0.0204	0.00252	0.559

[a] HFO is assumed to have a sulfur content of 26000 ppm, and MGO is assumed to have a sulfur content of 700 ppm.

[b] NOx emission factors are determined by the IMO NO_x regulations, dependent upon engine rpm and the keel laid date of the vessel, the values in this table reflect Tier 1 engines only, except for the engines burning LNG.

[c] The values are associated with otto-cycle LNG engines.

Table A3. Emission factors for rails/locomotives (g/L)

Source	NO_x	CO	SO_x	PM	CO_2	CH_4	N_2O	VOC
Line haul	44.0	4.7	0.187	1.5	2.663	0.15	1.1	1.7
Switch	77.9	4.7	0.187	2.3	2.663	0.15	1.1	1.7

Table A4. Emission factors for boilers used in Admin sources (g/hp-hr)

Fuel type	NO_x	CO	SO_x	$PM_{2.5}$	CO_2	CH_4	N_2O	VOC
Diesel/heating oil	0.168	0.042	0.002	0.016	2.663	0.15	1.1	0.005
Natural gas	0.113	0.002	0.002	0.009	1.82-2.45	0.000037	0.000037	0.000
Propane	0.159	0.092	0.000	0.009	1.51	0.24	0.108	0.012

Note: Unit for CO_2, CH_4, and N_2O is g/L.