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AIR EMISSIONS FROM IN-LAND ACTIVITIES OF CHITTAGONG PORT OF BANGLADESH

A. Dey*, M. A. Amin, A. Akther

Institute of Forestry and Environmental Sciences, University of Chittagong

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ABSTRACT

The study was conducted to estimate and describe air emissions generated from April 2017 to March 2018 by the in-land activities and cargo transportation of the Chittagong Port of Bangladesh, using activity-based approach. These emission sources include cargo handling equipment, head trucks and locomotives. The pollutants focused in this study are categorized into two groups: criteria pollutants consisting NO_x, CO, SO_2, Particulate matters and Black carbon, and greenhouse pollutants consisting of CO_2, CH_4 and N_2O. Head trucks are the major sources of all air emission (NO_x 91.35%, CO 94.83%, PM_{10}62.11%, $PM_{2.5}$ 60.47%and CO_2e 98.73%), demanding serious consideration to this sector.The locomotives cause the least emission among all sources and can be used as a tool to reduce emission from head trucks. About 3478.04tonne NO_x, 1134.22 tonne CO, 31.09 tonne PM_{10}, 30.97 tonne $PM_{2.5}$, 22.82 tonne SO_2, 23.88 tonne Black carbon, and 5141319.71 tonne of CO_2e were released in the atmosphere during the study period due to the in-land port activities.

Keywords: In-port shipping activity, Port emission, Criteria pollutant, Air pollution, CO_2.

Author Correspondence, e-mail: abirdey.cu@gmail.com

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1. INTRODUCTION

Portis key to a country's economy and serve as gateways through which more than 80% of all the world's trade goods are shipped. Carrying goods through the ports are increasing steadily with the growing global trade. With increased port activities, the risks of air pollution have also increased in the surroundings of the port areas. Numerous sources are required to be considered to evaluate air pollution from ports, including marine vessels, cargo handling equipment, rail locomotives, trucks used for moving cargo etc. (Trozzi and Vaccaro, 2000). These sources produce pollutants, such as oxides of Nitrogen (NO_x), Particulate matters (PMs), Black carbon and Sulfur oxides (SO_x), with greenhouse gases, i.e. Carbon dioxide (CO_2), Nitrous oxide (N_2O), and Methane (CH_4). These air pollutants effect the health of local communities adversely and are needed to be mitigated.

As a primary port of Bangladesh, Chittagong port is always busy with handling ships, loading-unloading cargoes from all around the world. It handles about 80% of the country's foreign trade. During 2016-17 it handled 2.42 million TEU container, 23.48 million tonnes of cargo, with its container handling capacity expected to grow by 2.7 million in 2020 and 5.4 million in 2040(CPA, 2017; Dhaka Tribune, 2017).A large amount of air pollutants is released from the day-to-day activities of Chittagong Port. Exhaust gases emitted from marine vessels, trucks and cargo handling equipment are the major emission sources within the port. It is necessary to measure emissions and identifying their sources to distinguish the areas for improvement. The purpose of this study is to estimate and explain the air emissions generated by mobile emission sources associated with the in-land activities maintained by the Chittagong port. These mobile emission sources include land-based mobile sources, such as cargo handling equipment, container vehicles, and locomotives. The emissions have been measured by activity-based approach according to the engine specifications, engine production year and activity hours.

Assessing the energy and fuel consumption, that produce pollutants such as greenhouse gasses, can be useful to identify areas needed to be improved, i.e. energy efficiency or improved port operations. Knowing the sources responsible for the emissions can guide through the formulation of emission reduction strategies for sustainable development of both financial and environmental sectors. The study may also be useful for other ports or production sectors for documenting emissions for future requirement to fulfill government policies as part of international agreements such as Kyoto and other protocols.

2. MATERIALS AND METHODS

2.1. Location of the study area

The Chittagong Port is the largest seaport of Bangladesh. The port is situated at 22° 18′ N Latitude and 91° 45′ E Longitude. It was built in 1887 near the Karnafuli river channel and positioned approximately 16 kilometers upstreamfrom the Bay of Bengal.The study measured the quantity of air emissions from mobile fuel-combustion sources associated with in-land activities maintained by the Port Authority and transportation of cargo from yard to yard. The measurements were based on activities that occurred in the time frame of April 2017 to March 2018. There are three primary categories of sources for which emissions have been calculated are Cargo Handling Equipment, Head Truck, andLocomotives.

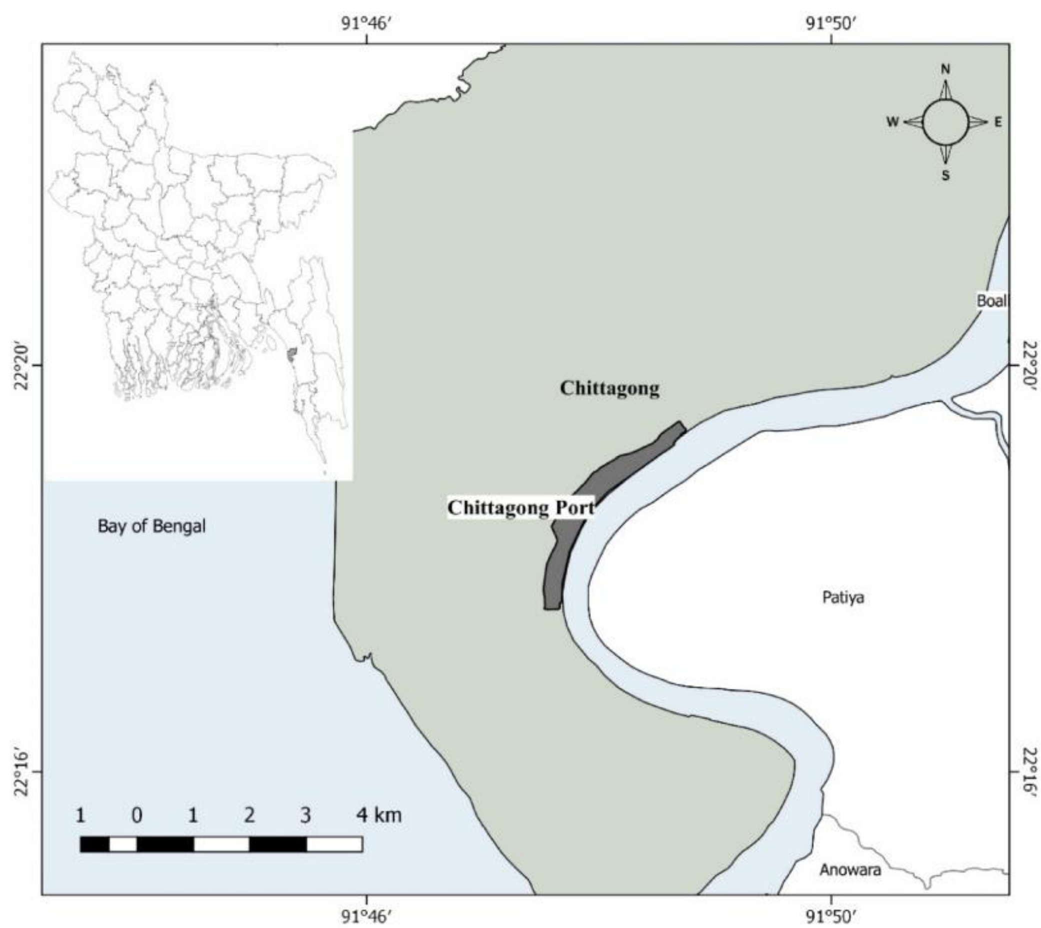

Fig.2-1. Location of Chittagong Port in Bangladesh

2.2. Pollutants measured in the study

The air pollutants can be classified into two groups. They are Criteria pollutants and Greenhouse gasses. The study estimated emissions of criteria pollutants such as:Oxides of Nitrogen (NO_x),Particulate matters with less than 10 microns in diameter (PM_{10}),and less than 2.5 microns in diameter ($PM_{2.5}$),Sulfur dioxide (SO_2), Carbon monoxide (CO), andBlack carbon.The following fuel combustion-related greenhouse gas emissions are also included: Carbon dioxide (CO_2), Methane (CH_4), and Nitrous oxide (N_2O).

The GHG emissions are presented in terms of "CO_2equivalents (CO_2e)", that is calculated by multiplying total emissions of each GHG by its corresponding GWP value from the IPCC Fifth Assessment Report, 2014 (AR5) (Pachauri et al., 2014). The products of each multiplication are then summed, stated as CO_2e emission. The GWP values used in the calculations were: CO_2= 1, CH_4= 28, and N_2O= 265.

2.3. Methodology for emission calculation

The emission inventory from in-land activities of the port can be estimated by applying a fuel-based or an activity-based methodology. The following equation has been used to estimate the emissions, which is the most current methodfor quantifying air pollutants.

"**E = A × EF**

Where: E = Emission, (gram/hour)

A = Activity, (hour/year or km/year)

EF = Emission Factor, (gram/hp-hour or gram/kW-hour)",(Browning, 2009; CARB, 2011).

2.3.1. Emission calculation for CHE

Air emission from cargo handling equipment was calculated using detailed data of each equipment type, engine type, production year, fuel type, engine power, load factor and number of operating hours of each equipment. Load factor is the fraction of average operation power tothe maximum power of the engine.The emission factorsfor emission calculation of CHE wereset on the basis of engine's power and production year from USEPA-ICF International 2009 and European Environment Agency 1996 (Browning, 2009; EEA, 1996).

"**E = P × A × LF× EF**

Where: P = Power, (hp or kW)

A = Activity, (hour/year)

LF = Load Factor

EF = Emission Factor, (gram/hp-hour or gram/kW-hour)”,(Browning, 2009; CARB, 2011).

2.3.2. Emission calculation for head truck

The activity of head truck includes both running and idling conditions.Activity during running condition was measured in VehicleKilometerTravelled (VKT) and idling condition in hour.The VKT was estimated based on the traffic information gathered from the security department of Chittagong Port. Interviews with guards and drivers were held to estimate the idling time of the head trucks, which include queues for loading-unloading and inspection at the security gate. On average the idling time is assumed 140.5 minutes.The emission factors for the head truck were adopted from the Tanjung Priok Port2015and Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015, according to their running and idling conditions(Tanjung Priok Port, 2015; US EPA, 2016).

“**E = A x EF**

Where: A = Activity (hour/month or km/month)

EF = Emission Factor (gram/hour or gram/km)”,(Browning, 2009; CARB, 2011).

2.3.3. Emission calculation for locomotive

Rail operations of Chittagong Port can be classified in two types: (1) On-port line-haul activities and (2) Off-port line-haul activities. The off-port line-haul activity was measured in respect to fuel consumption. The on-port line-haul activity was measured with horsepower-hours.The port uses diesel-fueled locomotives of Bangladesh Railway to transport cargo from Chittagong Port to Chittagong Terminal and then Chittagong Terminal to Dhaka Terminal. The average number of trips done from Chittagong Port to Chittagong Terminal is 6 trips per day which takes 40 minutes per trip.On the other hand, average number of trips from Chittagong Terminal to Dhaka Terminal is 14 trips per month taking 14 hours per trip. The information on the engine power, speed and load factor of the locomotiveswere collected from the Divisional Mechanical Officer of Pahartali Railway Station. The off-port line-haul emissionwere calculated using factors from Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015(US EPA, 2016) and the on-port line-haul emissions were calculated based on the EPA Technical Highlights: Emission Factors for

Locomotives, 2009(EPA, 2009).For the estimation of CO_2 emission, the emission factor has been used based on Mandatory Reporting of Greenhouse Gases 2009(Agency, 2009).

“E = A × EF

Where, A = Activity (hp-hour or gallons)

EF = Emission Factor (gram/hp-hour or gram/gallons)”,(Browning, 2009; CARB, 2011).

3. RESULTS AND DISCUSSION

3.1. Estimated Emissions for Cargo Handling Equipment (CHE)

Based on the available data, the estimated emissions of NO_x, CO, PM_{10}, $PM_{2.5}$, SO_2, and Black Carbon from CHE have been presented in Table 3-1.

Table 3-1. Criteriapollutants from CHE (in tonne)

No.	Type of Equipment	Operational Equipment	NO_x	CO	PM_{10}	$PM_{2.5}$	SO_2	Black Carbon
1	Container Mover	4	4.25	0.87	0.14	0.14	0.56	0.11
2	Forklift	114	31.53	8.06	1.46	2.07	1.95	1.59
3	Forklift Truck	6	4.14	0.28	0.03	0.03	0.25	0.02
4	Heavy Trailer	6	1.40	0.39	0.08	0.08	0.09	0.06
5	Industrial Tractor	4	0.15	0.10	0.01	0.01	0.09	0.00
6	Log Handler	2	1.89	0.53	0.11	0.11	0.12	0.09
7	Mobile Crane	23	5.85	1.65	0.35	0.34	1.08	0.26
8	Mobile Harbour Crane	2	10.44	0.43	0.13	0.13	0.70	0.10
9	Pick and Carry	3	0.94	0.48	0.05	0.05	0.04	0.04
10	Quay Gantry Crane	4	25.89	4.82	0.78	0.78	0.96	0.60
11	Reach Stacker	11	10.94	2.26	0.42	0.41	1.01	0.32
12	Rubber Tyred	20	51.22	11.32	1.85	1.85	3.79	1.43

	Gantry Crane							
13	Straddle Carrier	32	89.57	17.73	4.37	4.27	6.43	3.29
14	Terminal Tractor	26	47.65	8.25	1.64	1.63	1.84	1.26
Total Emission		**257**	**285.87**	**57.15**	**11.41**	**11.89**	**18.91**	**9.17**

Emission of NO_x from CHE is very significant among other criteria pollutants (285.87 tonne, 72.48%). Amongfive major sources,Straddle carrier emitsthe mostcriteria pollutants in CHE, followed by Rubber tyred gantry crane,Terminal tractor, Forklift, and Quay gantry crane respectively.Buton average, Quay gantry crane is responsible for most criteria emissions than other CHE types (table 3-1).

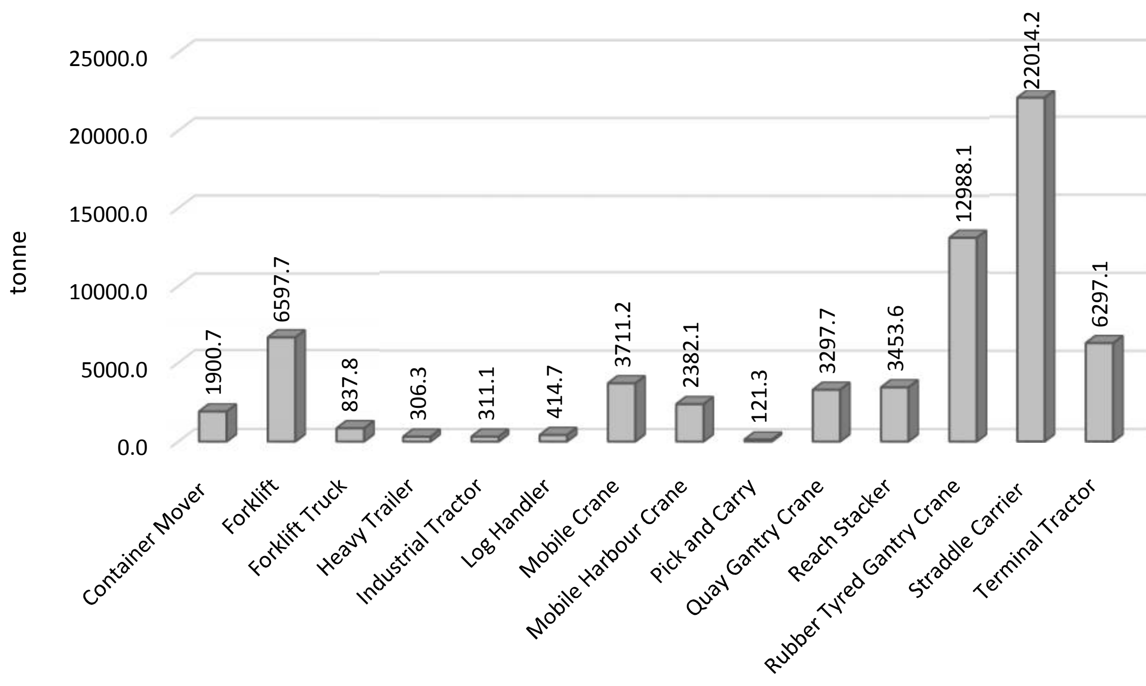

Fig.3-1. Emission of CO_2e from CHE in tonne

The cargo handling equipment of Chittagong port emitted 64633.59 tonne of CO_2eduring the one year period, which is lower than some ports, i.e. Port of New York and New Jersey (113001 tonne), Port of Long Beach (115792 tonne), except Tanjung Priok port (4516.46tonne)(PANYNJ, 2018; POLB, 2018; Tanjung Priok Port, 2015). As shown in figure 3-1, Straddle carriers cause most CO_2e emission (22014.2 tonne, 34.06%) among cargo handling equipment, followed by Rubber tyred gantry cranes (12988.1 tonne, 20.09%), Forklift (6597.7 tonne, 10.21%), and Terminal tractor (6297.1 tonne, 9.74%).Worn-out equipment and longershifts might be the cause of such high amount of emission.

3.2. Estimated Emissions for Head Truck

According to the traffic data, 70% of total vehicles are Light container vehicles, and other 30% belongs to Heavy container vehicles.Table 3-2and table 3-3 show the amounts of criteria and greenhouse pollutantsreleased, respectively, according to the vehicle type and their activity.

Table 3-2. Criteriapollutants fromHead Truck (in tonne)

Vehicle Type	Truck Activity	NO_x	CO	PM_{10}	$PM_{2.5}$	SO_2	Black Carbon
Light Container Vehicle	Running Condition	2273.27	748.22	14.15	13.72	2.79	10.58
	Idling condition	80.40	47.22	0.18	0.17	0.11	0.13
	Total Emissions	2353.67	795.44	14.32	13.89	2.90	10.72
Heavy Container Vehicle	Running Condition	788.39	259.49	4.91	4.76	0.97	3.67
	Idling condition	35.21	20.68	0.08	0.08	0.05	0.06
	Total Emissions	823.60	280.17	4.98	4.83	1.02	3.73
Total emissions		**3177.27**	**1075.61**	**19.31**	**18.73**	**3.91**	**14.44**

Table 3-3. GHGpollutants fromHead Truck (in tonne)

Vehicle Type	Truck Activity	CO_2	CH_4	N_2O	CO_2e
Light Commercial Vehicle	**Running Condition**	3601858.15	0.18	0.28	3601936.59
	Idling condition	156176.35	0.95	0.00	156202.93
	Total Emissions	3758034.50	1.13	0.28	3758139.51
Heavy Commercial Vehicle	**Running Condition**	1249149.94	0.83	0.78	1249380.50
	Idling condition	68396.16	0.42	0.00	68407.80
	Total Emissions	1317546.10	1.25	0.78	1317788.30
Total emissions		**5075580.60**	**2.38**	**1.06**	**5075927.81**

Light container vehicles emit more pollutants, both criteria and greenhouse, than Heavy container vehicles. It is because of their high number of trips and distances covered. NO_x is the highest amount of criteria pollutant (3177.27 tonne), followed by CO(1075.61 tonne), PM10(19.31 tonne), and PM2.5 (18.73 tonne) (table 3-2).Vehicles in idle condition produced 224610.73 tonne CO_2e or 4.43% of total CO_2e emission, whereas 4851317.09 tonne CO_2e (95.57%) is from vehicles in running condition (table 3-3).

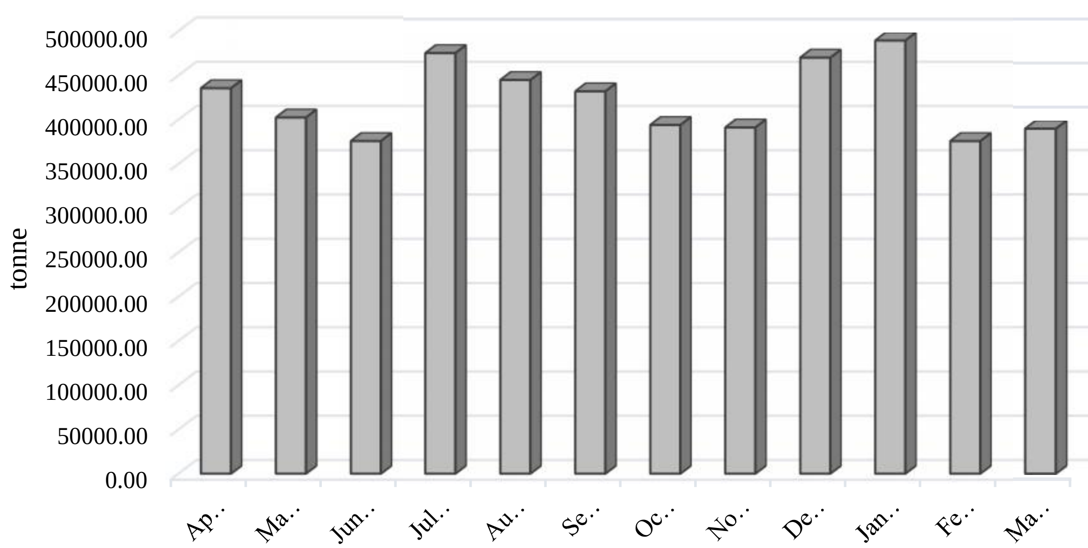

Fig.3-2. Emission of CO_2efrom Head trucks in tonne

Month-wise emissions of CO_2e by head trucks from April, 2017 to March, 2018 have been illustrated in figure 3-2. Seasonal variation can be observed in the emissions where highest emissions are released during July-August and December-January and lowest emissions during June, October-November and February-March. It is due to the increased demand of goods and traffic conditions in highways during fiscal periods which is at the begining and middle of the year. ANOVA test has been used to measure the significance among month-wise emissions from April 2017 to March 2018. According to the test, the value of CO2e emitted from head trucks for twelve months varies significantly. The result of Analysis of variance of other emissions (NOx, CO, PM10, PM2.5, SO2, BC) have also been found significant, which means emission differs in different months of the year.

The emission levels from head trucks are much higher than other ports. For example CO_2e emission from Port of New York and New Jersey is 311734 tonne, and Port of Long Beach is 296831 tonne(PANYNJ, 2018; POLB, 2018). It is because cargo transportation system of Chittagong Port mostly depends on trucks covering long distances and some of them have fitness issues. The port supports about 1.7 million trucks each year, which contributes to almost 99% of the total emissions.

3.3. Estimated Emissions for Locomotive

Table 3-4 presents the yearlyair emissions from Locomotives calculatedfor both on-port and off-port activities of Chittagong port.

Table 3-4. Total emissions from Locomotives (in tonne)

Engine Model	Build Yr.	Emission Type	NO_x	CO	PM_{10}	$PM_{2.5}$	SO_2	Black Carbon	CO_2e
2000 series	1953	**On-port Emission**	0.49	0.05	0.01	0.01	0.00001	0.01	34.78
		Off-port Emission	0.75	0.07	0.02	0.02	0.00001	0.01	28.41
Total emission per month			1.24	0.12	0.03	0.03	0.00002	0.02	63.19
Total emission per year			14.90	1.47	0.37	0.36	0.00024	0.27	758.30

Locomotives used for on-port and off-port activities by CPA are essentially similar models, which are very old (built in 1953) and not suitable for modern cargo transportation. Locomotives produce 14.90 tonne NOx, 1.47 tonne CO, 0.37 tonne PM10, 0.36 tonne PM2.5, 0.27 tonne Black carbon and 758.30 tonne CO2e annually (table 3-4). Although these are the least amount of emissions among other sources, emissions can be reduced more efficiently using latest models of locomotives.

3.4. Emission Comparison:Heavy Container Vehiclevs Locomotive

The carrying capacity of locomotives used in transporting cargoes from Chittagong terminal to Dhaka terminal is 1382.40 tonne (64 TEUs), whereas average carrying capacity of Heavy container vehicles is 40.68 tonne. Therefore, one trip of locomotive is equivalent to 34 trips of heavy container vehicle. Table 3-5 shows the relative emission changes when switching from heavy container vehicles to locomotives. The emission of CO_2e can be reduced by 96.08% per trip of locomotive. Similar changes can be noticed in Sulphur dioxide (98.41%) and Carbon monoxide (63.82%). However, extreme increase in Particulate matters and Black carbon can be observed (389.19%), followed by Nitrogen oxide (22.42%).

Table 3-5. Heavy Container Vehiclevs Locomotive***:*** change in emission through substitution

Pollutants	**Emission from 34 Heavy Container Vehicles (tonne)**	**Emission from Locomotives per trip (tonne)**	**Change in emission**
NO_x	0.14	0.18	-22.42% (increase)
CO	0.05	0.02	63.82% (decrease)
PM_{10}	0.001	0.004	-389.19% (increase)
$PM_{2.5}$	0.001	0.004	-389.19% (increase)
SO_2	0.0002	0.00	98.41% (decrease)
Black Carbon	0.001	0.003	-389.19% (increase)
CO_2e	230.38	9.03	96.08% (decrease)

3.5. Total Estimated Emission

The total estimated criteria and greenhouse gasemissions from in-land activities and cargo transportation of Chittagong Port from April 2017 to March 2018 are presented in Table 3-6 and 3-7 respectively.

Table 3-6. Total criteria pollutants of Chittagong Port (in tonne)

Sources	NO_x	CO	PM_{10}	$PM_{2.5}$	SO_2	Black Carbon
CHE	285.87	57.15	11.41	11.89	18.91	9.17
Head Truck	3177.27	1075.61	19.31	18.73	3.91	14.44
Locomotive	14.90	1.47	0.37	0.36	0.00	0.27
Total emissions from April 2017 to March 2018	3478.04	1134.22	31.09	30.97	22.82	23.88

Table 3-7. Total GHGpollutants of Chittagong Port (in tonne)

Sources	CO_2	CH_4	N_2O	CO_2e
CHE	62621.34	30.55	4.36	64633.59
Head Truck	5075580.60	2.38	1.06	5075927.81
Locomotive	751.54	0.06	0.02	758.30
Total emissions from April 2017 to March 2018	5138953.49	32.99	5.44	5141319.71

As shown in table 3-6, NO_x was the major pollutant, followed by CO, PM_{10}, $PM_{2.5}$, Black Carbon and SO_2, emitted from the in-land activities of Chittagong Port. Head truck is the major source of all emissions. They emit 91.35%NO_x, 94.83% CO, 62.11%PM_{10}, 60.47%$PM_{2.5}$and 98.73% CO_2eof total emission. Head truck emits 98.73% (5.08 million tonne) of total CO_2e emission. The other two sources contribute relatively very low; i.e. CHE 1.30% (64633.59 tonne) and Locomotives 0.01% (758.30 tonne) of total CO_2e emission. The total amount of CO_2e pollutant released in the atmosphere is 5141319.71 tonne per year which has a market value of 25.71 million dollars according to Kyoto protocol where onetonne CO_2e is priced $5.

4. CONCLUSION

Adverse effects of emissions from ports are already been recognized by various leading seaports around the world. The Port of Oakland have declared it's clean-air vision, apath to emissions-free cargo operations. According to the plan, diesel emissions are to be reduced by 85% by 2020(POO, 2018). The Port of Tacoma, Port of Seattle, and Port Metro Vancouver (Vancouver Fraser Port Authority), Canada have already been reducing emissions and fulfilling performance targets to improve air quality. Their "Northwest Ports Clean Air Strategy" has set reduction goals to reduce emission of diesel particulate matter and greenhouse gasses by 80% and 15% respectively by 2020(US EPA, 2017).On the other hand, Chittagong Port Authority doesn't monitor the emissions released in the port surrounding areas from the complex activities of the port.The study on estimating emissions from the in-land activities of Chittagong port isa first time initiative in Bangladesh. The study used international standard guidelines thus may act as guide for all national or international research work related to the topic. The methodologies followed are most recent and specific purpose oriented.The study shows the sources of emissions needed to be attended with some recommended strategies.Significant amount of investments and efforts in developing technology, and infrastructure is needed to achieve a zero-emission seaport. Engines with diesel fuels are the main reasons of air emission.Introduction of modern electric driven equipment is necessary to reduce emission. Old container handling equipment may be reconditioned and converted into electric powered engines. In addition, renewable energies like solar and wind-powered energies can be used as green power supply for port activities.Though bringing about fuel switch in the transport system is a big challenge, which requires commitement and nation's ambitions for fossil-free fuel. Establishment of air monitoring system may help to get up-to-date information on the air quality of the port and its surrounding areas.Carbon taxes may be applied to the export-import agencies for their involvement in port emission. These taxes will develop the fund for future carbon reducing initiativesjointly taken by the port and its stakeholders.

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