

Article

A Sustainable Port-Hinterland Container Transport System: The Simulation-Based Scenarios for CO₂ Emission Reduction

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Abstract: This paper calculates the CO₂ emissions for the port-hinterland container transport system and proposes possible emission reduction measures. This paper considers the Dhaka–Chittagong port-hinterland transport system in Bangladesh. The port-hinterland transport system represents 70% of the total international maritime containerised trade, including more than 2.0 million twenty-foot equivalent units (TEUs) per year. By implementing different scenarios using a simulation approach, this research suggests a substantial reduction in CO₂ emissions for the port-hinterland transport system. The scenarios include infrastructure development and performance and operational efficiency improvement in the port and modal shift for the hinterland. In formulating the scenarios, the current performance statistics of the port and its hinterland as well as the possibility of the implementation of these scenarios are carefully analysed. The findings depict that Bangladesh could significantly contribute to the reduction in port-hinterland CO₂ emissions by implementing the suggested scenarios.

Keywords: CO₂ emission reduction; port-hinterland container transport system; simulation-based scenario



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1. Introduction

Sustainability comprises the environmental, social and economic dimensions of ports. The environmental perspective is associated with noise pollution, air quality, dredging operation and dredging disposal. The economic perspective is very much concerned with financial performance, operational performance and investment for further performance enhancement. The social perspective covers the direct and indirect contributions to employment, the port–city interaction and relationship, liveability at the port neighbourhoods and the contribution to education and knowledge development [1,2]. Among these various dimensions of sustainability, CO₂ emission reduction directly affects the air quality, the liveability of the area surrounding the port and the operational efficiency and indirectly affects the other dimensions [3]. For example, by creating more jobs in port-related industries and more operational activities, ports are enabling more travel for people, which is indirectly linked with the port operation and port-related CO₂ emissions. As a result, CO₂ emissions from shipping operations are receiving greater emphasis as their contribution to global carbon emissions is expected to rise in the coming years. Even though shipping activities account for 2.4% of global CO₂ emissions, it is believed that this will be tripled by 2050 [3]. Ports, as the central stakeholder of shipping activities, have a greater role to play from the positions of regulator and operator. The main sources of carbon emissions within the port include the vessels calling the port, cargo handling equipment and inland cargo movement using different modes. Ports can play a role in all these areas by implementing different regulatory, monetary and operational measures to reduce emissions.

There is evidence that not only operational costs but also CO₂ emissions are influenced by operational efficiency in ports [4]. However, a port performance evaluation considering

the sustainability aspects proposed by Castellano and Ferretti [5] found that ports with the largest performance improvement in Italy are also the highest GHG emitters and that, at the same time, these ports had the port authorities who were most committed to adopting sustainable practices. This explains the notion that operational performance improvement means more operational activities, leading towards more carbon emissions. However, this is from the perspective of total emissions, and the emissions per container or per tonnage could show a decline. Another important aspect is the environmental impact of hinterland transport, which is basically an extension of the port services in which the actual producers or consumers are originated or destined. Therefore, sustainable port-hinterland connectivity can directly promote ports to claim their sustainable profiles [6]. Geerlings [7] pointed out that sustainability in the transport sector can be achieved in four ways, comprising three short-term actions and one long-term action. The short-term actions include (i) a reduction in the impact of modes by technological means, (ii) shifting to less damaging modes of transport and (iii) a reduction in the total amount of transport undertaken. The long-term action is the improvement of spatial planning, which can reduce the distance between activities and lower the need for mobility. Similarly, these actions can also be applied to achieve port sustainability.

In this paper, CO₂ emissions in Chittagong port and its hinterland are calculated, and some scenarios are implemented via simulations that contribute to sustainability by reducing CO₂ emissions. Firstly, the approximate fuel consumption in various operational activities of Chittagong port, which are marine operations, terminal and yard operations, and gate operations, as well as in the hinterland transportation of the port are calculated. The fuel consumption data are then used for the calculation of total CO₂ emissions from the Chittagong port and its hinterland operation. Then, some scenarios are implemented via simulation to examine the impact on fuel consumption and CO₂ emission reduction. In the development of the scenarios, the aspects of infrastructure, operational efficiency and modal shifting are taken into consideration. The findings show that a substantial CO₂ emission reduction is possible in the case of Chittagong port and the Dhaka–Chittagong hinterland transport. As the 58th largest container port in the world in terms of throughput and the main gateway port in Bangladesh, Chittagong port handles around three million TEUs annually and more than 90% of Bangladesh's containerised international trade. Notably, the Dhaka–Chittagong hinterland transports around 70% of these containers. As a result, any CO₂ emission reduction in the case of the port-hinterland container transport system can significantly impact the local emission scenarios. On the other hand, the existing port-related literature has not paid sufficient attention to port hinterlands from an environmental sustainability perspective. Referring to a recent study on the competitiveness of this port, users suggest that the environmental practices have the least competitive aspect for port attractiveness [8]. Therefore, the calculation of CO₂ emissions and the proposed emission reduction solutions via the implementation of different scenarios can contribute to the existing port management literature from an environmental sustainability perspective. In addition, this research provides implications for examining port users' CO₂ emissions while conducting their business, thereby contributing to port service providers and policymakers when formulating sustainability policies for port-hinterland transportation.

The paper begins by briefly discussing the literature concerning port-hinterland CO₂ emissions, the Chittagong port and the Dhaka–Chittagong corridor and their performance data in Section 2. The performance data are the main input data for calculating CO₂ emissions and designing and implementing various scenarios via simulation analysis. Then, the CO₂ emission calculation methods and materials are briefly presented in Section 3. In Section 4, the total CO₂ emissions in the Chittagong port and the Dhaka–Chittagong hinterland and the impact of the implementation of different scenarios and simulations on port emissions and modal shift on hinterland emissions are observed and discussed in detail. It is worth mentioning that Sections 2–4 include a respective data description and discussion with a consideration of data that is relevant to each section. Section 5 summarises the findings and the contributions of the paper, and Section 6 concludes the paper.

2. Literature Review

2.1. CO₂ Emissions in Port-Hinterland Transport System

In realising the current and future contributions of the maritime sector to global CO₂ emissions, much emphasis has been placed on the CO₂ emissions from shipping and port activities [3,9]. According to Wang and Peng [9], in the case of ports' CO₂ emissions, the focus was primarily on shipping activities and handling activities, while an increasing recent focus on the inland distribution system can also be noted in other studies [10]. For example, Chang and Song [11] estimated the fuel consumption of the container vessels in the case of Incheon port, and this estimation considered various sizes of vessels including the voice from the anchorage to the berth. This research only considers marine operations, focusing the location of the highest possible emissions and the types of the highest emitting vessels. On the other hand, Huzaifi and Budiyo [12] calculated the CO₂ emitted by the Jakarta International Container Terminal, considering the services from berthing to removing containers from the port and mainly examining berthing and terminal operations but not the waiting time. This research focuses on the importance of terminal layout on CO₂ emissions. Another study by Geerlings and van Duin [13] concluded that terminal layout is one of the most effective methods of CO₂ emission reduction.

Emissions from the terminal equipment and the measures for reduction in the port of Valencia were analysed by Martínez-Moya and Vazquez-Paja [14]. They categorised the highest emitting equipment and suggested retrofitting the RTGs and introducing LNG powered tractors. Alternative energy and fuels were identified as important influential factors for decreasing energy consumption and carbon emissions by the IMO and other reviews [15]. Utilizing renewable energy sources for port equipment operations is an increasing area of interest in current academic research [16]. On the other hand, the scheduling problems of port operating equipment have been extensively observed in the existing literature. For example, the carbon efficient scheduling of rubber-tyred gantry cranes (RTGs) and electric rubber-tyred gantry cranes (ERTGs) was analysed by Chen and Zeng [17]. A specific focus on emission reduction by optimizing truck operations in the port areas was also observed from Chen and Govindan [18]. Their findings indicated that the reduction in truck waiting time and shifting in truck arrival time can significantly reduce the emissions.

Liao and Tseng [19] calculated the CO₂ emissions for Taiwanese ports and their inland distribution system and came up with the solution that changing a transshipment route for the inland distribution of the containers can reduce the CO₂ emissions. Shin and Cheong [20] calculated the emissions in Busan port for all the port-related equipment, including marine vessels, cargo handling equipment, heavy duty trucks and rail locomotives. They mainly located the highest emitting areas and the relation between emissions and the amount of cargo. The case of Qingdao port in China was analysed by Mamatok and Huang [21] via the implementation of scenario-based simulations. They argued that scenarios such as operating time optimization, spatial measures, equipment modernization and modal shift are important to CO₂ emission reduction. The port-hinterland container transport system including three ports was analysed by Li and Kuang [22] considering various scenarios on port selection based on new routes and multimodal transport as well as their impacts. In order to reduce carbon emissions in the port of Shenzhen, possible suggestions, such as improving loading and unloading efficiency, connecting to shore power and using low sulphur fuel oil, were proposed by Yang and Cai [23]. In parallel to some of the solutions for reducing CO₂ emissions from port-related activities that were addressed in the above discussion, Yun and Xiangda [24] suggested that the most studied measures used to reduce CO₂ emissions in port-related activities are onshore power supplies, reduced speed in water channels and reduced turnaround time. It is observed that all the measures implemented to reduce CO₂ emissions highlighted above broadly cover the aspects of operational efficiency and infrastructural development. Therefore, in the case of formulating the scenarios for Chittagong port, the aspects of operational efficiency and infrastructure development are taken into consideration.

2.2. CO₂ Emissions in Different Inland Transport Systems

The four methods for achieving sustainability in transport that were suggested by Geerlings [7] were further explained and elaborated by Hou and Geerlings [6] and the IPCC [25] from the perspectives of actions to be undertaken. Several studies considered these methods to attempt to significantly reduce carbon emissions from road transportation [26,27] because roads are still the predominating contributor of carbon emissions in the transport sector. For example, McKinnon and Piecyk [28] offered recommendations for the emissions factor in chemical transport operations in Europe, for which they emphasised modal split, restructuring the supply chain, improving vehicle utilization and fuel efficiency. Wang and Peng [9] showed a comparative fuel consumption and emissions factor for three different modes, namely, road, rail and inland ships, in China for the period from 2006 to 2011. They suggested that phasing out obsolete and aging equipment, installing energy saving devices and new energy saving equipment, optimizing the container distribution network, implementing multimodal transport, improving the logistics information sharing and implementing a clean truck program can be promising solutions for CO₂ emission reduction. A comparatively generic CO₂ emission calculation was conducted by the IPCC [25]. The report included an extensive discussion of CO₂ emission reduction pathways in which vehicle technology and propulsion systems and the behavioural aspects of accepting their use in real life, modal shifts, infrastructure, new routes, the relocation of production and the reconfiguration of the global supply chain were covered.

The comparative picture of CO₂ emissions from the above studies is presented in Table 1 below. Even though there are dissimilarities among the quantity of emissions for different modes in the literature, it provides an understanding of the degree of emissions among the different modes.

Table 1. Comparison of gCO₂/ton-km emissions factors in different studies.

Modes	Type of Vehicle	McKinnon and Piecyk [28]	IPCC [25]	Wang and Peng [9] ¹
Road	Heavy duty	59–109; average: 62	100–190	188.50
	Medium		240–370	
Rail	Heavy	7.3–23; average: 22	18–25	8.30
	Light		26–33	
IWT		31		18.85
Barge			10–50	
Coastal container ship		14		
Rail–road		24–30; average: 26		
IWT–road		32–37; average: 34		
Shortsea–road		16–23; average: 19		

Source: Compiled by the author based on McKinnon and Piecyk [28], IPCC [25] and Wang and Peng [9] (¹ According to this research, in 2011, rail transport consumed 26.40 kg of diesel to transport 10,000 ton-km, whereas road transport used 6 L of diesel to transport 100 ton-km and inland shipping consumed 6 kg of diesel to transport 1000 ton-km. In order to convert this consumption to gCO₂/ton-km, for example, the 26.40 kg of diesel to transport 10,000 ton-km using rail is multiplied by 1000 to convert the consumption from kg to gram and then divided by 10,000 to obtain the amount gram (g) per ton-km and, finally, multiplied by the emissions conversion factor for diesel, which is 3.141, to obtain the final emissions for rail transport, which is 8.3 gCO₂/ton-km = ((26.40 × 1000)/10,000) × 3.141. Although the figure for road is given in litres, to convert litres to grams, the process is the same: multiply by 1000. Converting these data to the CO₂ emissions factor shows that the respective emissions for road, rail and inland shipping is approximately 188.5 gCO₂/ton-km, 8.3 gCO₂/ton-km and 18.85 gCO₂/ton-km).

Although the fuel consumption is very much associated with the type of vehicle, its age, the type of fuel in use and the infrastructure of the country of operation, the emission range observed in Table 1 for IWT barges or inland or coastal shipping show some sort

of similarities. The $\text{gCO}_2/\text{ton-km}$ emissions suggested by McKinnon and Piecyk [28] and Wang and Peng [9] lies within the range of inland shipping suggested by the IPCC [25]. It is important to highlight that the lower level of emissions mostly for road and rail represents the vehicles having dual fuel or technically sound combusting facilities. In the case of the emissions figure for rail, the calculations by McKinnon and Piecyk [28] and the IPCC [25] show relatively close figures, whereas the findings from Wang and Peng [9] show very low emissions from rail. On the other hand, the emissions figure for road transport shows some similarities between the IPCC [25] and Wang and Peng [9] but a significant difference with McKinnon and Piecyk [28]. It is further observed that, as the carrying load increases, the $\text{gCO}_2/\text{ton-km}$ starts declining, and this could be the reason behind a notable difference among the emission figures from these studies. McKinnon and Piecyk [28] showed that a carrying load for road from 10 tons to 30 tons reduces the emissions from 80 $\text{gCO}_2/\text{ton-km}$ to 50 $\text{gCO}_2/\text{ton-km}$. In their emissions calculations, they have considered a typical 40 ton capacity truck with a carrying load of 26 tons. Moreover, McKinnon and Piecyk [29] highlighted the role of interruption in vehicle movement as an important factor for road transport fuel consumption. The study pointed out that a truck carrying a 40-ton load and achieving an average speed of 50 km/h would consume 28, 52 and 84 L of fuel per 100 km if it stopped zero, one and two times per km. Therefore, variability seems quite logical in the case of the emissions factor for different places of operation, vehicles and road conditions. The IPCC [25] study showed that if the load factor increases the per ton-km emissions reduces for rail too. As shown in Table 1, the rail emissions reduce from 26–33 $\text{gCO}_2/\text{ton-km}$ to 18–25 $\text{gCO}_2/\text{ton-km}$ if the load is heavy. Moreover, the emission calculation by IPCC (2014) [25] emphasised that the measure is very much indicative here as there are not many comprehensive studies covering the full range of vehicles and technologies that are available. Therefore, to sum up the above discussion, it is observed that the CO_2 emissions for different modes in different regions could show significant variations. Among others, the type of vehicle, its age, the type of fuel in use and the infrastructure of the country of operation are important factors to consider. In order to calculate the CO_2 emissions in the case of hinterland transport, therefore, the real data on these factors are very important. However, if not available, the overall ranges represented in the various studies can be used, at least, to have some indicative measurements of the emission differences among modes. In this study, the emissions factor for road transport is proposed as 180 $\text{gCO}_2/\text{ton-km}$, which is within and close to the upper limit for the heavy duty truck emissions calculated by the IPCC [25] and very close to the emissions factor calculated by Wang and Peng [9]. For rail, it is proposed as 26 $\text{gCO}_2/\text{ton-km}$, which is close to the upper limit of the range calculated by McKinnon and Piecyk [28] and almost same as the highest value and the lowest value of both the heavy- and light-duty rail emission ranges calculated by the IPCC [25]. On the other hand, in the case of IWT, the emissions factor is considered 34 $\text{gCO}_2/\text{ton-km}$, which is very similar to that of the IWT–road combination calculated by McKinnon and Piecyk [28] and within and close to the upper limit of the range calculated by the IPCC [25]. The proposed emissions factor for IWT is higher than the emissions factor calculated by Wang and Peng [9]. If we compare the proposed emissions factor with the different ranges identified from the literature and summarised in Table 1, it is observed that, for road, rail and IWT, they have close to the highest possible emissions considering their heavy-duty cargo, which can at least indicate the highest possible total emissions from the individual sectors.

2.3. Chittagong Port and Its Performance

Bangladesh is the 41st largest economy in the world and has shown an average GDP growth rate of around 6% in recent decades. Its share of international trade comprises 35% of Bangladesh's national economy. Being the second largest exporter of readymade garments in the world, the country is showing prospective growth in the garment-related sectors such as textile, knitwear and others. The growing import and export of garments is highly dependent on maritime transportation. The Chittagong port is the prime facilitator

of garment trade, handling more than 90% of the international maritime trade of the country. The port shows an average 9% growth in the case of total cargo in tons, 6% growth in the case of container throughput in TEUs and more than 7% growth in the case of the total number of vessel calls, as presented in Table 2.

Table 2. Throughput and Vessel Call.

Year	Total MT	Growth	Total TEUs	Growth	Vessel Calls	Growth
2016	77,255,731		2,421,880		3014	
2017	85,246,948	10.344	2,667,223	10.130	3370	11.812
2018	96,311,224	12.979	2,903,996	8.877	3747	11.187
2019	103,077,736	7.026	3,088,187	6.343	3807	1.601
2020	103,209,724	0.128	2,839,977	−8.037	3728	−2.075
2021	116,619,158	12.992	3,214,548	13.189	4209	12.902
Average growth		8.694		6.100		7.085

Source: Compiled and calculated by author from Annual Report 2019–20 and Chittagong Port Authority (CPA) website [30,31].

Some of the other performance indicators including, for example, turnaround time, dwell time, berth occupancy or utilisation, and equipment availability are readily available from the Chittagong Port Authority (CPA) Annual Reports, which are presented in the Table 3.

Table 3. Different efficiency indicators.

Efficiency Indicators	Years					
	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20
Ship turnaround time (days)	4.26	2.79	2.83	2.68	2.88	2.86
Dwell time of container (days)	17.48	11.88	11.15	10.81	10.78	9.99
Berth occupancy (in %)	65.04	73.95	76.93	93.38	90.55	89.42
Equipment availability (in %)	60.63	54.06	46.69	45.63	45.64	45.03

Source: Compiled by author from CPA Annual Reports [30,32–35].

In Table 3, it is observed that the berth occupancy and equipment availability indicators are showing low performances, and this is because of the lack of efficiency and infrastructure development complying with the growth of container handling. The berth occupancy rate has reached 90%, which is alarming. According to Alderton [36], when the utilisation rate of port resources exceeds 70%, congestion starts. Haralambides [37] pointed out that the utilisation rate is around 75% when congestion starts to set in. On the other hand, turnaround time and dwell time on a year-by-year basis show almost similar durations, which also indicates low performance compared to international practices. At an international level, the median turnaround time is 0.7 days for a container ship and 0.97 days for a typical ship [38]. It is important to mention that the turnaround time calculated by the CPA in Table 3 only has taken into consideration the berthing and unberthing time without incorporating the waiting time. An analysis of the berthing schedule collected from the CPA for 90 vessels in 2020 shows that, before berthing, a container ship needs to wait for 6 days on average (an example berthing schedule is attached as Appendix A). A similar analysis of the berthing schedule of 45 vessels in 2022 shows that ship waiting time on average is 4 days [39]. The port is showing a very high berth occupancy (Table 3), which is an indication of ship congestion in the port. This is a significant delay affecting the supply chain and needs to be considered in the lead time analysis. Based on the above discussion, a process flow of the Chittagong port for the container handling services is

presented in Figure 1, which includes the sequence of different services and the required average time in days. Although Figure 1 only displays the import of containers, the export follows the same process in reverse.

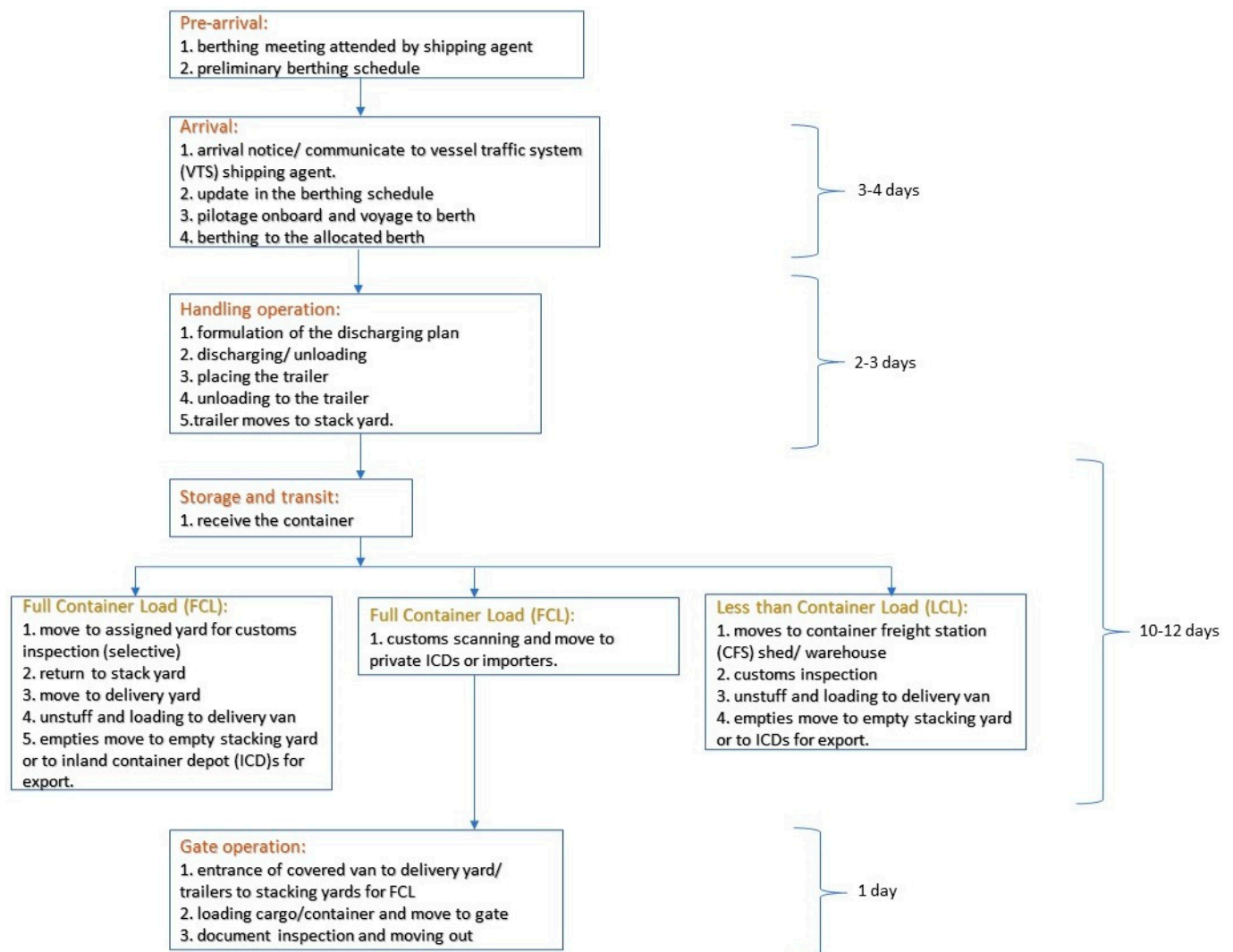


Figure 1. The process flow with required times in Chittagong port. Source: prepared by the author based on different sources.

Given the above performance data, the yard utilisation ratio, which is the ratio of the container holding capacity to the number of containers on hand, has been examined for two randomly selected periods of time in June 2020 (an example vessels' particulars and yard utilisation data sheet is attached as Appendix B) and May 2022 [40]. It shows that, in 2020, the yard utilisation ratio was more than 75%, whereas in 2022, it was close to 90%, which is also very high and indicates a container congestion in the yard operation.

The container handling facilities in Chittagong port include the general cargo berth (GCB), the Chittagong Container Terminal (CCT) and New Mooring Container Terminal (NCT). The GCB is traditionally dedicated to the handling of bulk commodities, but to cope with the increasing pressure of the containerised trade, part of it has now been dedicated to container handling. There is a total of 11 berths under the GCB, but 6 berths are used for general cargo handling and 5 berths are used for handling the container ships. In the CCT and NCT, there are 8 berths dedicated to container handling, totalling 13 berths for container handling for the CPA. Table 4 shows the year-wise and terminal-wise infrastructure data.

Table 4. Comparative Container Handling Facilities.

Items	Quantity 2021	Quantity 2020	Quantity 2017–18	Quantity 2015–16
Container berths by number	13	11	11	11
Holding capacity (GCB + CCT + NCT+) in TEUs	49,018	49,019	38,917	36,357
Yards in number	22	22	22	20
Quay gantry crane in number	14	14	4	4
Rubber tyred gantry crane (40-ton capacity) in number	41	41	21	19
Rail-mounted yard gantry crane (40-ton capacity) in number	1	1	-	-
Mobile harbour crane (84-ton capacity) in number	5	3	2	2
Straddle carrier (4 containers high) (40-ton capacity) in number	44	48	36	38
Straddle carrier (2 containers high) (40-ton capacity) in number	1	2	2	
Reach stacker (45-ton capacity) in number	17	11	15	11
Forklift truck (42-ton capacity) in number	-	3	5	5
Forklift (spreader) (16-ton capacity) in number	4	9	17	19
Reach stacker (7-ton capacity) in number	9	9	6	6
Container mover (50-ton capacity) in number	-	8	5	5
Container mover (32-ton capacity) in number	8	-	-	-

Source: Compiled by author from Chittagong Port Overview [41–44]. Note: the blank cell (-) means there is no such equipment for that particular year.

Among the terminals, the GCB handles all the self-geared vessels. This terminal does not have any quay gantry cranes, whereas CCT and NCT are installed with quay gantry cranes. It is observed that the port had only four quay gantry cranes till the beginning of 2020. The CPA procured 10 new gantries in 2020 leading the ports to currently have 14 gantries in operation. Before these 10 new gantries, the 4 gantries were installed in the CCT. To understand the crane performance, the throughput of the CCT and the NCT is examined. It is found from the CPA officials and operators that the average output of a quay crane is 22 TEUs per hour and an operating hour is around 20 h considering some wastage of time in 2020. An improvement is possible in this area also as, on large ports, the average crane output can reach 25–40 moves per hour [45]. In Australia, it is observed that the operating minutes per moves ranges from 0.92 to 1.32 min [46]. Even if the highest duration of 1.32 is considered, as a general assumption, 45 containers can be handled per hour. According to Bartošek and Marek [47], a quay crane can conduct about 30–50 moves per hour in practice. The type and design of the crane could be a factor here, but, no matter which are used, from the above examples it could be stated that Chittagong port is lagging behind in the context of performance and operational efficiency. In the formulation of different scenarios, all these infrastructural improvement and performance data are taken into consideration to examine the impact of infrastructure and performance improvement for CO₂ emissions.

2.4. Dhaka–Chittagong Hinterland and Its Performance

The port is around 300 kilometres (km) away from the primary growth centre of the country. The main freight corridor in Bangladesh carries around two million TEUs annually. The corridor is well connected to the Chittagong port via roads, railways and inland waterways [48]. Road transport carries more than 90% of container cargo, while rail transport carries 5–6% and inland waterway transport (IWT) has a share of around 1%. For export and import, the port is supported with a total of 21 inland clearance depots (ICDs). Among these 21 ICDs, 18 are located in the adjacent area of Chittagong port. They are mainly used for stuffing/unstuffing containers. The containers move from the port to the ICDs and are stripped with their contents placed onto trucks or covered vans for inland destinations. In contrast, all the export cargo is moved from their origin, by trucks or covered vans, to the ICDs where it is stuffed in containers to move to the port for final shipment [49]. However, for rail and IWT all the containers are transported to ICDs located in the Dhaka region where the stuffing/unstuffing operations are undertaken. There is one inland container terminal located in Dhaka with an annual handling capacity of 90,000 TEUs, which is connected by rail to the Chittagong port [50]. Two inland container terminals are operating near Dhaka, connected by IWT to Chittagong port, with a total handling capacity of around 250,000 TEUs annually [51,52].

The essential features of the three different modes connecting the Dhaka–Chittagong corridor to the Chittagong port are presented in Table 5. It is observed that the IWT transit time is very long compared to road and rail, and it requires more time due to the lack of regular and timely services. But in the cases of road and rail, there are always problems of congestion.

Table 5. Basic features of three different modes.

Mode	Approximate Average Distance in km	Transit Time in Hours
Road	250	10
Rail	310	18
IWT	300	36

Source: Compilation by the authors based on [53] and data provided by transport operators.

3. Methodology and Materials

The fuel consumption in different port activities is very much associated with their time performance. The various units or equipment operating in different areas of ports, including the cargo vessels, service vessels, handling and other terminal equipment, trucks and trailers, are all emitting CO₂ emissions, and the longer they operate the more they emit. The concept here is estimating emissions based on energy consumption when using different operational units or equipment to undertake different activities or movements and the distance between activities by different operational units or equipment [3,19,20]. For example, in order to calculate carbon emissions in a container terminal, Budiyo and Huzaifi [54] categorised the fuel or energy consumed by a container crane, handling equipment and terminal trucks and estimated a certain period of working time. In the case of Chittagong port, a similar methodology is used in which alongside the port activities in CCT and NCT, the emissions from the hinterland distribution for these two terminals are also taken into consideration. After calculating the amount of fuel consumption for different activities, it is then converted to CO₂ emissions using the conversion factor from the Fourth IMO GHG study 2020 [55]. Therefore, to calculate the CO₂ emissions from CCT and NCT in Chittagong port from shipping, handling, gate operations and the inland distribution including the Dhaka–Chittagong corridor, the following equation, used to keep consistency with Budiyo and Huzaifi [54], and the operational order discussed in Section 2.3 are used:

$$F_{cph} = F_{cm} + F_{ty} + F_g + F_{cdc} \quad (1)$$

where:

F_{cph} ~ fuel consumption in port and hinterland;

F_{cm} ~ fuel consumption from container ship and marine operation;

F_{ty} ~ fuel consumption in terminal and yard;

F_g ~ fuel consumption in gate operation;

F_{cdc} ~ fuel consumption in Dhaka–Chittagong corridor.

Looking at the performance data presented in Section 2 (Sections 2.3 and 2.4), it is observed that there are plenty of opportunities to improve the performance in the port as well as the hinterland area. In the case of marine operations, the ship waiting time and turnaround time were considered for, respectively, 3 and 2 days in 2020 (Figure 1), during which the ships were generating CO₂ emissions as the auxiliary engines of the ships were running. Therefore, the improvement in the ship waiting time and turnaround time by reducing the current time of 5 days can achieve CO₂ emission reduction. It is notable that the reduction in the turnaround time will enable the port to handle more containers, which requires more tugging and other services and may increase CO₂ emissions, but the per TEU CO₂ emissions might be reduced. In the case of the terminal and yard operations, the performance measurement is considered from two aspects: one aspect is the number of days the container is staying at the yard, and the other aspect, concerning productivity, is the operation hours and the per hour output of different equipment. Taking into consideration the above two aspects, this will also result in higher CO₂ emissions due to the increase in employment hours of the equipment as a result of performance improvement. Although this is in the case of overall emissions only, the per TEU emissions might be reduced. In the case of gate operations, the duration of trucks in the port and the extra combustion of fuel due to congestion are measured. All these data are discussed in Section 2.3 and collected from the CPA web sources, and some missing data from the Port and Traffic Department of the CPA are included in the relevant sections of the paper.

In the case of the hinterland, as roads carry more than 90% of containers sent to the Dhaka region, and since the empirical research suggests the possibility of a modal shift [53], the saving of fuel due to a shift of containers to a more economically and environmentally efficient mode of transport from the road is calculated. In calculating the CO₂ emissions for three different modes connecting the Dhaka–Chittagong hinterland, the data on the types of vehicles and the transport and other infrastructural facilities are important to use, at least, for road transport as road transport comprises more than 90% of the market share for containers. In order to understand emissions from road transport on this corridor, the various road transport factors along the corridor, including the types of vehicles, average speed, distance and the fuel efficiency data, are collected from the draft Road User Charge 2016–17 report published by the Roads and Highways Department, Bangladesh [56]. According to this report [56], the freight transport in Bangladesh is composed of three types of trucks, namely, heavy and articulated trucks, medium trucks and small trucks. It defines the heavy and articulated trucks as those that can carry more than 7.5 tons of payloads. The medium trucks are those that can carry 3 tons of payloads. The registered trucks operating in the country show that 2% of trucks are articulated, 47% are heavy trucks and 16% are medium trucks. Therefore, considering the loading capacity of these trucks, it seems that only the heavy and articulated trucks are the most suitable carriers to run in the Dhaka–Chittagong corridor. However, it is observed that some medium trucks are also involved in carrying goods along the corridor [57]. Therefore, in calculating the emissions, mostly heavy trucks in operation are considered, while the operation of very few articulated and medium trucks are considered for average fuel consumption data. As a result, the following equation from Uddin and Mizunoya [57] is used, which includes activity of the truck such as the total amount of traffic, travel time, average speed and the fuel consumption rate:

$$F_{cdc} = N_{traffic} * T_t * \frac{v}{F_e} \quad (2)$$

where:

F_{cdc} ~ fuel consumption in Dhaka–Chittagong hinterland;

$N_{traffic}$ ~number of vehicles in traffic;
 T_t ~travel time;
 v ~average speed;
 F_e ~fuel efficiency.

4. CO₂ Emissions in Chittagong Port and Dhaka–Chittagong Hinterland

4.1. CO₂ Emissions and Findings from the Simulation-Based Scenario Implementation in Chittagong Port

Table 6 presents the estimated CO₂ emissions for Chittagong port only. The hinterland part is calculated in a later section, and the two are finally combined to understand the total port-hinterland emissions.

Table 6. Estimated CO₂ emissions in 2020 based on the number of equipment and ship calls.

Emissions from Different Activities	Working Time in Days/Hours	Fuel Consumption in Litre/Days or Hours	No. of Ships	Total Fuel Consumption in Tons	Emissions in Tons	Per TEU Emissions in kg
Ships and marine operation						
Container ships	5 days on average, only auxiliary engine is running	2000	1050	10,500.00	33,663.00	19.80
Service vessels—Tug	2 h	576	1050	1209.60	3799.35	2.23
Service vessels—others	0.5 h	155	1050	81.38	255.60	0.15
Sub-total				11,790.98	37,717.95	22.19
Handling and yard operation						
CPA						
RTG	20 h	23	41	4356.66	13,684.27	8.05
SC	20 h	18 ¹	48 ²	3991.68	12,537.87	7.38
RST-45 tons	20 h	15	11	762.30	2394.38	1.41
RST-7 tons	20 h	13	9	540.54	1697.84	1.00
FLT-16 tons	20 h	13	9	540.54	1697.84	1.00
Sub-total				10,191.72	32,012.19	18.83
Private operator's equipment, Sub-total ³				4184.95	13,144.93	7.73
Sub-total						26.56
Gate operation	4 h	4	3000	17,640.00	55,407.24	32.59
Total				43,807.65	138,282.31	81.34

Source: Calculated by author using data and information from CPA performance data [31,58], annual report [30,35] and terminal operators. ¹ Consumption per hour for some equipment matches results from [59]. ² A total of 60% use is taken into account, here, considering the CCT and NCT handle 60% of the containers. ³ This data is from the private operator, who has only provided the average total fuel consumption data.

In the above calculation, the fuel consumption only considers an average size of vessel carrying 2000 TEUs, which is the average size of container vessels entering the port (the average size of ships and average container carrying capacity for the year 2020 is, respectively, considered 19,300 GRT and 1722 TEUs according to [60]). It is important to mention that the consumption of the main engine within port movement is not taken into consideration for conducting the simulation. This is because no scenarios for the improvement of vessel speed in the channel is considered. Taking into account the channel

characteristics in terms of depth, width and sharp bends, it does not seem possible to achieve a considerable improvement in terms of speed increase/decrease within this channel. Therefore, the vessel movement within the port from anchorage to berth will not change even if the performance in waiting and berthing is improved. As a result, the consumption of the auxiliary engine is only considered in the simulation rather than the main engine. It is observed from Table 5 that the total fuel consumption and CO₂ emissions from the container vessels entering the CCT and NCT in 2020 are 10,500 tons and 33,663.00 tons, respectively. The fuel consumption per vessel is 10,000 kg and the CO₂ emissions per TEU are 19.80 kg from container vessels. The total per TEU emissions for the overall marine operations including the allied tug and pilotage services is 22.19 kg per TEU. For terminal handling, CO₂ emissions are 26.56 kg per TEU, whereas, in the gate, they are 32.59 kg per TEU. The total emissions including the waiting, berthing, terminal operation and final delivery through the gate are 81.34 kg CO₂ per TEU. There are not many similar studies in the literature, except for Huzaifi and Budiyo [12], which found that carbon emissions in the Jakarta International Container Terminal are 29.08 kg per TEU, but, as mentioned earlier, their study considered the inward services from berthing to taking the containers out of port. Another study by Yang et al. calculated that the CO₂ emissions per TEU in the port of Shenzhen are 23.49 kg [22,23]. Comparing the fuel consumption with previous empirical findings, noticeable differences can be seen, which are mainly due to the performance gap between Chittagong port and the above ports. That is, the performance of Chittagong port in every aspect of waiting, berthing, dwell time and gate operation time is not up to the mark. Therefore, policymakers have the opportunity from this calculation to look at the emissions status of the port and the performance issue from an environmental sustainability perspective.

The results from the simulation for 2020, 2022 and different scenarios are presented in Table 7. As highlighted in the literature review section, the formulation of the scenarios is based on the infrastructural development and performance and operational efficiency of the CPA. As we can see, some infrastructural improvement was conducted from 2020 to 2022 (Table 4); therefore, the impact of this improvement has been studied in the simulation. Moreover, due to the improvement in the infrastructure, changes in the performance and operational efficiency, mostly indicating improvement in the working hours and handling rate of gantries, are considered. As discussed in Section 2.3, the working hours for gantries were 20 h, and the handling rate was 22 TEUs per hour in 2020; therefore, some improvement in the performance of these indicators is considered. Moreover, due to the improvement in the handling of gantry cranes along with other associated equipment, an improvement in the waiting and turnaround times is also considered. As discussed before, the median turnaround time for container ships is 0.7 days [38] in ports, and on large ports, the average crane output can reach 25–50 moves per hour [45–47]. Therefore, the scenarios include an increase in the working hour of cranes and equipment from 20 h to 22 h; an increase in the handling rate of gantries and other equipment from 22 TEUs per hour to 24 TEUs per hour; and, finally, an impact of the handling operation on the yard handling time reduction and a reduction in the customs time, which will have a corresponding impact on the waiting and turnaround time. It is important to discuss that, in the simulation analysis, the waiting time of ships, berthing duration of ships, number of ships in the berth, duration of a container staying at the yard, number of quay cranes per ship and their output, equipment availability and daily containers handling in the yard, and trucking and gate operations are considered as the input variables. Among these input variables, some are considered random, and some are considered fixed. The random input variables and their probability distributions are shown in Appendix C. As discussed, the data for all these input variables are collected from the CPA web sources and some missing data from the Port and Traffic Department of CPA, examples of which are attached in Appendices A and B. On the other hand, the total lead time for containers, the throughput, the fuel consumption in various operations and the CO₂ emissions are considered the output variables in the simulation analysis. A sample sheet of the simulation is presented in Appendix C.

Table 7. Simulation and scenarios findings.

Sl. No.	Emissions from Different Activities	Average of Total and per TEU Emissions			
		Mean	St. Deviation	Maximum	Minimum
In 2020					
Total emissions in tons					
1.	Total from CCT and NCT	150,310.44	20,042.07	184,646.70	116,759.65
Per TEU emissions in kg					
2.	Ship and marine operations	35.09	13.30	61.53	13.92
3.	Handling and yard operations	24.86	3.09	36.34	21.69
4.	Gate operations	31.96	3.97	46.71	27.89
5.	Per TEU from CCT and NCT	91.92	17.39	141.32	65.39
In 2022					
Total emissions in tons					
1.	Total from CCT and NCT	151,366.79	19,429.13	186,731.64	116,600.39
Per TEU emissions in kg					
2.	Ship and marine operations	32.26	12.18	60.24	12.09
3.	Handling and yard operations	23.52	2.96	33.03	20.47
4.	Gate operations	31.75	4.00	44.59	27.63
5.	Per TEU from CCT and NCT	87.52	16.11	134.26	63.71
Scenario I: Increase in quay crane working hours					
Total emissions in tons					
1.	Total from CCT and NCT	152,313.51	19,523.20	188,557.34	119,548.19
Per TEU emissions in kg					
2.	Ship and marine operations	27.29	10.87	51.40	10.07
3.	Handling and yard operations	23.16	2.43	31.44	20.47
4.	Gate operations	28.42	2.99	38.57	25.12
5.	Per TEU from CCT and NCT	78.87	13.77	117.24	57.90
Scenario II: Increase in quay crane per hour TEU handling rate					
Total emissions in tons					
1.	Total from CCT and NCT	152,059.51	19,938.91	186,713.69	117,143.49
Per TEU emissions in kg					
2.	Ship and marine operations	24.25	10.21	44.06	6.88
3.	Handling and yard operations	23.10	2.58	29.88	20.53
4.	Gate operations	26.76	2.99	34.62	23.78
5.	Per TEU from CCT and NCT	74.11	13.10	105.95	53.38
Scenario III: Reduction in yard operation and customs time					
Total emissions in tons					
1.	Total from CCT and NCT	147,338.87	18,868.48	179,019.49	113,937.69
Per TEU emissions in kg					
2.	Ship and marine operations	23.52	10.09	44.41	6.65
3.	Handling and yard operations	21.99	2.56	29.59	19.38
4.	Gate operations	26.98	3.15	36.31	23.78
5.	Per TEU from CCT and NCT	72.49	13.48	109.68	52.43

Source: Calculated by author.

The simulation results show that via the implementation of different scenarios the per TEU CO₂ emissions can be reduced from 91.92 kg in 2020 to 72.49 kg under Scenario III, that is, a reduction in the yard operation and customs time (duration), as this will impact the waiting and turnaround time. A step-by-step implementation of the different scenarios and the respective findings are discussed in the following parts. From Table 7, it is observed that, even though there are some fluctuations in the total emissions, the mean emissions per TEU reduce from scenario to scenario, and there are further emission reduction opportunities with the existing capacity if a desired performance is achieved, which is examined in the simulation.

In 2020, the average total emissions were 150,310.44 tons, and they could be as low as 116,759.65 tons. The emissions per TEU were 91.92 kg on average, but could be as low as 65.39 kg. In 2022, the average total emissions rose a bit to 151,366.79 tons, but the emissions per TEU reduced to 87.52 kg on average and could be as low as 63.71 kg per TEU. In 2022, the operation of additional gantry cranes and other allied equipment were taken into consideration in the port operations as the port was supplied with new gantry cranes and other equipment starting from 2020 (Section 2.3 and Table 4). The operation of additional equipment has increased the total emissions, but the emissions per TEU show a reduction.

(i) Scenario I—Increase in the working hours for the quay crane

Under Scenario I, the working hour of the equipment increases from the base 20 h to 22 h, and the total emissions increase to 152,313.51 tons on average and the emissions per TEU decrease to 78.87 kg on average and could be as low as 57.90 kg. The increase in the total emissions seems not that high even though all the equipment is operating longer compared to 2022. This could be mainly due to the reason that a performance improvement of the handling operation always results in the reduction in the ships waiting and berthing time. This has reduced the total emissions to some extent, which has traded-off the increase in total emissions due to the equipment operational time increment.

(ii) Scenario II—Increase in the TEU handling rate per hour for the quay crane

In the case of Scenario II, a decrease in the total emissions is observed and the emissions per TEU decrease further to 74.11 kg and could be as low as 53.38 kg on average. In this case, an increased output per hour for gantries and other equipment is considered. In the base case, the output of gantries is 22 TEUs per hour, which increases to 24 TEUs per hour under this scenario. This increased the total throughput without impacting the consumption of fuel as the gantries and other equipment became more efficient and were able to handle comparatively more containers while their operating duration remained the same. Moreover, it improved performance impacts on the berthing and waiting time for ships. As a result, the total emissions as well as the emissions per TEU are reduced.

(iii) Scenario III—Port reduces the yard operating time and a simultaneous reduction in customs services

Under Scenario III, a reduction in the time required in the yard and for the customs procedures is considered. It is observed from Figure 1 that the port requires a container to stay in the yard for 10–12 days on average for customs and other inspections and, finally, to unstuff and load the contents in a trailer, truck or covered van for final delivery. Moreover, the improvement in the quay operation in scenario II requires a simultaneous operational improvement in the yard as well; otherwise, there will be congestion in the yard leading towards a deterioration of achievement in the quay operation. Therefore, in the third scenario an improvement in the yard operation (duration) and customs services is considered to understand the overall impact on the emissions. This improvement has further impacted the waiting and berthing times without any increase in the equipment operation hours. The same number of containers are handled by the yard and customs but with higher efficiency in doing the same work. This impacts the total as well as the emissions per TEU. The average total emissions reduce to 147,338.87 tons, and the emissions per TEU reduce to 72.49 kg and could be as low as 52.43 kg on average.

Via the implementation of these scenarios, it is observed that the Chittagong port can reduce around 20 kg CO₂ emissions per TEU on average. Considering that a total handling in the CCT and NCT is 1.7 million TEUs, a total of 34,000 tons of CO₂ emissions could be reduced. If we consider the lowest possible CO₂ emissions, the reduction in CO₂ emissions per TEU could be as low as 40 kg of CO₂ emissions, totalling to 68,000 tons of CO₂ emissions that could be reduced in the CCT and NCT. If this reduction in CO₂ emissions is considered for the total throughput of Chittagong port, which is 3 million TEUs, the country can save a total of 60,000 tons of CO₂ emissions from Chittagong port operation on average, which could be as low as 120,000 tons of CO₂ emission reduction.

4.2. Calculation of CO₂ Emissions in the Dhaka–Chittagong Hinterland and the Findings from the Modal Shift

In order to understand the fuel efficiency, certain information on the types of trucks are needed, which is also collected from the Road User Charge 2016–17 report [56]. In Table 8, the particulars of the trucks are provided. The fuel efficiency for these types of trucks is either 4–6 km/L, or 17–25 L/100 km.

Table 8. Truck particulars.

Motorised Vehicle	Description	Most Popular Brand	Model	CC	Cylinders	HP	Tires
Articulated and heavy truck	Three or more axles. Includes multi-axle tandem trucks, container carriers and other articulated vehicles.	Tata (44%)	Tata LPT 2516	5883	6	157	10
Medium truck	Two axle rigid trucks. >three tonne payload agricultural tractors and trailers are also included	Tata (23%)	Tata LPT 1615	5883	6	145	6

Source: Compiled from Road User Charge 2016–17 report [56].

The average speed of trucks on the highway is 30 km/h [56]. In the case of the Dhaka–Chittagong corridor, the average time is considered to be 10 h and the distance is 250 km. For rail, the distance is 310 km, and, for IWT, it is 300 km (Table 5). However, for both the rail and IWT, around 25 km of last/first mileage trucking needs to be considered to calculate CO₂ emissions. Chittagong port handled 2.7 million TEUs and 25.7 million containerised tons in the 2020–21 financial year. As discussed, 70% of this is destined for and originated from Dhaka and the Dhaka–Chittagong corridor is carrying this volume. Road is carrying more than 90%, rail is carrying 5–6% and IWT is carrying 1%. Therefore, road is carrying around 16.7 million tons or 1.8 million TEUs. As a result, it is assumed that at least 2.5 million truck trips in both directions are required. Consequently, considering Equation (2), the fuel consumption and the same conversion factor from the Fourth IMO GHG study [55], the emissions figure for road transport is presented in Table 9. In the cases of rail and IWT, it is not possible to calculate the emissions using Equation (2) due to the poor data availability, which can be overcome by using the emissions factor from McKinnon and Piecyk [28], the IPCC [25] and Wang and Peng [9]. An indicative emissions factor for all the three modes based on these three studies are proposed in Section 2.2, which is 180 gCO₂/ton-km for road, 26 gCO₂/ton-km for rail and 34 gCO₂/ton-km for IWT. Moreover, as mentioned earlier, the ranges in the emissions data for all studies show a variety of emissions depending on the vehicle, fuel, infrastructure and even the behaviour of the drivers. Considering the socio-economic context of the hinterland, the highest possible emissions factor is considered while calculating the emissions per TEU for rail and IWT. In order to have a comparative picture, in addition to the emissions calculation of road transport using Equation (2), emissions are also calculated using the gCO₂/ton-km

emissions factor proposed by McKinnon and Piecyk [28], the IPCC [25] and Wang and Peng [9] and presented in Table 9. Since the McKinnon and Piecyk [28] and the IPCC [25] reports produced the emissions factor in $\text{gCO}_2/\text{ton-km}$, the total TEU tonnage is therefore divided by the total number of TEU and used to convert the $\text{gCO}_2/\text{ton-km}$ to $\text{gCO}_2/\text{TEU-km}$ and finally multiplied by the distance and divided by 1000 to convert it to CO_2 emissions in kg/TEU . A comparison of CO_2 emissions per TEU for the Dhaka–Chittagong corridor is presented in Table 9 below.

Table 9. CO_2 emissions for different modes in the Dhaka–Chittagong corridor.

Transport Mode	Equation (2)	An Average from Table 7
	CO_2 Emissions kg/TEU	CO_2 Emissions kg/TEU
Road	363.01	417.94
Rail–Road		107.72
IWT–Road		128.24

Source: Calculated by the author.

From the above table, if we consider that the CO_2 emissions for road are $363.01 \text{ kg}/\text{TEU}$ and the emissions for rail–road and IWT–road are, respectively, $107.72 \text{ kg}/\text{TEU}$ and $128.24 \text{ kg}/\text{TEU}$, it seems that rail emits the least CO_2 for modes of carrying containers in the Dhaka–Chittagong hinterland. It is important to mention that, although it was not possible to calculate the approximate emissions per TEU for rail and IWT using the real scenarios for the hinterland, among the global emissions data ranges as proposed by McKinnon and Piecyk [28] and the IPCC [25], the highest emissions data for these two modes were used to estimate the emissions per TEU. Therefore, the calculated differences of emissions among different modes specifically between road vs. rail and road vs. IWT will be at least an indicative measurement and could be close or lower than the actual or real emissions. Therefore, it can at least provide the minimum of CO_2 savings for modal shifting. A modal shift of containers from road to rail can reduce per TEU emissions by 255.29 kg and to IWT per TEU by 234.76 kg . Considering the total TEUs using the Dhaka–Chittagong hinterland, which is 1.8 million TEUs, if 50%, or 900,000 TEUs, can be shifted to rail or IWT, approximately a total of 229,500 tons or 211,000 tons of CO_2 emissions can be reduced. Moreover, a modal shift of 900,000 TEUs to rail or IWT means that the current number of truck entrances to Chittagong port will reduce by a substantial number, meaning a further reduction in the port emissions by around 29,333.25 tons of CO_2 emissions.

5. Summarising the Findings

By implementing different scenarios using a simulation technique, this paper first finds that the significant reduction in CO_2 emissions can be achieved in the case port. In calculating the CO_2 emissions, activity-based formulae have been used where the fuel or energy consumption from the marine operation and container ships, terminal and yard operations and gate operations are being summed up. To calculate the emissions from different operations, the working hours of different equipment and their per hour fuel consumption has been considered, and finally, using the Fourth IMO GHG study 2020 [55] conversion factor, the total as well as the emissions per TEU in ports are calculated. From the different scenarios of the simulation, the average emissions per TEU in the CCT and NCT in 2020 were 91.92 kg but could be as low as 65.71 kg . In 2022, the emissions per TEU on average reduced to 87.52 kg and the minimum was 63.71 kg . Via the implementation of the other scenarios, such as increasing the equipment working hours, increasing the handling output of gantries per hour and reducing yard operation time and customs time, it was demonstrated that the average emissions per TEU can be, respectively, 78.87 kg , 74.11 kg and 72.49 kg , and these can be as low as 57.90 kg , 53.38 kg and 52.43 kg respectively. It is observed that, in this way, the Chittagong port can reduce around 20 kg of CO_2 emissions per TEU operation on average, which could be as low as 40 kg of CO_2 emissions per TEU.

Considering the total handling in the CCT and NCT, which is 1.7 million TEUs, a total of 34,000 tons of CO₂ emissions could be reduced, and the lowest possible CO₂ emissions could be of 68,000 tons of CO₂ emissions. If this reduction is considered for the total throughput of Chittagong port, which is 3 million TEUs, the country can reduce a total of 60,000 tons of CO₂ emissions from Chittagong port operations on average and 120,000 tons of CO₂ emission reduction in the lowest possible emissions case.

Furthermore, the emissions from the hinterland are also analysed from the perspective of modal shift to low carbon emissions modes among the four widely discussed strategies, which include (i) avoiding journeys when possible, (ii) a modal shift to a lower-carbon transport mode, (iii) lowering energy intensity and (iv) reducing the carbon intensity of fuel. This shows that shifting to rail or IWT from road can reduce CO₂ emissions by 255.30 kg and 234.75 kg per TEU, respectively. Considering the total TEUs using the Dhaka–Chittagong hinterland, which is 1.8 million, if 50% of that can be shifted to rail or IWT from a policy or other operational and infrastructural perspectives, approximately a total of 229,500 tons or 211,000 tons of CO₂ emissions can be reduced. Moreover, a modal shift of 900,000 TEUs to rail or IWT will reduce the entrance of the current number of trucks entering the Chittagong port, meaning a reduction in the port emissions by around 29,333.25 tons of CO₂ emissions. It is important to mention that, in the calculation of the emissions from road, the data from the Road User Charge 2016–17 report from the Bangladesh Roads and Highway department has been used, which includes the particulars and fuel efficiency of the types of vehicles operating in the Dhaka–Chittagong corridor. But in the cases of rail and IWT, the emission figures have been calculated based on the various global secondary studies as the vehicle particulars and fuel efficiency data for these two modes are not readily available.

To sum up the above findings, it can be argued that the overall CO₂ emission reduction for one TEU to travel from Dhaka region through the Chittagong port using rail or IWT instead of road transport could be from 454.93 kg to 170.90 or 190.90 kg on average and could be as low as 150.40 or 170.45 kg. Considering the total emission reduction, if 900,000 TEUs can be shifted to rail or IWT, the country can reduce a total of 319,091.20 or 300,620.95 tons of CO₂ emissions, which could be as much as 379,091.20 or 360,620.94 tons of CO₂ emissions, which would be a very important achievement for the overall transportation system.

6. Conclusions

This paper shows that by implementing different scenarios for infrastructure development and performance and operational efficiency improvement, the CO₂ emissions in ports can be reduced significantly. Moreover, the modal shift from road to rail or IWT can also create significant emission reduction for container transportation from Dhaka using the Chittagong port for international shipment. The scenarios for the port infrastructure and operational efficiency include the inclusion of new cranes and other equipment, an increase in operation time, an increase in per hour handling quantity and a reduction in yard operation and customs operation time. All these scenarios comply with most of the scenarios that are observed in the literature review section. Furthermore, the modal shift from road to rail or IWT, which is one of the methods for achieving sustainability in the transport sector, is implemented in this research. As discussed in Section 3, there is also empirical evidence that the modal shift to rail or IWT is very much possible for the hinterland. Therefore, the scenarios developed and implemented in this research can contribute considerably to the sustainable port operation for the case port and its hinterland.

For the case port-hinterland, this research first demonstrates the possibility of sustainable port-hinterland transport. It further indicates that the ports in developing countries like Bangladesh have a great scope to concentrate on operational efficiency as well as infrastructure development to achieve sustainability in the port-hinterland transport system. At the same time, this research could benefit researchers as well as practitioners, explaining the implication of operational performance improvement and infrastructure development on the sustainable port-hinterland container transport system. The port operators, port authorities and policy makers can focus on these areas for CO₂ emission reduction. A policy could focus on the maximization of resource utilization and the addition of equipment in the short term and could gradually invest in additional infrastructure. A reduction in CO₂ emissions from such initiatives can contribute to the air quality and liveability in the port-hinterland neighbourhood as well as the port-city interaction and relationship.

Scenarios such as increasing/decreasing speed in the channel and truck entrance optimization are excluded in this paper. Considering the geophysical characteristics of the channel, including the length, width and bends in several places as well as the current traffic, changes in the speed of vessels in the channel might not be possible. On the other hand, the research is emphasising the modal shift from road to rail or IWT, which will reduce the number of trucks entering the port. Via the implementation of the modal shift, there will be already fewer trucks and less congestion, which will improve the current combustion scenarios and improve the reduction in the emissions from gate operations improving the queuing of trucks. One potential limitation for the emissions calculation was poor data availability (e.g., fuel type, fuel efficiency and the breakup of energy sources) for rail and IWT transportation to calculate the fuel consumptions. As a result, in calculating the emissions for these two modes, some of the examples from the literature are used. This might not be providing the most accurate picture of emissions, but for both rail transport and IWT, the highest possible emissions are taken into consideration so that the indicative reduction in CO₂ emissions could provide the minimum possible reduction for the studied hinterland. Further research including the primary investigation and data collection for the port-hinterland operation will provide a much clear picture for the case port.

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Conflicts of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

Appendix A

PERMISSIBLE F.W.DRAUGHT:		BERTHING POSITION & PERFORMANCE						DATED: 15/06/2020, 16/06/2020, 17/06/2020, 18/06/2020, 19/06/2020 & 20/06/2020:									
DATED :	15/06,16/06,17/06, 18/06,19/06 & 20/06/20	OF VESSELS: DATED : 14/06/2020:						TIME	HGT:	TIME	HGT:	TIME	HGT:	TIME	HGT:	TIME	HGT:
INWARD:	9.50 9.50 9.50 9.50 9.50 9.50	www.cpa.gov.bd						L.W.:	0251 1.15	0355 1.12	0454 1.01	0544 0.89					
OUTWARD:	9.50 9.50 9.50 9.50 9.50 9.50							H.W.:	0906 3.71	1010 3.88	1101 4.11	1143 4.30	0002 4.00	0039 4.09			
								L.W.:	1532 1.31	1638 1.18	1735 1.03	1823 0.92	0626 0.80	0704 0.75			
								H.W.:	2125 3.64	2228 3.73	2320 3.87		1219 4.42	1251 4.50			
								L.W.:					1903 0.88	1941 0.87			

JETTY NO.	NAME OF VESSEL	LENGTH	CARGO	LAST PORT	FLAG	LOCAL AGENT	DT. OF ARRIVAL	BERTHING	SHIF- TING	LEA- VING	IMPORT DISCH.	B. ON BOARD	EXP. LIFTED	T. ON BOARD	NAME OF VESSELS
J/2	XIN HAI ZHOU 3(IMO:9444182)	139.13	GI(SCRAP)	BUSAN	PANA	SEAWORLD	10/06	13/06	-	-	400	9800			
J/3	*NORDTRUST(IMO:9454187)	189.99	GI(ST.COIL)	SING	PANA	SPECTRUM	02/06	10/06	-	14/06	6098	X			SPRING AMR
J/4	(NO SPACE)														
J/5	KONG QUE SONG(IMO:9416769)	179.50	GI	YANG	HONG	COSCOL	11/06	13/06	-	-	304	2562			
J/6	MARIA THEO1(IMO:9384863)	169.26	LOG	KAND	PANA	RENU	R/A	11/06	-	-	676	9838			
J/7	OCEAN FUTURE(IMO:9418779)	190.00	GI(SCRAP)	SING	MALT	SRSL	05/06	12/06	-	-	2115	26360			
J/8	CHARLENE(IMO:9125360)	170.00	GI(SCRAP)	KINU	TUVA	EVERETT	06/06	12/06	-	-	3065	14710			
J/9	ALENTEJO(IMO:9626118)	179.99	GI(ST.COIL)	INDO	MARSH	LITMOND	08/06	12/06	-	-	5590	16181			
J/10	ELA(IMO:9516777)	175.50	CONT	P.KEL	SING	KARNAPHULI	08/06	12/06	-	-	251	X	525/		
J/11	MAERSK BINTULU(IMO:9840702)	185.99	CONT	S.HAI	SING	MBDL	06/06	11/06	-	-	422	119	666/		
J/12	(NO SPACE)														
J/13	MOUNT KELLETT(IMO:9760627)	169.99	CONT	SING	HONG	APL	11/06	13/06	-	-	686	507			
CCT/1	*XPRESS KOHIMA(IMO:9155016)	168.00	CONT	COL	TUVA	SEACON	03/06	11/06	-	-	6	X	802/		GEL DELTA
CCT/2															
CCT/3	THORSKY(IMO:9162277)	183.65	CONT	COL	CYP	MSCL	11/06	14/06	-	-	-	1169			
NCT-1															
NCT-2	CNC NEPTUNE(IMO:9836658)(GL)	172.00	CONT	SING	SING	APL	07/06	13/06	-	-	568	604	194/		
NCT-3	WARNOV MATE(IMO:9509786)(GL)	180.36	CONT	P.KEL	CYP	TML	10/06	13/06	-	-	879	22	209/		
NCT-4	XPRESS KABRU(IMO:9793727)(GL)	186.00	CONT	SING	SING	SEACON	05/06	11/06	-	-	123	X	586/		
NCT-5	*ORNELLA(IMO:9534660)	172.00	CONT	SING	PORTU	CT	04/06	11/06	-	-	86	X	785/		KOTA RUKUN

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CCJ																
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GSJ																
TSP																
DOJ-3	REEM 1(IMO:9687631)	102.51	BITUMEN	HAMAR	PANA	GOSL	14/06	14/06	-	-						
DOJ-4	*TMN PRIDE(IMO:9333254)	179.99	HSFO	SING	THAI	AQUAT	11/06	11/06	-	14/06						
DOJ-5	*NAVIG8 AMETHYST(IMO:9714501)	184.60	GAS OL	TANJ	MARSH	PRIDE	12/05	12/06	-	14/06						
DOJ-6																B SHOURASH
DOJ-7																
DD																
DDJ-1	OCEAN LOVE(IMO:9641352)	189.99	STONE	KAND	LIBE	VISION	07/06	10/06	-	-						
DDJ-2																
RM/8																
RM/9	TUG ZAO ZOUZOU TUG QINATONG 11 HAO BARGE DA ZOUZOU	37.75 28.80 30.00	BALLAST BALLAST BALLAST	PATRA PATRA PATRA	CHINA CHINA CHINA	???	04/06 04/06 04/06	04/06 04/06 04/06	- - -	- - -						
RM-10	*AU LIBRA(IMO:9236339)	124.00	RBD	PADAN	PANA	MTCL	09/06	12/06	-	-						

Figure A1. Copy of Berthing Schedule.

Appendix B

AT A GLANCE

CHITTAGONG PORT AUTHORITY

OFFICE OF THE DIRECTOR (TRAFFIC).

VESSELS PARTICULARS & CONTAINER LYING POSITION CLOSING AT 0800 Hrs. ON 15/06/2020 Time- 11.30 hrs.

NO. CPA / D (T). OPERATION / VESSEL & CONT POSITION / 2014

A) COMMODITY WISE VESSELS PARTICULARS IN PORT :-

COMMODITY WISE VESSELS	AT OUTER ANCHORAGE			AT RM & SPL BERTH			AT MAIN JETTIES			TOTAL
	WORK	NOT WORK	TOTAL	WORK	NOT WORK	TOTAL	WORK	NOT WORK	TOTAL	VESSEL IMPORT
CONTAINER		6	6			0	3		3	15
GENERAL CARGO	12	4	16	2		2	7		7	25
FOOD GRAIN	7	2	9			0			0	9
FERTILIZER	1		1			0			0	1
C / CLINKER	4	2	6			0			0	6
SUGAR	1	1	2			0			0	2
SALT			0			0			0	0
RAPE SEED			0			0			0	0
M / SEED			0			0			0	0
OIL TANKER		7	7	3	1	4			0	11
WORKABLE VESSEL	25	22	47	5	1	6	16	0	16	63
REPAIR / IDLE			0			0			0	0
W / INSTRUCTION		20	20			0			0	20
SCRAPPING		11	11			0			0	11
Waiting for Sail			0			0			0	0
ATTACHED/NAVY SHIP			0			0			0	0
Non Workable Vessel	0	31	31	0	0	0	0	0	0	31
TOTAL VESSEL	25	53	78	5	1	6	16	0	16	100

B) TOTAL WORKING VESSEL	46
TOTAL NOT WORKING VESSEL	23
TOTAL WORKABLE VESSELS	69

NOT WORKING VESSELS AT OUTER ANCHORAGE	
READY:-CONT./06(NB-06),GH,TANK/CCI,FERTI,FOOD/ W/For	
W/For Docs :-GH/04,FOOD/02,SUGAR/01,SALT/1,FERTI/0,TANK/07	

EJ. CONTAINER LYING POSITION IN PORT.

CONT. CAPACITY (IN TEUS)	LYING ON 14/06/2020	LYING ON 15/06/2020
43018	40512	39057

LAST 24 HRS. CONT. DELIVERY	14/06/2020 2833	15/06/2020 3407
-----------------------------	-----------------	-----------------

F) LAST 24 HRS. CONT. HANDLING (TEUS)

IMPORT CONTAINER RECEIVED	2669
CONTAINER SHIPPED TO VESSEL	4435
TOTAL HANDLING	7104
CONTAINER DESPATCHED TO ICD	23
CONTAINER RECEIVED FROM ICD	52
ICD CONT. RECEIVED FROM VESSELS	15
PANGAON CONT. RECEIVED FROM VESSELS	0
LCL CONTAINER UNSTUFFED	182
CONTAINER LYING AT AUCTION - U	7831
EMPTY CONT. REMOVED TO DEPOT	209
EMPTY CONT. SHIPMENT FROM PORT	1753

C) VESSELS MOVEMENT & PILOT BOARDING TIME

	NOS	TIME		D) VACANT BERTH :04	
i) LAST 24 HRS. SAILED VESSELS :	09	0500	1500		4,12
ii) LAST 24 HRS. CALLED VESSELS :	11	0630	1630		CCT-2, NCT-1
iii) VESSELS OUTGOING ON DATE :	06	0500	1630		
iv) VESSELS INCOMING ON DATE :	06	0630	1630		
v) VESSELS SHIFTING ON DATE :		X	X		

LAST 24HRS. TOTAL INCOMING IN CPA			LAST 24HRS. TOTAL DESP. FROM CPA		
	BOX	TEUS		BOX	TEUS
REC. FROM VESSEL	1743	2669	SHIPPED TO VESSEL	3022	4435
REC. FROM ICD(DHAKA)	39	52	CONTAINER DESPATCHED TO ICD	14	23
LOAD CONT. REC. (FROM DEP)	365	1818	LOAD CONT. DESPATCHED (TO)	1033	1728
EMPTY CONT. IN (FROM DEP)	1078	1374	EMPTY CONT. REMOVED TO DEP	113	209
REC. FROM PANGAON	0	0	CONT. DESPATCHED TO PANGAON	0	0
			LOAD CONT. DELIVERED (ON CH)	442	657
			DELIVERY FROM YARDS	644	1022
TOTAL	3831	5913	TOTAL	5268	8074

Traffic officer (H.Q.)
For Director (Traffic)
Chittagong Port Authority

XLS/24 Hrs Handling/Sheet-I/TP-01.

Figure A2. Vessel particulars and Yard Utilisation Data Sheet.

Appendix C

Table A1. Example simulation table from Excel.

Random Number	Waiting Time in Days	Random Number	Berthing Capacity	Ships at Berth	Newly Berthed Ships	Total Ship at Berth	Random Number	Berthing Duration in Days	Crane Output	Container Received	Containers Departing	Containers Added to Yard	Other Equipment Availability	Random Number	Yard Duration Other than Customs	Customs Duration	Trucking and Gate Duration	Total Lead Time	Annual Throughput (Import) in Million TEUs	MFO-Marine	Diesel—Terminal	Diesel—Gate	CO ₂ MFO -Marine	CO ₂ Diesel—Terminal	CO ₂ Diesel—Gate	CO ₂ —Total in Tons	CO ₂ —Total/TEU
59	6	8	1	7	0	7	89	3.5	48	6600	4800	1800	45	85	9	1	1	21	2.31	21,240.98	14,376.67	17,640	68,098.58	44,768.95	54,930.96	167,798.49	72.64
76	7	28	2	6	0	6	37	1.5	48	5808	4800	2808	45	25	3	1	1	14	2.03	19,140.98	14,376.67	17,640	61,365.98	44,768.95	54,930.96	161,065.89	79.23
69	7	1	1	7	1	8	45	1.5	48	6600	4800	4608	45	6	3	1	1	14	2.31	19,140.98	14,376.67	17,640	61,365.98	44,768.95	54,930.96	161,065.89	69.73
86	8	93	2	6	2	8	40	1.5	48	5808	4800	5616	45	17	3	1	1	15	2.03	21,240.98	14,376.67	17,640	68,098.58	44,768.95	54,930.96	167,798.49	82.55
75	7	42	2	6	2	8	23	0.5	48	5808	4800	6624	45	60	6	1	1	16	2.03	17,040.98	14,376.67	17,640	54,633.38	44,768.95	54,930.96	154,333.29	75.92
70	7	89	2	6	1	7	12	0.5	48	5808	4800	7632	45	25	3	1	1	13	2.03	17,040.98	14,376.67	17,640	54,633.38	44,768.95	54,930.96	154,333.29	75.92
59	6	23	1	7	0	7	18	0.5	48	6600	4800	9432	45	84	9	1	1	18	2.31	14,940.98	14,376.67	17,640	47,900.78	44,768.95	54,930.96	147,600.69	63.90
36	3	57	2	6	1	7	49	1.5	48	5808	4800	10,440	45	42	6	1	1	13	2.03	10,740.98	14,376.67	17,640	34,435.58	44,768.95	54,930.96	134,135.49	65.99
52	4	17	1	7	0	7	20	0.5	48	6600	4800	12,240	45	35	3	1	1	10	2.31	10,740.98	14,376.67	17,640	34,435.58	44,768.95	54,930.96	134,135.49	58.07
98	9	42	2	6	2	8	5	0.5	48	5808	4800	13,248	45	28	3	1	1	15	2.03	21,240.98	14,376.67	17,640	68,098.58	44,768.95	54,930.96	167,798.49	82.55
36	3	11	1	7	1	8	11	0.5	48	6600	4800	15,048	45	89	9	1	1	15	2.31	8640.98	14,376.67	17,640	27,702.98	44,768.95	54,930.96	127,402.89	55.15
46	4	75	2	6	2	8	35	1.5	48	5808	4800	16,056	45	10	3	1	1	11	2.03	12,840.98	14,376.67	17,640	41,168.18	44,768.95	54,930.96	140,868.09	69.30
89	8	55	2	6	2	8	32	1.5	48	5808	4800	17,064	45	62	6	1	1	18	2.08	21,240.98	14,376.67	17,640	68,098.58	44,768.95	54,930.96	167,798.49	82.55
41	3	47	2	6	2	8	29	1.5	48	5808	4800	18,072	45	39	3	1	1	10	2.03	10,740.98	14,376.67	17,640	34,435.58	44,768.95	54,930.96	134,135.49	65.99
95	8	75	2	6	2	8	77	3.5	48	5808	4800	19,080	45	74	6	1	1	20	2.03	25,440.98	14,376.67	17,640	81,563.78	44,768.95	54,930.96	181,263.69	89.17
38	3	94	4	4	3	7	70	2.5	48	4224	4800	18,504	45	67	6	1	1	14	1.47	12,840.98	14,376.67	17,640	41,168.18	44,768.95	54,930.96	140,868.09	95.28
46	4	84	2	6	2	8	34	1.5	48	5808	4800	19,512	45	31	3	1	1	11	2.03	12,840.98	14,376.67	17,640	41,168.18	44,768.95	54,930.96	140,868.09	69.30
99	10	42	2	6	2	8	27	1.5	48	5808	4800	20,520	45	28	3	1	1	17	2.03	25,440.98	14,376.67	17,640	81,563.78	44,768.95	54,930.96	181,263.69	89.17
64	6	26	2	6	2	8	93	3.5	48	5808	4800	21,528	45	69	6	1	1	18	2.03	21,240.98	14,376.67	17,640	68,098.58	44,768.95	54,930.96	167,798.49	82.55
36	3	63	2	6	2	8	35	1.5	48	5808	4800	22,536	45	52	6	1	1	13	2.03	10,740.98	14,376.67	17,640	34,435.58	44,768.95	54,930.96	134,135.49	65.99
91	8	98	4	4	4	8	3	0.5	48	4224	4800	21,960	45	8	3	1	1	14	1.47	19,140.98	14,376.67	17,640	61,365.98	44,768.95	54,930.96	161,065.89	108.95
97	9	88	2	6	2	8	44	1.5	48	5808	4800	22,968	45	20	3	1	1	16	2.03	23,340.98	14,376.67	17,640	74,831.18	44,768.95	54,930.96	174,531.09	85.86
71	7	14	1	7	1	8	60	2.5	48	6600	4800	24,768	45	72	6	1	1	18	2.31	21,240.98	14,376.67	17,640	68,098.58	44,768.95	54,930.96	167,798.49	72.64
9	1	42	2	6	1	7	0	0.5	48	5808	4800	25,776	45	18	3	1	1	7	2.03	4440.98	14,376.67	17,640	14,237.78	44,768.95	54,930.96	113,937.69	56.05
21	2	40	2	6	2	8	65	2.5	48	5808	4800	26,784	45	91	9	1	1	16	2.03	10,740.98	14,376.67	17,640	34,435.58	44,768.95	54,930.96	134,135.49	65.99
93	8	35	2	6	2	8	68	2.5	48	5808	4800	27,792	45	33	3	1	1	16	2.03	23,340.98	14,376.67	17,640	74,831.18	44,768.95	54,930.96	174,531.09	85.86
80	7	78	2	6	2	8	80	3.5	48	5808	4800	28,800	45	67	6	1	1	19	2.03	23,340.98	14,376.67	17,640	74,831.18	44,768.95	54,930.96	174,531.09	85.86
4	0	46	2	6	2	8	49	1.5	48	5808	4800	29,808	45	48	6	1	1	10	2.03	4440.98	14,376.67	17,640	14,237.78188	44,768.95038	54,930.96	113,937.6923	56.05
55	5	47	2	6	2	8	54	2.5	48	5808	4800	30,816	45	33	3	1	1	13	2.03	17,040.98	14,376.67	17,640	54,633.38188	44,768.95038	54,930.96	154,333.2923	75.92
93	8	70	2	6	2	8	28	1.5	48	5808	4800	31,824	45	37	3	1	1	15	2.03	21,240.98	14,376.67	17,640	68,098.58188	44,768.95038	54,930.96	167,798.4923	82.55

Waiting time:

=IF((IF(G15/100<\$AJ\$5,\$AG\$5,IF(G15/100<\$AJ\$6,\$AG\$6,IF(G15/100<\$AJ\$7,\$AG\$7,IF(G15/100<\$AJ\$8,\$AG\$8,IF(G15/100<\$AJ\$9,\$AG\$9,IF(G15/100<\$AJ\$10,\$AG\$10,IF(G15/100<\$AJ\$11,\$AG\$11,IF(G15/100<\$AJ\$12,\$AG\$12,\$AG\$13))))))))))

Berthing capacity:

=IF(I16/100<\$AJ\$45,\$AG\$45,IF(I16/100<\$AJ\$46,\$AG\$46,IF(I16/100<\$AJ\$47,\$AG\$47,IF(I16/100<\$AJ\$48,\$AG\$48,IF(I16/100<\$AJ\$49,\$AG\$49,\$AG\$50))))))

Berthing duration:

=IF((IF(\$Q\$12<20,IF(N15/100<\$AJ\$29,\$AG\$29,IF(N15/100<\$AJ\$30,\$AG\$30,\$AG\$31)),IF(N15/100<\$AJ\$29,\$AG\$29,IF(N15/100<\$AJ\$30,\$AG\$30,\$AG\$31))))

Yard duration:

=IF(U15/100<\$AJ\$39,\$AG\$39,IF(U15/100<\$AJ\$40,\$AG\$40,\$AG\$41))

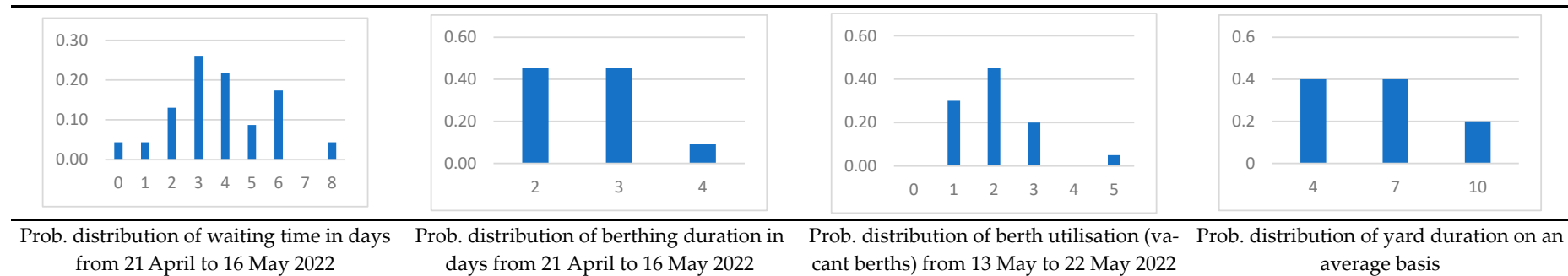


Figure A3. Simulation MS Excel Formulae.

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