The Influence of Seaport Operations on the Coastal City Environment

Mamatok Yuliya and Chun Jin

Abstract The main objective of this research is to explore the influence of activities of a seaport on the carbon pollution of the surrounding city and suggest the adequate measures for its reduction. This paper focuses on the land-side area of the seaport by considering three kinds of emissions sources: cargo handling equipment, heavy-duty vehicles, and locomotives, as they pollute the seaport land-side area and are included into the transport infrastructure of the city. The multiple methodologies were used in this research to confirm the environmental effectiveness, including the total frame of three approaches, the multiple case study to choose suitable evaluation methods, case study for verification of the proposed method, and the quantitative method to calculate the emission and inventories. A case study was carried out on the influence of the operations of Qingdao Port on Qingdao city. As a result, some measures of emission reduction are proposed for Qingdao Port to decrease CO_2 produced by CHE, HDV, and RL through improving operation, such as using clean fuels, controlling emissions, encouraging the choice of the rail transportation, and developing dry ports.

Keywords Coastal city environment · Emissions estimation · Qingdao port · Seaport carbon emissions

1 Introduction

The development of port facilities and their associated operations contributes significantly to the growth of maritime transport and the economic development of coastal regions (Puig et al. 2014). However, the pollution from ports' operations has

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been remained the key problem concerned by proximity of the ports (Acciaro et al. 2014). The most common pollutants associated with port-related operations are the following: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), particulate matter (PM) (10, 2.5 μ), diesel particulate matter (DPM), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), and carbon monoxide (CO) (IAPH Tool Box for Port Clean Air Programs 2008). For example, heavy-duty vehicles account for 10 % of diesel PM, 36 % of NO_x, and 1 % of SO_x (Giuliano and O'Brien 2007). Port operations impact on air, water, and soil, affecting both the terrestrial and marine environments. The situation with seaside mobile emissions was investigated by a lot of researches (Qi and Song 2012; Schrooten et al. 2008, 2009; Miola and Ciuffo 2011; Adamo et al. 2014) and that with the land-side has not been studied thoroughly. Considering the seaside emissions, the precise calculation methodologies in this area are of high demand. Automatic identification system (AIS) is regarded as a very effective tool to create a state-of-the-art inventory of marine vessel emissions. The data of vessel identification, position, course, and speed are transmitted continuously, providing a comprehensive and detailed data set for individual vessels, which can be used to estimate and allocate emissions based on improved traffic pattern data (Perez et al. 2009).

This paper focuses on emission estimates of greenhouse gases (GHGs) from the land-side mobile emissions of the seaport. Land-based emission sources include cargo handling equipment (CHE), heavy-duty vehicles (HDVs), and rail locomotives (RLs) which are operating within a port area (World Ports Climate Initiative 2010). The contribution of this research involves the following points:

- Establishment on the emissions estimation methodologies by analyzing the most progressive experiences of seaports;
- Empirical study on the emissions estimation in Qingdao Port to evaluate the carbon emissions pressure on the city environment;
- Recommendations for the seaport executives in land-side emissions mitigating strategies.

The rest of this paper is arranged as follows: Sect. 2 represents the literature review. Section 3 describes the methodology applied in this research. Section 4 discusses the results from the emissions estimation of the case study. The Sect. 5 provides some recommendations for the seaport operations. Finally, the conclusions are summarized.

2 Literature Review

The problem of seaport land-side emissions was developed according to the following aspects.

The first aspect is the calculation methodology applied for the estimation of land-side emissions. Two general approaches could be represented as the solution of this problem. The first one is a detailed approach, which uses source-specific data. It makes use of the greatest levels of detail and provides the highest levels of accuracy. The second one is a streamlined approach, where land-side emissions are estimated from other detailed inventories, using the surrogates to estimate their activities. The streamlined approach requires a lower level of detail, but it is based on assumptions limiting accuracy (Browning 2009). This approach was tested to calculate air emissions in Saigon Port in Vietnam. The results showed that the total emissions of all pollutants were dominated by cargo handling equipment (Ho 2013).

The second aspect of the land-side emissions is terminal operations and associated energy consumption. By providing the insight into the energy of the terminal processes, the model of bottom-up calculation could be suggested. This model included a bottom-up calculation of the amount of work supplied by machines, not using the amount of fuel as input, but as the result of the model. This model was applied in Rotterdam (Geerlings and van Duin 2011). In addition, an operational activity-based method was developed in contrasts to the traditional aggregated activity-based method. The results showed that the aggregated method could better overestimate CO_2 emissions and the operational activity-based method is more appropriate (Dong-Ping and Jingjing 2012).

The seaport environment influences the city environment to a big extent. The monitoring of the city and seaport pollutions is the vital problem, which could be solved starting from the development of a system of sustainable environmental management indicators. The attempt to analyze a total of 17 pressure/state indicators with the potential environmental impacts was made in the Port of Valencia in Spain (Peris-Mora et al. 2005). In addition, estimating the emissions due to seaports in such a way that they can be included as part of the cities inventory or be used by the port itself has a great optimization potential. This methodology was adapted in the Port of Barcelona in Spain and helped to find out that the highest polluters were auto carriers (Villalba and Gemechu 2011).

Many studies were devoted to the problem of the sustainability of the coastal cities. They described the methodologies and data used to determine GHG emissions, attributable to the following cities or city-regions: Greater Toronto, New York City, Greater London, Barcelona, Cape Town, and Bangkok. The problem of CO_2 pollution is urgent for China as well. Some researches tried to investigate the scale of pollution in several Chinese cities and regions such as Hong Kong (Harris et al. 2012), Nanjing (Bi et al. 2011), Macao (Li et al. 2013), and Suzhou (Wang et al. 2014).

The majority of the observed researches developed the aspects of the seaport emissions inventories designing. In addition, the problem of the cities emissions inventories from the global perspective gains the growing interest. The observation of the provided papers also represents the scientific research situation in different world regions.

3 Methodology

The multiple methodologies were used in this research to confirm the environmental effectiveness, including the total frame of three approaches, the multiple case study to choose suitable evaluation methods, case study for verification of the proposed method, and the quantitative method to calculate the emission and inventories.

Case studies have been used extensively in port economics and management. Considering the exploratory nature of the paper, which investigates the influence of seaport land-side operations on the city environment, the application of case studies is particularly appropriate.

In this research, the multiple case study method was used to investigate the experience of some seaports, which are progressive in the low-carbon port construction and emissions inventories development (Port of Los Angeles (USA), Port of Gothenburg (Sweden), Port of Jurong (Singapore), and Port of Rotterdam (The Netherlands)). The investigated ports were chosen because of the following criteria: They are leaders in their regions; they are on the cutting edge of the environmental policy solutions implementation; their carbon emission impacts on the city environment are significant; and their achievements are representative and should be studied thoroughly to be applied by others.

An emission inventory is a quantification of all emissions of criteria and other pollutants (including toxics and greenhouse gases) that occur within a designated area by their source. An emission inventory is necessary for port authorities, state and local entities as well as other interested parties to understand and quantify the air quality impacts of current port operations and to assess the impacts of port expansion projects or growth in port activities. Emission-producing activities for ports are grouped into three scopes, represented in Table 1. These scopes include port direct, port indirect, and port tenants' emissions according to the ownership and responsibility aspects (World Ports Climate Initiative 2010).

When developing carbon footprint inventory, the detailed approach is highly preferable (Browning 2009). Three data elements are critical in this approach. These elements include the following:

Table 1 Port-related emission sources

Type	Style	Source examples
Scope 1	Port indirect	Purchased electricity for port-owned buildings and operations
Scope 2	Port direct	Port-owned fleet vehicles, buildings, stationary sources
Scope 3	Port tenants	Ships, trucks, cargo handling equipment, rail, harbor craft, port employee vehicles, buildings, purchased electricity

1. Source data (detail the emissions source characteristics, which include size or rating of the engine, type of fuel consumed, engine technology information, age of the engine, manufacturer, model);
2. Activity data (detail how the source operates over time and how engine loads and/or fuel consumption change by mode of operation, distance traveled by speed, power production rates);
3. Emission factors (provide the means to convert the estimates of energy output or fuel consumption into the pollutant emission rates).

Detailed approach closely models actual port operations and can provide emission reduction strategy progress but requires significant time to conduct first inventory. The attempt to adapt the detailed approach was made is this research based on the Qingdao Port case.

4 Seaport Land-Side Carbon Emissions

4.1 Land-Side Mobile Emission Sources Structure and Estimating Methodologies

Land-based emission sources include CHE, HDVs, and RLs, operating within a port area (World Ports Climate Initiative 2010). CHE might consist of terminal tractors, top and side loaders, forklifts, wharf cranes, rubber tire gantry cranes, and skid loaders. HDVs include on-road trucks, buses, and other port vehicles. RLs are divided into line haul locomotives and switch yard locomotives.

The methodologies of seaport land-side emissions calculation are based on WPCI recommendations. The input parameters are collected in Table 2.

1. Cargo Handling Equipment

   The calculation of emissions from CHE 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 helps point out potential targets for emission reduction efforts. It is important for both fuel-based and energy-based calculations to calculate the emissions generated from equipment, using different fuels separately, because the emission factors of each fuel are different.

$$\mathrm{TE}_{\mathrm{CHE}} = \sum_{i=1}^{n} \mathrm{TE}_{\mathrm{CHE}(i)} \tag{1}$$

   where, is the particular type of cargo handling equipment (e.g., forklift).

   Energy-based method

Table 2 Input parameters and symbols interpretation

Parameter	Interpretation	Dimension
Cargo handling equipment		
$\mathrm{TE}_{\mathrm{CHE}}$	The sum of emissions from all the cargo handling equipment per year	tonnes CO_2E
$\mathrm{TE}_{\mathrm{CHE}(i)}$	Total emissions from the cargo handling equipment of particular type	tonnes CO_2E
$R_{\mathrm{p}(i)}$	Rated power (for a particular type of equipment)	kW
$L_{\mathrm{f}(i)}$	Load factor	dimensionless
$O_{\mathrm{t}(i)}$	Operating time per year	h
$E_{\mathrm{fe}(i)}$	Emission factor of the equipment engine	gCO_2/kW-h
$F_{\mathrm{c}(i)}$	Fuel consumption per year	l/year
$E_{\mathrm{ff}(i)}$	Emission factor of the particular fuel consumed	$kgCO_2$/l
Heavy-duty vehicles		
$\mathrm{TE}_{\mathrm{HDV}}$	The sum of emissions from all types of HDVs per year	tonnes CO_2E
$\mathrm{TE}_{\mathrm{HDV}(j)}$	Total emissions from a particular type of HDV per year	tonnes CO_2E
$E_{\mathrm{iter}(j)}$	Emissions caused by the vehicle idling mode in the terminal	tonnes CO_2E
$E_{\mathrm{rter}\ (j)}$	Emissions caused by the vehicle running mode in the terminal	tonnes CO_2E
$E_{\mathrm{rreg}(j)}$	Emissions caused by the vehicle running mode in the region	tonnes CO_2E
$P_{(j)}$	Population of HDV type j in the port truck fleet	dimensionless
$N_{\mathrm{t}(j)}$	Number of truck trips per year	dimensionless
$I_{\mathrm{t}(j)}$	Average idle time	min per truck trip
$E_{\mathrm{fi}(j)}$	Emission factor in idling	gCO_2/h
D_{term}	Average trip distance on-terminal	km
$E_{\mathrm{fr}(j)}$	Emission factor in running	gCO_2/h
D_{reg}	Average region trip distance	km
$F_{\mathrm{c}(j)}$	Average fuel consumed per trip	gallons
$E_{\mathrm{ff}(j)}$	Emission factor of the particular fuel consumed	$kgCO_2$/gallon
Locomotives		
$\mathrm{TE}_{\mathrm{LOG}}$	The sum of emissions from all the locomotives per year	tonnes CO_2E
$\mathrm{TE}_{\mathrm{LOG}(i)}$	Total emissions from the locomotives of particular type	tonnes CO_2E
$R_{\mathrm{p}(i)}$	Rated power (for a particular type of locomotive)	hp
$L_{\mathrm{f}(i)}$	Load factor	dimensionless
$O_{\mathrm{t}(i)}$	Operating time—time in notch per year	h/year
$E_{\mathrm{fe}(i)}$	Emission factor of the locomotive engine	gCO_2/hp-h
$F_{\mathrm{c}(i)}$	Fuel consumption per year	gallons/year
$E_{\mathrm{ff}(i)}$	Emission factor of the particular fuel consumed	$kgCO_2$/gallon

$$\mathrm{TE}_{\mathrm{CHE}(i)} = \sum_{i=1}^{n} \left(R_{\mathrm{p}(i)} \times L_{\mathrm{f}(i)} \times O_{t(i)} \times E_{\mathrm{fe}(i)} \right) \tag{2}$$

Fuel-based method

$$\mathrm{TE}_{\mathrm{CHE}(i)} = \sum_{i=1}^{n} \left(F_{c(i)} \times E_{\mathrm{ff}(i)} \right) \tag{3}$$

2. Heavy-duty Vehicles

   When estimating emissions, generated from heavy-duty trucks, two modes of operation are considered: (1) idle emissions occur, when the engine is on yet the vehicle is not moving; (2) running emissions occur, when the engine is on and the vehicle is also in motion. Greenhouse gas emissions from trucks can also be classified by truck operation area: "on-terminal," where trucks traverse the terminals with their loads, idling to pick up or drop off cargo; "on-port," where trucks enter or exit port property or travel between terminals; and "regional," where trucks operate outside of port property to deliver goods.

$$\mathrm{TE}_{\mathrm{HDV}} = \sum_{j=1}^{n} \mathrm{TE}_{\mathrm{HDV}(i)} \tag{4}$$

where, j is the particular type of heavy-duty vehicle.
Energy-based method

$$\mathrm{TE}_{\mathrm{HDV}(j)} = \sum_{j=1}^{n} \left(E_{\mathrm{iter}(j)} + E_{\mathrm{rter}(j)} + E_{\mathrm{rreg}(j)} \right) \tag{5}$$

$$\begin{aligned}\mathrm{TE}_{\mathrm{HDV(j)}} = \sum \Big(\big(& P_{(j)} \times N_{t(j)} \times I_{t(j)} \times \frac{1\mathrm{h}}{60\mathrm{min}} \times E_{\mathrm{fi}(j)} \big) \\ & + \big(P_{(j)} \times N_{t(j)} \times D_{\mathrm{term}} \times E_{\mathrm{fr}(j)} \big) + \big(P_{(j)} \times N_{t(j)} \times D_{\mathrm{reg}} \times E_{\mathrm{fr}(j)} \big) \Big)\end{aligned} \tag{6}$$

Fuel-based method

$$\mathrm{TE}_{\mathrm{HDV(j)}} = \sum_{j=1}^{n} \left(P_{(j)} \times N_{t(j)} \times F_{c(j)} \times E_{\mathrm{ff(j)}} \right) \tag{7}$$

3. Locomotives

   Unlike heavy-duty diesel trucks, engine load for locomotives is not a direct function of vehicle speed. The activity of locomotives tends to be expressed in terms of "time in notch" or "throttle position" which ranges from idle to one of eight different operating modes, each of which represents successively higher average engine load. Only the emissions associated with the combustion of diesel fuel would be considered in estimating greenhouse gases from these engines.

$$\mathrm{TE_{LOC}} = \sum_{i=1}^{n} \mathrm{TE}_{\mathrm{LOC}(i)} \tag{8}$$

where, i is the particular type of locomotive (line haul or switchers).

Energy-based method

$$\mathrm{TE_{LOC(i)}} = \sum_{i=1}^{n} \left(R_{p(i)} \times L_{\mathrm{f}(i)} \times O_{t(i)} \times E_{\mathrm{fe}(i)}\right) \tag{9}$$

Fuel-based method

$$\mathrm{TE}_{\mathrm{CHE}(i)} = \sum_{i=1}^{n} \left(F_{c(i)} \times E_{\mathrm{ff}(i)}\right) \tag{10}$$

4.2 Qingdao Container Terminal Case Study

In this research, the attempt to apply and adopt the practice and best experience of the worldwide seaports in CO_2 emissions calculation was taken for Qingdao Port in China. The case study consisted of several steps. First, all available relevant documents (annual reports, strategic plans, and statistics) were analyzed. Second, interviews with the responsible managers of Qingdao Qianwan Container Terminal Ltd. (QQCT) were conducted. These interviews were based on a list of questions, derived from the literature review and other case study documents. The results of adaptation and calculation of emissions for Qingdao Port are provided in the next subsection.

4.2.1 Qingdao City and Port Brief Introduction

As a sub-provincial city, Qingdao had permanent resident population of 8.71 million totally in 2012. Qingdao covers an area of 11.6 km^2. Qingdao city has pioneered a new way by applying the low-carbon economic mode to the features of its city development. Qingdao is the industrial center of the West Coast Economic New Zone. The planning area of this Cooperation Region is 190 km^2 with the leading and demonstrative role of Sino-German Eco-Park and Sino-Japan and Sino-South Korea innovative industrial parks, as shown in Fig. 1.

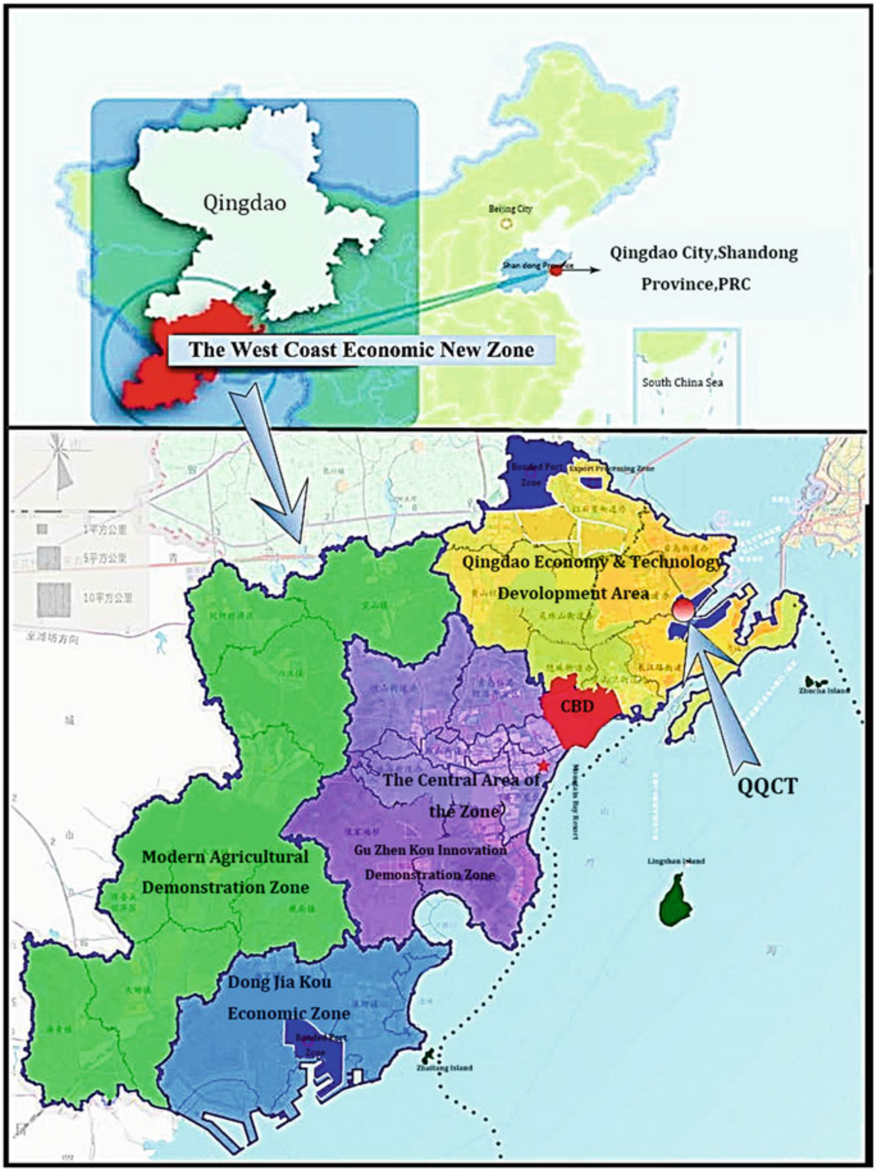

Fig. 1 The west coast economic new zone

The Sino-German Eco-Park is committed to the development of a smart city and is enthusiastically building a top ranking information base in China. The project realizes the following results as thoroughly sense: Internet with ubiquitous broadband and the application of intelligence blending. As a result, a new type of city development will be formed with new characteristics, such as the high integration of smart technologies, high-end development of smart industries, and convenient and high-efficient smart services.

Qingdao Port is located in the Yellow River Basin and on the western Pacific Rim. Port of Qingdao is an important hub of international trade and seagoing transportation. The port has established trade relations with over 450 ports in more than 130 countries and areas. In 2011, the Qingdao Port total cargo volume was 372,000 t and containers volume 13.02 mTEUs. The Port of Qingdao is composed of three areas: Qingdao Old Port, Huangdao Oil Port, and Qianwan New Port. It provides services of loading and unloading, storage and logistics for containers, coal, iron ore, crude oil, grain, etc.

Qingdao QQCT, a joint venture, was founded in July 2000. QQCT operates 11 container berths, which can accommodate six-generation mega-vessels of over 10,000 TEUs. The terminal CY area occupies 2.25 million km^2, enjoying the minimum depth draft water of up to −17.5 m. QQCT, one of the largest terminal operators in the world, has the total berth length of 3,400 m and the designed container throughput of 6.5 million TEUs.

QQCT is located in the West Coast Economic New Zone and only 68 km to Qingdao city through Jiaozhou Bay Expressway. QQCT has efficient road access to Jinan-Qingdao Highway, Yantai-Qingdao Highway, and 308 National Highway. It connects outside area in Shandong Province. Tongsan Highway goes through the North–South coastal line and Qinglan Highway. Starting from the east to the west and Jiaozhou-Huangdao Railway inside the terminal, it connects QQCT to the hinterland. Furthermore, the bridge and the sea channel, opened to traffic in 2011, could also short the distance from QQCT to Qingdao downtown.

Jiaozhou-Huangdao Railway can reach the dock area directly and link the national railway net, which provides great convenience for inland provinces and cities to conduct sea–railway combined transport through QQCT.

4.2.2 Emissions Estimation Results

The year of 2012 was chosen as the basis year of activity. We limit the scope of emissions estimation to the area of QQCT responsibility, which is the main operator of Qingdao Container Terminal, as shown in Fig. 2 Activity-based bottom-up approach is chosen as the main estimating methodology. Hybrid approach is applied for the data collecting (combination of detailed and surrogate approaches). The available data for some ports in developing countries are not sufficient to make a detailed estimation. Some surrogate data are taken from the other sources: US Environmental Protection Agency (EPA) guidence, PoLA and PoLB inventories 2012, which are considered to be the best current practice in inventory development. For CHE emissions evaluation, energy-based approach is used (Eq. 2), which is considered to be more accurate in comparison with the fuel-based approach. For HDV and locomotives, we also use energy-based approach (Eqs. 6 and 9).The boundary of the emissions estimation is limited to the in-terminal, in-port, and in-region container transportation.

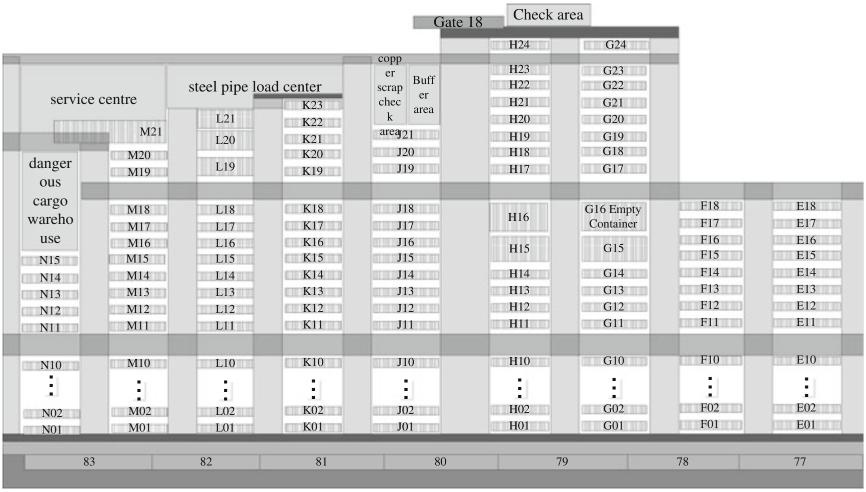

Fig. 2 Qingdao Qianwan container terminal layout

Input data collecting process generally consists of the collecting activity data, represented in Tables 3, 4 and 5, and choosing the emission factors. CHE load factors and operating time are calculated for each month and then summarized per year. Emission factors including those factors for HDVs are taken from the US EPA guidance document (Browning 2009). Locomotives emission factors, expressed in terms of grams of pollutant per kilogram of fuel consumed, are taken from both the California EPA (Air Resource Board 2013) and the US EPA (Office of Transportation and Air Quality 2009).

Figure 3a–d represents the emissions structure by the source category. Results' analysis will be provided in the next section.

Table 3 CHE input data

No.	Types	Count	Engine type	Power, kW	Annual operating hours, h	Load factor
1	RTG	106	Electric	134	3,565	0.42
2	ITV	84	Diesel	75	1,657	0.2
3	Heavy forklift	6	Diesel	450	1,880	0.22
4	Empty forklift	14	Diesel	130	3,231	0.39
5	Small forklift	27	Diesel	37	1,163	0.14
6	Crane	2	Electric	500	360	0.04

Table 4 HDV input data

No.	Heavy-duty vehicle type	Population (number)	Number of truck trips per year	Average idle time/ min per truck trip	Emission factor in idling gCO_2/h	Average trip distance in terminal/ km	Emission factor in running/ gCO_2/h
1	Trucks (container facility)	1,000.0	14,501.0	62.0	4,655.3	1.3	1,293.0
2	Trucks (non-container facility)	100.0	3,741.0	47.0	4,655.3	0.5	1,293.0

Table 5 RLs input data

No.	Locomotive Type	Population (number)	Rated power/ hp	Load factor/-	Time in notch 4/h per year	Emission factor/ $gCO_2/hp\text{-}h$
1	Locomotive (line haul)	2	2,500.00	0.3	950	510.1
2	Locomotive (switchers)	3	2,500.00	0.3	580	505.5

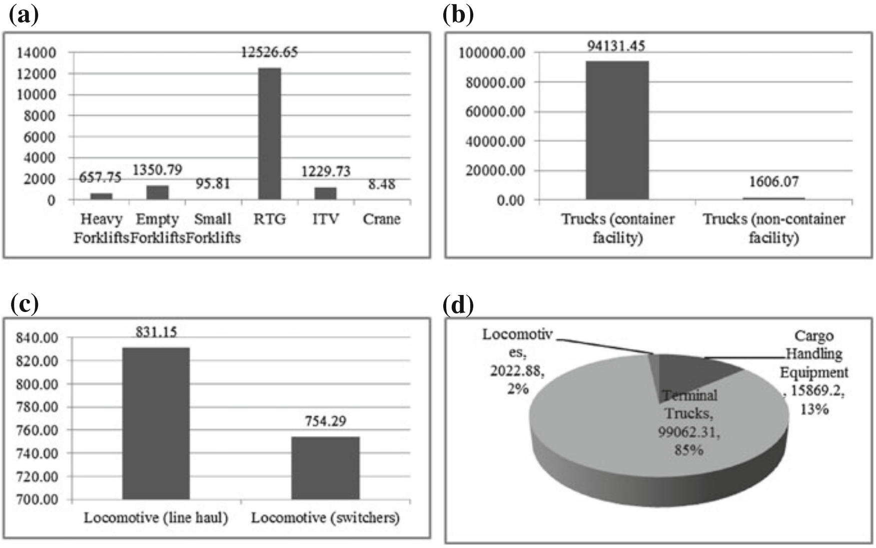

Fig. 3 Emissions structure by the source category, tCO_2E. **a** Cargo handling equipment, **b** heavy-duty vehicles, **c** locomotives, **d** total land-side emissions

5 Discussion

The main aim of the conducted research is to evaluate the CO_2 emissions from the seaport activities and their influence on the city environment as well as to propose some suggestions for the carbon emissions mitigation.

The seaport activity includes both the seaside and land-side operations. Considering the seaside area, many investigations and seaport inventories have proved that the emissions from the oceangoing vessels create the largest amount of emissions on the territory of the seaport. It goes without saying that the seaport authorities should take urgent measures for the decreasing emissions from oceangoing vessels activities.

At the same time, the analysis of the seaport land-side emissions claims for the close attention as well. Seaport land-side infrastructure is a part of urban territory, thus influencing the city ecology. The analysis of the received results shows that HDVs create the largest amount of land-side CO_2 emissions (99,062.31 tCO_2E) in comparison with CHE (15,869.2 tCO_2E) and RLs (2,022.88 tCO_2E) correspondingly. Total amount of CO_2 emissions from QQCT land-side mobile sources in 2012 was evaluated as 116,954.39 tCO_2E.

It should be noticed that the received results could become more representative if the activities of the other terminals in Qingdao Port (oil, dry bulk, and passengers' terminals) were also included in the evaluation. At the same time, the research process detected the problem of the data collection. The input parameters for the emissions evaluation need to be collected from the different sources (different terminal operators). This process supposes their close cooperation in information exchange. As the problem of carbon emissions calculation for the port activities has risen relatively recently, the seaport authorities have not created the uniform informational base used for the emissions calculation.

Apart from, the collected data accuracy also is quite a problematic question. When calculating the carbon emissions, the hybrid approach was used, and some parameters like the emissions factors were taken from the outside sources and the reports of the other seaports, which have created quite a long history of emissions inventories. Thus, one of the outcomes of the conducted research is the necessity of creating the uniform database for the CO_2 emissions calculation, assuming all the stakeholders cooperation.

Despite of the mentioned limitations, the received results could lead us to the following findings and suggestions.

1. Seaport and City CO_2 Emissions
   The diversity of greenhouse gas accounting methodologies currently utilized by cities around the world makes meaningful comparisons of their emissions and the seaport emissions almost impossible. There are no reliable sources providing with the information about the Qingdao city carbon emissions. The Governmental Report 2012 of the Qingdao City Statistical Department gives just the statistics about SO_2 (100,000 t), NOx (120,000 t), and PM (45,000 t) polluters. Among the observed literature, just the results of land-side emissions calculation

Table 6 Chinese cities emissions

City/Province	Source	Year	City emissions, millions tCO_2E	City territory, km^2	Population, millions
Nanjing/ Jiangsu	Bi et al. (2011)	2009	75,43	6,582	8
Suzhou/ Jiangsu	Wang et al. (2014)	2010	169,44	8,488.42	10.46
Shanghai	Liu et al. (2011)	2008	188,32	6,340.5	25
Hong Kong	Harris et al. (2012)	2008	42	1,104	7.18
Xiaolan/ Guangdong	Feng et al. (2014)	2010	2,072	71.96	0.317
Qingdao/ Shandong	–	–	–	11.6	8.71

of Port of Barcelona—156,206 tCO_2 (in 2008)—could be taken into consideration for the comparative purposes (QQCT—116,954 tCO_2, in 2012). In addition, the results of the carbon emissions from some Chinese cities, towns, and regions were given in Table 6 for the purpose of some general comparison. This outcome indicates the theoretical and practical gap in the methodologies of the cities emissions evaluation and the seaport emissions, caused by the increasing land-side activities. This aspect needs further development in the academic research.

2. Qingdao Seaport Case.
   The results of the empirical research of QQCT indicated that the largest amount of the CO_2 emissions is caused by the HDVs activities. The terminal authorities should focus on the measures for their reduction in the first place. But the measures for the CO_2 emissions reduction from CHE and RL are necessary to be developed as well. The possible CO_2 emissions mitigating strategies could be combined into several main categories such as equipment replacement, clean fuels, emission control technologies, operational improvements, and idle reduction technologies. Equipment replacement implies replacement with engines meeting cleaner standards. Clean fuels mean low- to ultra-low-sulfur diesel fuel, emulsified diesel fuels, oxygenated fuel (O_2 diesel fuel), biodiesel, LNG, and CNG. Emission control technologies usually might involve diesel oxidation catalysts (DOCs), diesel particulate filters (DPFs) with PM emission reduction benefits, and selective catalytic reduction (SCR). Operational improvements could be implemented through the using of radio frequency identification (RFID) and optical character readers (OCR) to enhance the efficiency of gates and terminals. Idle reduction technologies include truck stop electrification (provides cab power for the truck while a truck is stationed in an area for a period of time) as well as automatic shutdown and start-up systems, battery power, auxiliary power units, diesel-driven heating systems for HDVs

Table 7 Energy use and emissions for typical transport units of different modes

Energy use/Emissions g/t/km	Rail electric	Rail diesel	Heavy truck
kWh/t/km	0.043	0.067	0.18
CO_2	18	17	50
SO_x	0.44	0.35	0.31
NO_x	0.10	0.00005	0.00006
PM	n/a	0.008	0.005

and automatic engine stop–start controls (AESS), auxiliary power unit (APU), diesel-driven heating systems (DDHS), shore power plug-in unit, and a hybrid switching locomotive for RLs.

These strategies could be implemented through the following instruments: lease requirements; tariff charges; voluntary programs; capital funding; and memorandum of understanding with the port, regulatory agencies, and other stakeholders.

Along with the mentioned measures for CO_2 emissions reductions from HDVs, the strategy of switching on the rail transportation could be carried out by the QQCT authorities. The rail transport is considered to be more efficient than trucks, as represented in Table 7.

Using rail transportation is closely connected with the dry port concept. For environmentally conscious shippers, it offers the possibility of using rail mode instead of road mode and thus decreases the environmental impact of their products. Rail operators obviously benefit from dry ports, especially from distant dry ports, because it increases the scale of their business in a comparatively lucrative segment. This is particularly important for rail transport depending on economies of scale and can make continental services viable although ports are reluctant to bring in containers not relating to shipping. At least, the fixed costs of the intermodal terminal itself can be distributed between transshipments when adding the dry port flows. Road transport operators do not benefit from this configuration directly since the aim is to move transport of containers from road to rail, but they are still involved in the intermodal transport chains. As they are not particularly paid for waiting in congestion or at crowded gates at the port, they can serve the dry port surroundings with shorter hauls and better total revenues.

The strategy of dry port implementation is extremely vital for QQCT as this container terminal is located on the territory of Qingdao West Coast Economic New Zone that follows the strategy of low-carbon development and smart city concept. In addition, Qingdao city plans to implement the new construction strategy and to establish an eco-coastline along Jiaozhou Bay with different functional emphases. For example, it might include conferences and exhibitions in Hongdao and logistics operation in Huangdao District. The new construction strategy is expected to fuel economic growth of Qingdao's satellite cities.

QQCT needs to take into account the mentioned development policies and work in collaboration with its tenants, terminal operators, and governmental authorities when developing its infrastructure and CO_2 emissions mitigating strategies.

6 Conclusion

The conducted research resulted in the following conclusions:

1. The seaports need to develop the comprehensive database for the precise CO_2 emissions estimation in cooperation with all the stakeholders;
2. The seaport mobile sources emissions should be included in the city inventories, and further improvement in city GHG inventory procedures is warranted;
3. The research gives the suggestions for QQCT in decreasing CO_2 from CHE, HDV, and RL via the operational improvements, using clean fuels, emissions control technologies, and idle reduction technologies;
4. The implementation of the dry port concept, supposing the modal shift from road to rail transportation, seems to be the most effective strategy, considering the governmental region development in future.

The further research might be developed in the mobile sources, used in dry bulk and oil terminal, the analysis of the dry port concept implementation, and the cities GHG inventories methodologies, including the seaport activities.

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