A Study on Ports' Emissions in the Adriatic Sea

Luca Braidotti[1,2](✉) and Marco Mazzarino[3]

[1] Venice International University, Isola di S. Servolo, 30133 Venice, Italy
[2] University of Trieste, Via Valerio 10, 34127 Trieste, Italy
lbraidotti@units.it
[3] Università IUAV di Venezia, Ca' Tron - Santa Croce 1957, 30135 Venezia, Italy

Abstract. Environmental sustainability and energy efficiency are some of the most challenging objectives to be pursued in port areas. In this context, the SUSPORT project aims to provide its contribution, affecting the Adriatic area. In the initial phase, before applying new technologies/solutions to enhance port sustainability, the baseline status shall be assessed in order to evaluate the impact of tested measures. To this end, a review of the peculiarities of the main ports of the Adriatic Sea (Italian and Croatian), including the evaluation of their carbon footprint should be carried out. The present work reports the results of this phase, focusing on the main statistics of the involved ports and their greenhouse gases inventory at an aggregated level.

Keywords: Greenhous gases · Port · Adriatic Sea

1 Introduction

The improvement of environmental sustainability and energy efficiency in port areas is a very challenging objective, due to the geographical and economical complexity of these areas and the large number of stakeholders and entities contributing to the pollutants emissions. They include port authorities, private companies, dealers, shippers, service providers, shipping companies, etc. In the last decades, increasing attention has been paid to these topics, especially in the European context. This led to a large number of actions devoted to reducing the emissions of pollutants [1, 2] and developing new tools and policies to reduce the environmental impact of navigation [3–5] and port operations [6–8]. In this context, the SUSPORT project aims to provide its contribution. The project involves all the main ports from Italy and Croatia, thus, offering a very useful channel to share past experiences and best practices dealing with port environmental sustainability and the improvement of energy efficiency in port areas. Furthermore, since all relevant ports in terms of traffic and volumes of goods/passengers are engaged, the project enables to analyse globally the environmental impacts of port activities on the whole area: the Adriatic Sea.

In the literature, plenty of works deals with the assessment of port emissions related to a specific aspect [9, 10] or a specific port [11, 12]. However, works focusing on both maritime and terrestrial emissions in a wide geographical area based on a common methodology are still missing. Nevertheless, such kind of studies might be very useful to assess the overall carbon footprint in a region of interest and plan proper cross-border policies to improve port sustainability and energy efficiency. This is one of the goals of the SUSPORT project. In order to to assess the effectiveness of different alternative measures, a comprehensive picture of the existing emissions for the area is required.

To this end, the present work defines the current carbon footprint related to port activities in the Adriatic Region. All the ports involved in the SUSPORT project have been required to provide data to assess the emissions of Green House Gasses (GHG) according to a common methodology which considers both terrestrial and maritime sources. Disaggregate data decomposed by main emission source is then elaborated to get an aggregate picture for the whole geographical region.

2 Methodology

The methodology to assess port emissions refers to the UNI EN ISO 14064 standard, which specifies the equivalent tons of carbon dioxide (t CO2eq) as a unit of measurement for the assessment of greenhouse gas emissions, as established by the Convention on Climate Change (UNFCCC). Based on the aggregation of data collected from each involved port, the processing of the information and the actual emissions calculations have been carried out as prescribed in [13, 14]. In the present study, both terrestrial and maritime emissions have been considered. Terrestrial emissions are related to all the relevant emissions sources on the land-side, whereas maritime emissions are related to all the ships and boats within the port area. In what follows, the considered categories and their assessment methodology are detailed.

2.1 Terrestrial Emissions

In the present work, the following categories have been considered regarding terrestrial emissions in port areas:

- Electric energy: accounting for the overall electricity consumption of all the users inside the port area;
- Heating: accounting for the emissions produced by heating systems of all the buildings/plants inside the port area;
- Service vehicles: emissions related to all the light vehicles used by the port authority or other entities based in the port area;
- Port operational vehicles: emissions related to all the vehicles and systems used inside the port area to move cargo (e.g. wheel loaders, forklifts, excavators, sweepers, cranes, harbour tractors, etc.);
- External vehicles: related to the emissions coming from trucks, coaches, busses, light-duty vehicles and private cars within the port area;
- Railway tractors: related to all the emissions of trains within the port area;
- Others: including the emissions due to power generators or actuators, recharges of air conditioners, consumption of gas not previously entered (Natural gas and LPG for domestic use)

In the following, the adopted methodologies for the assessment of GHG emissions are detailed. Emissions coming from combustion have been evaluated according to:

$$E_{gsc} = AD_{sc} \cdot EF_{gsc} \tag{1}$$

where E are the emissions measured in t CO2eq of the gas g produced by a source s from the fuel c, AD is the activity data (usually, the total consumption of energy required by s while employing c) and EF is the emission factor for g considering s and c. Emission factors have been taken from [13, 14].

Besides, direct emissions of GHG shall be considered too. For instance, leaks of refrigerant gases or gases contained in fire extinguishing systems belong to this category and can be quantified based on the refills carried out in the considered period. The emissions in equivalent t CO2eq are obtained by multiplying the refilled gas quantities by its global warming potential GWP as provided in [15].

Emissions related to electric energy consumption can be computed based on the consumption records and the information and sources employed by energy suppliers. The latter is compulsory to properly convert the electric energy consumption into t CO2eq. If this data is not available, reference has been made to the regional or national energy sources adopted for electric generation.

The calculation of the emissions due to vehicles transited in the port area has been carried out by collecting information on the number of transits from multiple sources and comparing the values obtained to validate them. The number of transits is multiplied by an estimated average route inside the port. In such a case emission factor is measured in kg of greenhouse gas per km and has been taken according to ISO EN 16258: 2013. The obtained emissions are increased by 5.6% to account for stops and manoeuvres [16].

2.2 Maritime Emissions

In the present work, the following categories have been considered regarding maritime emissions in port areas:

- Maritime port services: including all the shipborne emissions coming from port service vessels (tugs, pilot boats, etc.);
- Anchored ships: emissions related to the ships while anchored nearby the port and waiting for access;
- Ships manoeuvring: emissions deriving from the manoeuvring phase of the ships up to their arrival at berth and subsequent inverse departure of the ship;
- Moored ships: the emissions produced during the actual mooring phase of the ship at berth, including waiting and cargo loading and unloading operations (e.g. goods and/or trailers and/or the transit of passengers, etc.).

Usually, freight ships adopt slow-speed 2-stroke main engines directly connected to the shaft line and propeller. These engines usually adopt Heavy Fuel Oil (HFO). In addition, they are equipped with auxiliaries including medium/high-speed 4-stroke engines for electric generation and steam boilers. The auxiliaries often adopt Marine Diesel Oil (MDO). Passenger ships have higher power demand even at berth due to hotel loads. Usually, the main engines of passenger ships are medium-speed 4-stroke engines using HFO or MDO. Most of the recent cruise vessels adopt a diesel-electric propulsion system where electric motors are connected to the shaft lines and electric generation is ensured by medium-speed diesel engines. Finally, small service boats might use lighter fuels, such as diesel, and usually do not emit pollutants while are moored, but only during operation.

The emission factors in kg of GHG per fuel tonne have been taken from IMO (International Maritime Organization) standards for different gases, fuel types and engine speed [17]. Recently, the adoption of Liquefied Natural Gas (LNG) as a marine fuel is also increasing [18]. In the Adriatic Sea, the LNG bunkering facilities are mainly still under development. However, if any LNG fuelled vessel visited the port, the emission factors for LNG have been adopted according to [19].

The emissions factors shall be multiplied by the fuel consumption FC in the port area. If available, the actual fuel consumption in the port area has been used byapplying the top-down approach. For instance, for service vessels directly operated by the port authority or a subcontractor, bunkering records provide the most accurate metric to evaluate emissions.

For commercial ships, data regarding actual fuel consumption in a specific port area is usually not available. Hence, it is necessary to estimate the fuel consumption from operations records by applying the bottom-up approach. Starting from data about commercial ship traffic in the port, the hours spent at anchor t_a, moored at berth t_b and in manoeuvring t_m have been determined for each ship entering the port. Moreover, for manoeuvring phases, the actual speed V (measured in knots) and draught T of the vessel shall be also determined or estimated. Moreover, the essential ship data shall be acquired from databases (e.g. IHSF technical specifications), including the installed power (main engine Maximum Continuous Rating MCR), the maximum speed V_{max} and draught at maximum speed T_{max}. If this data is not available, another known condition characterised by a reference engine power P_{ref} at a reference speed V_{ref} and draught T_{ref} can be used instead (mean values related to ship types and deadweight can be assumed [17]). According to [20], reference speed can be taken as the design speed and the reference power as 80% of MCR. Considering a generic ship speed, the actual propulsion engine power can be estimated according to the Admiralty formula:

$$P = P_{ref} \left(\frac{T}{T_{ref}} \right)^{2/3} \left(\frac{V}{V_{ref}} \right)^3 \tag{2}$$

Then, the fuel consumption FC during the maneouvring phase is given by:

$$FC = c_l \cdot SFOC \cdot P \cdot t_m \cdot 10^{-6} \tag{3}$$

where $SFOC$ is the specific fuel consumption in g/kWh and c_l is a correction factor taking into account the variation of $SFOC$ at lower engine loads [21]. Reference values for $SFOC$ are given in [17], according to the main engine age.

In all the operation modes (anchor, manoeuvring and moored) the auxiliaries' emissions shall be considered too, including the ones coming from auxiliary engines and auxiliary boilers. The power demand depends upon the operation mode, the ship type and its deadweight. Reference values can be found in Annex 1 of [17]. Then, related fuel consumption can be computed with Eq. (3) assuming unitary correction factor and *SFOC* according to [22].

3 Application on Ports in the Adriatic Region

The methodology has been applied to the major ports of the Adriatic Area in order to map the GHG emissions. In the following, the studied area is briefly described, and then the GHG inventory is presented. All data is related to 2019. Only, Ploce Port Authority used 2020 data.

3.1 The Adriatic Area

Figure 1 shows the ports involved in the present study. They include all the major ports from Italy and Croatia. It is worth noticing that in many cases a single port authority is responsible for multiple ports. It is the case of almost all the Italian port authorities that have been grouped according to the decree n. 169/2016. On the contrary, in Croatia, single port authorities are in charge of single ports. In Tables 1, 2 and 3, the main traffic statistics related to the ports in the project area are reported, including a comparison of figures in Italy, Croatia and the combined cross-border reference values.

Fig. 1. Ports considered in the cross border study

Table 1. Main traffic statistics for the ports in the project area (Source: Eurostat)

Port	N. Ships	N. Pax Ships	% Pax Ships	N. Fright Ships	% Freight Ships	Total GT (kton)	GT Pax Ships (kton)	% Pax Ships	GT Freight Ships (kton)	% Freight Ships	Mean GT (ton)	Mean GT Pax (ton)	Mean GT Freight (ton)
Dubrovnik	35,031	34,006	97.07%	838	2.39%	33,685	31,832	94.50%	1,845	5.48%	962	936	2,202
Ploce	2,266	43	1.90%	2,214	97.71%	10,734	32	0.30%	10,641	99.13%	4,737	744	4,806
Rijeka	1,672	1,168	69.86%	486	29.07%	16,836	1,864	11.07%	14,930	88.68%	10,069	1,596	30,720
Split	23,145	15,001	64.81%	8,104	35.01%	55,520	20,910	37.66%	34,535	62.20%	2,399	1,394	4,261
Zadar	16,535	8,601	52.02%	7,922	47.91%	30,407	8,634	28.39%	21,772	71.60%	1,839	1,004	2,748
Ancona	2,068	58	2.80%	1,958	94.68%	55,389	3,082	5.56%	52,188	94.22%	26,784	53,138	26,654
Bari	2,764	216	7.81%	2,535	91.71%	59,696	10,211	17.10%	49,423	82.79%	21,598	47,273	19,496
Barletta	362	n.a.	0.00%	362	100.00%	1,641	n.a.	0.00%	1,641	100.00%	4,533	n.a.	4,533
Brindisi	1,833	30	1.64%	1,701	92.80%	33,713	1,903	5.64%	30,786	91.32%	18,392	63,433	18,099
Chioggia	660	2	0.30%	609	92.27%	1,923	1	0.05%	1,892	98.39%	2,914	500	3,107
Monfalcone	702	n.a.	0.00%	541	77.07%	7,573	n.a.	0.00%	7,539	99.55%	10,788	n.a.	13,935
Porto Nogaro	405	n.a.	0.00%	401	99.01%	1,929	n.a.	0.00%	1,927	99.90%	4,763	n.a.	4,805
Ravenna	4,082	15	0.37%	3,348	82.02%	45,515	663	1.46%	43,734	96.09%	11,150	44,200	13,063
Trieste	2,530	55	2.17%	2,308	91.23%	77,355	4,501	5.82%	72,759	94.06%	30,575	81,836	31,525
Venezia	3,903	517	13.25%	3,289	84.27%	85,063	21,978	25.84%	62,972	74.03%	21,794	42,511	19,146
Total	**97,958**	**59,712**	**60.96%**	**36,616**	**37.38%**	**516,979**	**105,611**	**20.43%**	**408,584**	**79.03%**			
Croatia	285,456	171,065	59.93%	112,774	39.51%	380,377	96,207	25.29%	283,776	74.60%	1,333	562	2,516
Italy	472,540	40,517	8.57%	428,079	90.59%	2,865,882	404,595	14.12%	2,455,367	85.68%	6,065	9,986	5,736
Italy + Croatia	757,996	211,582	27.91%	540,853	71.35%	3,246,259	500,802	15.43%	2,739,143	84.38%	4,283	2,367	5,064
% Italy + Croatia	**12.92%**	**28.22%**		**6.77%**		**15.93%**	**21.09%**		**14.92%**				

Table 2. Main statistics for the ports in the project area regarding passenger transport (Source: Eurostat)

Port	N. Cruise ship	N. Other Pax	GT Cruise Ship (kton)	GT Other Pax (kton)	N. Cruise Pax	N. Other Pax	Total N. Pax
Dubrovnik	533	33 473	27 631	4 201	78 000	2 332 000	2 410 000
Ploce	10	33	22	10	0	383 000	383 000
Rijeka	24	1 144	1 488	376	0	114 000	114 000
Split	274	14 727	12 765	8 145	0	4 958 000	4 958 000
Zadar	125	8 476	6 290	2 344	1 000	2 318 000	2 319 000
Ancona	58	n.a.	3 082	n.a.	19 000	1 089 000	1 108 000
Bari	133	83	10 191	20	165 000	1 226 000	1 390 000
Barletta	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Brindisi	30	n.a.	1 903	n.a.	16 000	504 000	520 000
Chioggia	2	n.a.	1	n.a.	n.a.	n.a.	n.a.
Monfalcone	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Porto Nogaro	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Ravenna	15	n.a.	663	n.a.	n.a.	n.a.	n.a.
Trieste	55	n.a.	4 501	n.a.	n.a.	n.a.	n.a.
Venezia	350	167	21 912	66	571 000	283 000	854 000
Total	**1 609**	**58 103**	**90 449**	**15 162**	**850 000**	**13 207 000**	**14 056 000**
Croatia	1 434	169 631	52 143	44 064	79 000	34 063 000	34 142 000
Italy	4 704	35 813	395 354	9 241	5 018 000	81 512 000	86 530 000
Italy + Croatia	6 138	205 444	447 497	53 305	5 097 000	115 575 000	120 672 000
% Italy + Croatia	**26.21%**	**28.28%**	**20.21%**	**28.44%**	**16.68%**	**11.43%**	**11.65%**

Table 3. Main statistics for the ports in the project area regarding freight transport (Source: Eurostat)

Port	GT Liquid Bulk (kton)	GT Dry Bulk (kton)	GT Container Ship (kton)	GT Spec. Carrier (kton)	GT Geng. Cargo (kton)	t of Goods Handled	TEU Handled
Dubrovnik	n.a.	n.a.	n.a.	1	1 844	21 000	n.a.
Ploce	784	1 322	1 240	50	7 245	3 507 000	33 956
Rijeka	16	184	14 099	0	631	3 356 000	287 920
Split	701	478	461	5	32 890	1 942 000	9 430
Zadar	432	81	n.a.	6	21 253	418 000	n.a.
Ancona	75	858	8 510	n.a.	42 745	5 313 000	212 444
Bari	213	1 433	1 433	34	46 310	6 134 000	86 088
Barletta	420	102	n.a.	n.a.	1119	1 084 000	n.a.
Brindisi	4 433	3 243	50	n.a.	23 060	8 583 000	1 654
Chioggia	n.a.	196	9	n.a.	1 687	1 597 000	0
Monfalcone	n.a.	2121	4	2564	2 850	4 489 000	319
Porto Nogaro	n.a.	80	35	n.a.	1 812	1 440 000	n.a.
Ravenna	8 796	13 875	9 569	1 627	9 867	31 348 000	246 983
Trieste	26 866	1 166	24 731	18	19 978	60 333 000	917 866
Venezia	8 972	7 619	18 288	1 056	27 037	27 935 000	547 563
Total	51 708	32 758	78 429	5 361	240 328	157 500 000	2 344 223
Croatia	8 629	3 117	15 800	67	256 163	20 580 000	331 304
Italy	211 868	56 021	377 750	66 117	1 743 611	508 074 000	9 795 968
Italy + Croatia	220 497	59 138	393 550	66 184	1 999 774	528 654 000	10 127 272
% Italy + Croatia	23.45%	55.39%	19.93%	8.10%	12.02%	29.79%	23.15%

In the project area, most of the traffic is composed of freight vessels. In terms of total Gross Tonnage (GT), in 2019, the first port in the area is Venice, followed by Trieste. Considering the number of ships the first port is Dubrovnik, which, however, mostly operates passenger transport (over 90% in terms of both the number of ships and the GT). Rijeka, Split and Zadar show a more balanced split between passenger and freight traffic in terms of the number of ships; however, considering the GT of vessels in all the cases the balance moves towards freight vessels that are characterised, in general, by higher mean GT compared to the passenger vessels in Croatia. On the other hand, considering the Italian ports, the average GT of passenger vessels is usually higher than the freight one.

3.2 Results

Considering the Adriatic Area, which includes all the ports involved in the present study, the aggregate picture of GHG emissions is provided in Table 4. It shall be noted that in most ports, no data about anchoring time was available or it has been grouped with emissions in the mooring phase. Furthermore, the ports of Rijeka and Bari neglect to report the maritime services emissions, whereas the port of Ravenna grouped these emissions in the manoeuvring related emissions. The emissions in the studied area can be decomposed as shown in Figs. 2, 3 and 4.

Table 4. Ports included in the cross border study

Category	Emissions (t CO2eq)	Emissions (%)
Electric energy	20192.1	3.21%
Heating	3230.7	0.51%
Service vehicles	4223.1	0.67%
Operational port vehicles	43519.4	6.93%
External vehicles	32262.1	5.14%
Railway tractors	1875.0	0.30%
Other	1231.0	0.20%
Maritime port services	8800.3	1.40%
Anchored ships	5714.6	0.91%
Ships manoeuvring	93592.4	14.90%
Moored ships	413635.8	65.84%
TOTAL	**628276.4**	**100.00%**

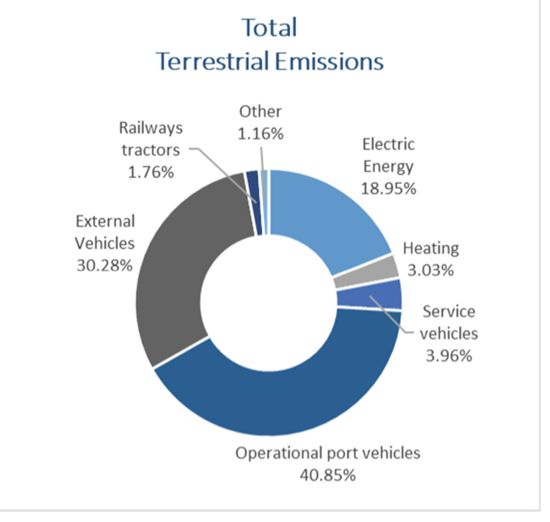

Fig. 2. Decomposition of total terrestrial emissions in the Adriatic Sea

4 Discussion

It is worth noticing that, maritime emissions are the largest contributor (83.04% of the total emissions of GHG) in the studied area. This situation is even more emphasised for passenger ports, such as Dubrovnik, Split or Zadar, where maritime emissions can reach more than 90% of the total. At thee same time, terrestrial emissions are limited to the lighting system, the heating of terminals, a small number of service vehicles and the traffic emissions within the port area.

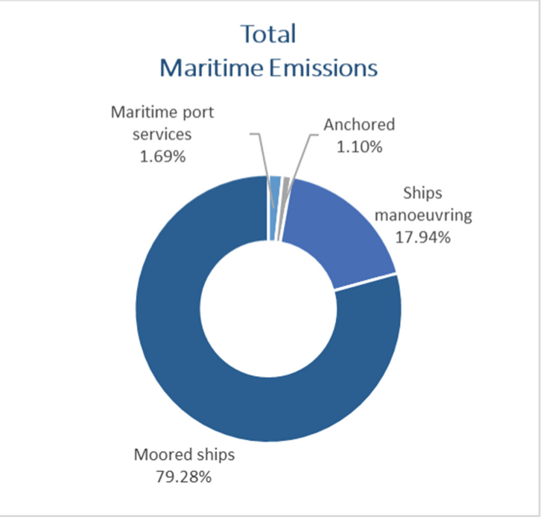

Fig. 3. Decomposition of total maritime emissions in the Adriatic Sea

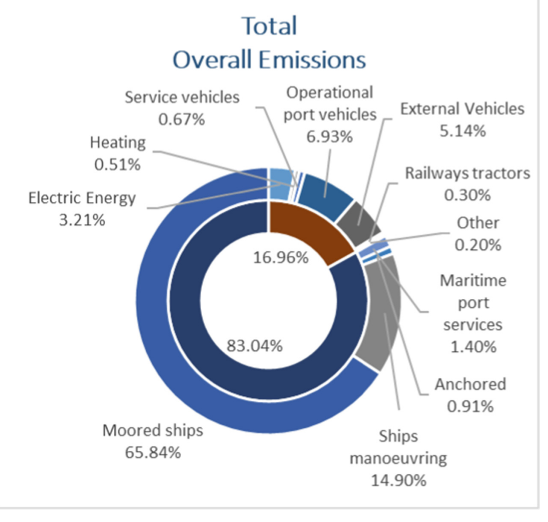

Fig. 4. Decomposition of total emissions in the Adriatic Sea

By decomposing the maritime emissions, the first contribution comes from moored vessels (79.28% of the maritime emissions of GHG), followed by ships manoeuvring (17.94% of the maritime emissions of GHG). The contribution from manoeuvring is strictly dependent on the port access and layout. It reaches the maximum value in the only channel port considered in the present study, e.g., Ravenna (37.04% of the maritime GHG emissions). Emissions from moored and anchored ships relate to the port efficiency, which determines the hotelling and standby time respectively. Besides, no information about anchored ships, i.e. ships waiting to enter the port, was available in several cases. Hence, it is expected that total maritime emissions should be slightly increased in the project area.

Regarding the terrestrial emissions, the main contributors are operational port vehicles (40.85% of the terrestrial emissions of GHG), heavy vehicles entering the port area (30.28% of the terrestrial emissions of GHG) and electric energy (18.95% of the terrestrial emissions of GHG). It is worth noticing that for passenger ports, electric energy consumption represents the main source of terrestrial emissions, reaching, for instance, 90% of terrestrial emissions in the port of Dubrovnik. However, the balance is significantly affected by the port layout and the distances between port access and terminals, which have an impact especially on the external vehicles category.

5 Conclusions

The present work originally elaborated and presented the current status of the Adriatic Area focusing on the GHG emissions in the ports involved in the SUSPORT project. It shall bared in mind that data refers to a pre-pandemic situation, hence, the GHG emissions are not affected by the effects of COVID-19, which caused in many cases a drop in port activities and, consequently, in the related emissions. This is especially true for the passenger ports, that experienced a heavy reduction of calls and passengers (especially the ones related to the cruise sector) in 2020.

Nevertheless, the work provided a portrait of the area carbon footprint that, together with the best practices, will provide a strong baseline to effectively plan the pilot actions that will be implemented during SUSPORT project. From this consolidation process some remarkable conclusions can be drawn. First, most of the emissions in the project area come from the sea-side, and in particular from moored ships. Regarding terrestrial emissions, the situation is different and it depends case by case, thus, a more in-depth analysis is needed. In particular, the distinction between mainly freight or passenger ports might be helpful, along with an analysis of the peculiar geographical characteristics of each specific site. Hence, the specific situation shall be carefully analysed and considered to improve the port sustainability and energy efficiency.

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