Olukanni & Esu, *Cogent Engineering* (2018), 5: 1507267
https://doi.org/10.1080/23311916.2018.1507267

cogent engineering

ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

Estimating greenhouse gas emissions from port vessel operations at the Lagos and Tin Can ports of Nigeria

David O. Olukanni[1]* and Charles O. Esu[1]

Received: 30 April 2018
Accepted: 30 July 2018
First Published: 07 August 2018

*Corresponding author: David O. Olukanni, Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria
E-mail: david.olukanni@covenantuniversity.edu.ng

Reviewing editor:
Mutiu Kolade Amosa, University of the Witwatersrand, South Africa

Additional information is available at the end of the article

Abstract: Greenhouse gas (GHG) emission, the number one contributor to global warming is not just a product of in-land transportation, industries and other anthropogenic effect but also the maritime and shipping industries. This article estimates the amount of greenhouse gases emitted from port vessel operations in the Lagos and Tin Can ports of Nigeria. The emission estimate was carried out based on the type of the vessel and its movement from the moment of its arrival (400 km from the coast). The emission estimate was done using the bottom-up approach based on the characteristics of individual vessels and using data on vessels processed by both ports in the first and second quarter of the year 2017. Among various types of vessels, Premium Motor Spirit (PMS) carriers are the heaviest emitters, followed by the container vessels and general cargo vessels. Result for the first and second quarter of 2017 indicates that approximately 16,335 t and 773 t of CO_2 were produced and emitted during anchorage and while passing through lock gates movement, respectively. Also, 644 t of CO_2 was emitted through maneuvering to the dock movement. Consequently, these three movements account for 85% of the total CO_2

ABOUT THE AUTHOR

Professor David O. OLUKANNI is a faculty in Civil Engineering Department at Covenant University. He is a Fulbright Scholar; studied at the University of Oklahoma, Norman and researched at North Carolina State University, Raleigh, U.S.A. He was Chair of Civil Engineering and currently Director, Quality and Academic Standards, Covenant University. He is a member of Council for the Regulation of Engineering in Nigeria (COREN); Nigerian Society of Engineers (NSE) and American Society of Civil Engineers (ASCE). He has published widely and serves on Editorial Board and reviewer for several journals. He serves as assessor and external examiner for postgraduate dissertations and thesis. He is the research cluster head of Urban Environmental Issues and National Development at Covenant University. His research interest includes: Solid Waste Management; Environmental Sustainability; Rural-Urban Water Supply, Wastewater Management, Rural/Urban Sanitation and Hygiene studies. He has supervised and mentored several students towards the award of their degrees.

PUBLIC INTEREST STATEMENT

Greenhouse gas (GHG) emission, the number one contributor to global warming is not just a product of in-land transportation, industries and other anthropogenic effect, but also the maritime and shipping industries. These emissions are known to contribute to lung cancer, cardio vascular and cardio pulmonary functions, allergies and asthma, particularly for the inhabitants of communities lying along the sea shore. This article estimates the amount of GHGs emitted from port vessel operations in the Lagos and Tin Can ports of Nigeria. The emission estimate was done using the bottom-up approach based on the characteristics of individual vessels and using data on vessels processed by both ports in the first and second quarter of the year 2017. These movements of vessels considered account for 85% of the total CO_2 emission from Lagos and Tin Can ports. It was found that if provisions are made for electricity from land, about 5% of the estimated emissions during cargo handling can be avoided.

emission from Lagos and Tin Can ports. These emissions are known to contribute to lung cancer, cardio vascular and cardio pulmonary functions, allergies and asthma, particularly for the inhabitants of communities lying along the sea shore. However, if provisions are made for electricity from land, about 5% of the estimated emissions during cargo handling can be avoided.

Subjects: Transportation Engineering; Environmental Health; Pollution

Keywords: Maritime traffic; GHG emissions; air pollution; environmental pollution; health impacts

1. Introduction

The rise in shipping activities in the past two decades has made shipping standout amongst the most polluting industries. Emissions related with shipping industries have been overlooked in the past. However, attention of researchers is now drawn to gas emissions (Olukanni & Adebiyi, 2012) and the pollution effect (Olukanni & Aremu, 2017; Williams & Nsikak, 2010) as this medium of transportation is viewed as a very proficient method of transportation with regard to tonnage of cargo transported per kilometre travelled (IMO, 2016a). Global emissions from shipping have increased considerably, contributing to global anthropogenic emissions and most importantly impacting air pollution through climate change, reduction of ozone layer thickness and acid rain (Saraçoğlu, Deniz, & Kiliç, 2013; Song & Shon, 2014). Consequently, public concerns about environmental and health impacts of maritime traffic emissions are increasing and the need to protect people and their socio-economic activities is important (Olukanni, Adejumo, Adedeji & Salami, 2016).

The most important pollutants produced by ships in in-port and international routes are particulate matters, volatile organic compounds and carbon (II) oxide (with effect on human wellbeing), as well as sulphur oxides (SOx) and nitrogen oxides (NOx) (contributing to the formation of acid rain), particulate matter through photochemical pathway and tropospheric ozone (O_3) formation, carbon dioxide (CO_2), black carbon (BC) and methane (CH_4) due to their role on the greenhouse effect (Eyring et al., 2009; Matthias, Bewersdorff, Aulinger, & Quante, 2010)

CO_2 is a major ozone depleting substance discharged by ships with respect to amount and global temperature alteration potential. As presented in the 3rd International Maritime Organization Greenhouse Gas Emission Study (2014), global shipping discharged 796 million tons of CO_2 in 2012, showing 2.2% of aggregate emission volume that year. It was projected that by 2050, 15% of aggregate CO_2 emissions would be attributed to maritime transport (IMO, 2016a). Recent global assessments show that no less than 70% of emissions from vessels occur within 400 km from the coast, and the pollutants of these discharges can be transported several kilometres into the mainland, causing air quality issues even in extremely remote territories of the seaside zone (Corbett et al., 2009; Song & Shon, 2014). Emissions are also generated while ships are at ports and most of the environmental impacts associated with ships are caused due to the day-to-day operations such as in-port shipping activities (Ng et al., 2013; Song & Shon, 2014). These emissions contribute to lung cancer, loss of lung, cardio vascular and cardio pulmonary functions, allergies and asthma, particularly for inhabitants of regions lying along the sea shore (Eyring et al., 2009; Song & Shon, 2014).

From the forgoing, a more critical investigation of GHG emissions from ports is required, so as to help port authorities control current emission levels and figure out strategies to reduce GHG discharge. This work bridges a gap in literature by giving a thorough investigation of GHG emissions with respect to information from all vessels handled by Lagos and Tin Can ports in the first and second quarter of 2017. In precise terms, this article gauges GHG emissions emanating with respect to the category of vessel and the course of the vessel from the moment it arrives at the port, 400 km from the coast to unloading and finally departure.

2. Description of the study area

2.1. The Lagos and Tin Can Ports of Nigeria

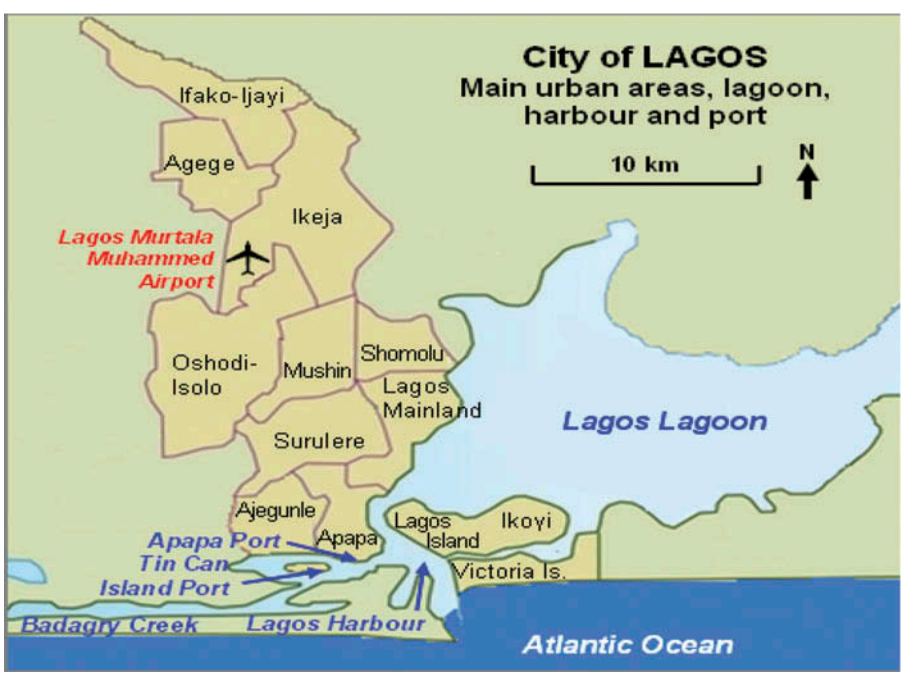
The oldest and biggest port in Nigeria is the Lagos Port which is also referred to as Premiere Port (Apapa Quays). It is located in the commercial hub of Nigeria, Apapa, Lagos State (Figure 1). The Port was established in 1913 and the construction of the first four deep water berths commenced in 1921. The port is made of state of the heart facilities ranging from modern cargo handling equipment to personnel support facilities. It has good linkages with various means of transportation such as rail, road and water. It has four wheel gates of 8 meters long for oversize cargoes which gives it an added advantage in oversize cargoes handling (NPA, 2017).

The federal government introduced the landlord Port model for improved efficiency and operational activities. In 2006, the operation of the terminals was carried out by private operators. Now, Lagos port has five terminals all run privately by five operators with expert management and individuals with local and international experience in port operation. The Terminal Operators are: Green view Development Nigeria Ltd. (GNDL), Lily pond Inland Container Terminal, Apapa Bulk Terminal Ltd. (ABTL), AP Moller Terminal Ltd. (APMT) and ENL Consortium Ltd (Ng et al., 2013).

There are two logistics bases in the Lagos port, these are; Eko Support Services Ltd. and Lagos Deep Offshore Logistics (LADOL). These logistics bases have eight jetties. Operators own factories where sugar, salt and flour are produced in the port. Lagos port is registered and certified with the International Maritime Organization (IMO). The port runs for 24 hours with remarkable vessel turnaround time. The security personnels in the port are made of armed and unarmed individuals. Monitoring is also carried out with CCTV cameras placed at strategic positions in the port (NPA, 2017).

Close to Lagos Port Complex is the Tin Can Port (North West of Lagos port). During the oil boom period in 1975, there was a hike in economic activities in the country. Also, the rebuilding activities that took place after the civil war led to a rise in the volume of import and export which gave rise to congestion in Lagos port. As a result; there was need for the government to construct a new

Figure 1. City of Lagos showing urban areas, lagoon, harbour and ports.



port. This was done on Tin Can Island. The construction started in 1976 and was commissioned in 1977. The Tin Can Port is capable of handling 10-16 vessels at a time (NPA, 2017).

3. Method of data collection

Emissions by each type of vessels at each phase of their course were gauged, from the moment it enters the port, 400 km from the coast to the point of unloading and exit. To estimate the CO_2 emitted, a measure of the fuel consumed by each type of vessel over their course of movement in the port was gauged. Fuel consumed by a ship for a given distance is taken into consideration and the quantity of fuel consumed by both the main and auxiliary engine of the ship was gauged (Corbett et al., 2009). Typical examples of the application of this technique involving Equations (1) and (2) in assessing CO_2 emissions in Taiwan's Kaohsiung harbour and Korea's Port of Incheon are based on NPA (2017) and Chang, Younghun, & Younghoon (2013), respectively. Based on the success of previous works and the type of data available from the Nigeria Port Authority (NPA), this method was adopted. The method was harnessed mainly to evaluate fuel consumptions of both the main and auxiliary engines from point to point from when the vessel is at about 400 km (215 nautical miles) from the coast of each of these ports (Figure 2).

The quantity of fuel used by a vessel at any stage of its movement within the port is given in Equation 1 (Chang et al., 2013; NPA, 2017) as:

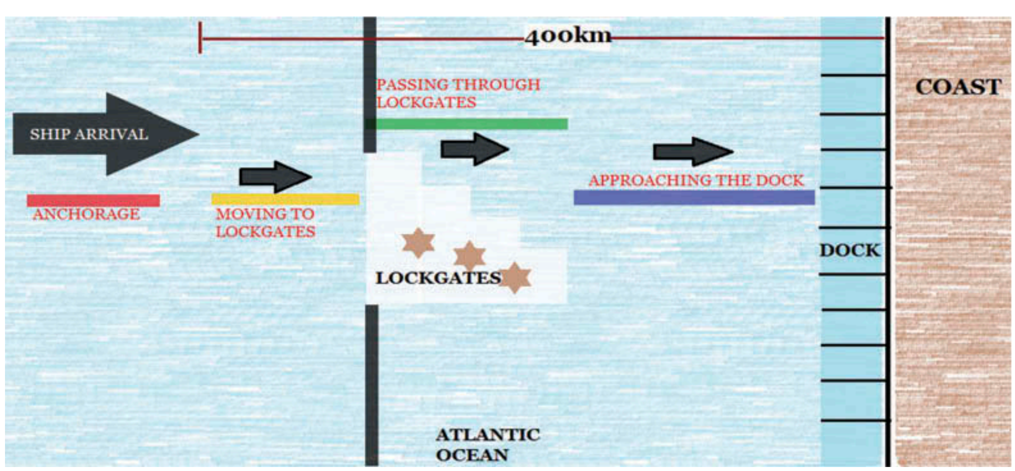
$$F_{ijk} = \left[MF_k \times \left(\frac{S_{1k}}{S_{0k}}\right)^3 + AF_k\right] \frac{d_{ij}}{24S_{1k}} \tag{1}$$

where $\boldsymbol{F_{ijk}}$ denotes the quantity of fuel used by vessel k moving from point i to j; $\boldsymbol{MF_k}$ denotes the fuel used by the main engine daily; $\boldsymbol{AF_k}$ denotes the fuel used by the auxiliary engine daily; $\boldsymbol{S_{1k}}$ denotes the operational speed of the vessel (nm/h); $\boldsymbol{S_{0k}}$ denotes the design speed of the vessel (nm/h) and $\boldsymbol{d_{ij}}$ denotes the distance between point $\boldsymbol{i}$ and $\boldsymbol{j}$.

After estimating the fuel used, CO_2 emissions are then calculated from fuel combustion. Variations in the type of fuel used by vessels are normal, but for the purpose of this work, it is largely known that residual marine oil is the commonly used type of fuel for vessels, and is made up of 86.4% of carbon per unit weight. Also, the CO_2/C is known to be 44/12. As a result, CO_2 emissions resulting from residual marine oil combustion can be evaluated with Equation (2) (Chang et al., 2013; NPA, 2017):

$$\mathbf{CO_2} = (0.8645) \times (44/12) \times \sum_{\mathbf{i,j,k}} \mathbf{F_{ijk}} = 3.17 \times \sum_{\mathbf{i,j,k}} \mathbf{F_{ijk}} \tag{2}$$

Figure 2. Ship movement from the coast.



Substituting Equation (1) into Equation (2) gives:

$$CO_2 = 3.17 \times \sum_{i,j,k} \left[MF_k \times \left(\frac{S_{1k}}{S_{0k}} \right)^3 + AF_k \right] \frac{d_{ij}}{24S_{1k}} \tag{3}$$

The parameters required for calculating CO_2 emissions based on Equation (3) include: $\boldsymbol{MF_k}$ which denotes the fuel used by the main engine daily; $\boldsymbol{AF_k}$ which denotes the fuel used by the auxiliary engine daily; $\boldsymbol{S_{1k}}$ which denotes the operational speed of the vessel (nm/h); $\boldsymbol{S_{0k}}$which denotes the design speed of the vessel (nm/h) and $\boldsymbol{d_{ij}}$ which denotes the distance between point ***i*** and ***j.***

The data acquired from the NPA database show that a total of 1,275 vessels were processed: Lagos (595) and Tin Can ports (680) from January to June (first and second quarter) of 2017 excluding Navy vessels. This came with other information such as docking time, berth number, nationality, vessel type, exit time, tonnage, cargo amount, etc. as can be seen on the NPA website http://nigerianports.gov.ng.

Some essential data used in this work are not available in the Nigerian Port Authority website. These include; vessel operating and design speed, time and distance traversed at various stages of the vessel's movement, engine power (kW h), engine load factor and fuel consumption rate (g/kW h). The data for time and distance traversed at various stages of the vessel's movement were obtained by tracking the vessels movement in the port by individuals in the pilot organization. The data for the vessel's operating and design speed by vessel type are obtained based on assistance from major shipbuilding websites as well as authorities in ship building research institutes. The data on fuel consumption rate, engine load factor were obtained from Corbett et al. (2009) and Chang & Wang (2012), while the engine power was based on European Environment Agency (2002) and Villalba & Gemechu (2011).

4. Results and discussion

The results for fuel consumed depending on the category of ship and various movement of the vessel are presented in Table 1 and Figure 3. The result indicates that PMS (premium motor spirit) carriers are the highest consumers of fuel, followed by container ships and general cargo vessels. The curve indicating passing through the lock gates movement and that anchorage movement overlap showing that the vessel CO_2 emission in both stages of movement are similar. This is as a result of the same time and distance covered during these movements. It is also observed that PMS vessels are the highest emitters of CO_2 followed by container vessels and general cargo vessels. Used vehicle vessels are the highest fuel consumers per vessel, followed by general cargo vessels and passenger ships. The error estimate of the CO_2 emitted is presented in Table 2.

In general, the vessel call which is the number of a particular type of vessel processed by a port determines the vessel with the most CO_2 emission. Figure 3 indicates the vessel call for each of the vessel types. This gives the reason why PMS vessels are the highest gross emitters of CO_2 as they have the highest vessel call in these ports. Figure 4 gives the percentage of fuel consumed based on the stage of movement of the vessel. The highest fuel consumption is recorded during anchorage and when passing through the lock gates, with 30% each leading to 60% of the total emission from a particular ship type. The least fuel consumed was during cargo handling at the dock which accounts for about 5% of the total emission from a ship as shown in Figure 4. Therefore, over 5% of the total emission can be curbed by powering the vessel from the national grid during cargo handling and in fact, a better situation can be obtained by using the national grid when the vessel gets to the port vicinity.

4.1. Uncertainties

The correctness of this CO_2 emission estimate is dependent on the information utilized and the presumptions made. As stated earlier, basic information regarding the vessels were acquired from NPA website which is a totally dependable source for essential ship data for the two ports in consideration. Experimental values utilized for vessels speeds, and engine powers were utilized as

Table 1. Fuel consumed based on ship type and movement

Ship type	Anchorage (kg)	Moving to lockgates (kg)	Passing through lockgates (kg)	Approaching the dock (kg)	Docking (kg)	Total consumption (kg)	Vessel calls	Average per unit (kg)	Total CO_2
LNG Carrier	29,848.8	9,949.6	29,848.8	24,874.0	4,974.8	99,496.0	163	610.4	315,402.6
LPG carrier	26,725.6	8,908.5	26,725.6	22,271.4	4,454.2	89,085.6	155	574.7	282,401.4
Cement ship	64,996.5	21,665.5	64,996.5	54,163.7	10,832.7	216,655.0	96	2,256.8	686,796.5
PMS	12,2807.8	40,935.9	122,807.8	102,339.8	20,467.9	409,359.5	226	1,811.3	1,297,670
General cargo vessel	87,045.1	29,015.0	87,045.1	72,537.6	14,507.5	290,150.4	54	5,373.1	919,777
Jet A-1	58,634.7	19,544.9	58,634.7	48,862.3	9,772.4	195,449.3	65	3,006.9	619,574.3
AGO	63,554.3	21,184.7	63,554.3	52,961.9	10,592.3	211,847.9	88	2,407.3	671,558.1
Container vessel	10,6505.6	35,501.8	106,505.6	88,754.6	17,750.9	355,018.7	262	1,355.0	1,125,409
Passenger ship	28,888.2	9,629.4	28,888.2	24,073.5	4,814.7	96,294.0	22	4,377.0	305,252.1
Used vehicle carrier	81,059.8	27,019.9	81,059.8	67,549.8	13,509.9	270,199.3	30	9,006.6	856,532.1
Dry bulk carrier	29,013.5	9,671.1	29,013.5	24,177.9	4,835.5	96,711.9	38	2,545.0	306,576.8
Chemical products	35,567.2	11,855.7	35,567.2	29,639.3	5,927.8	118,557.4	45	2,634.6	375,827.1
Other chemicals	38,282.5	12,760.8	38,282.5	31,902.0	6,380.4	127,608.3	31	4,116.3	404,518.4
TOTAL	**772,930.1**	**257,643.3**	**772,930.1**	**644,108.4**	**128,821.6**		**1,275**		**8,167,296**

Figure 3. Fuel consumed based on ship type and movement.

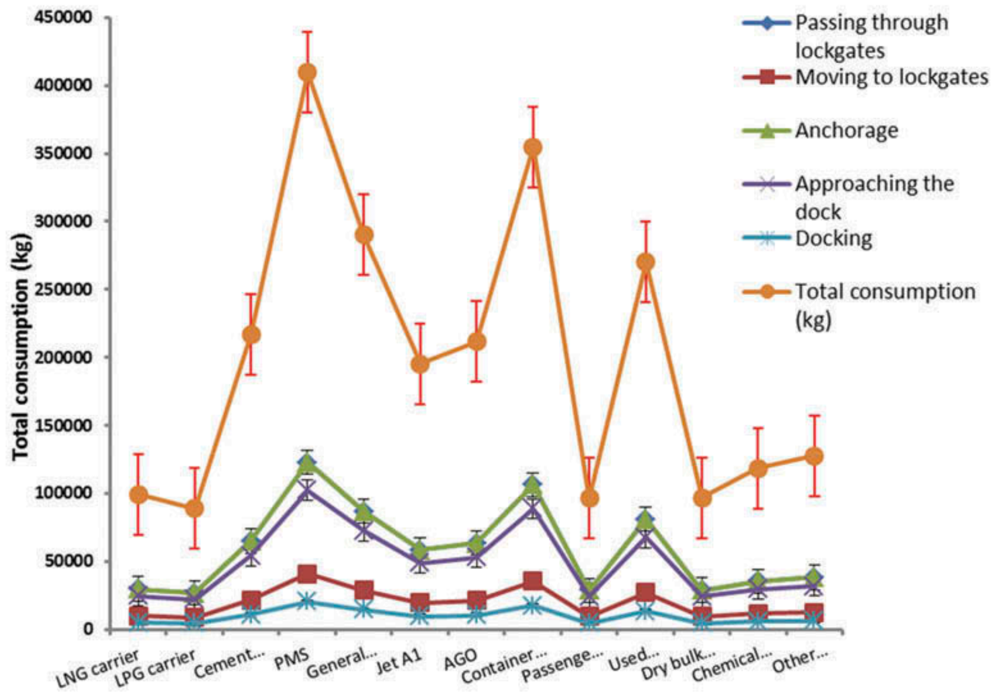


Table 2. Error estimate on CO_2 emitted

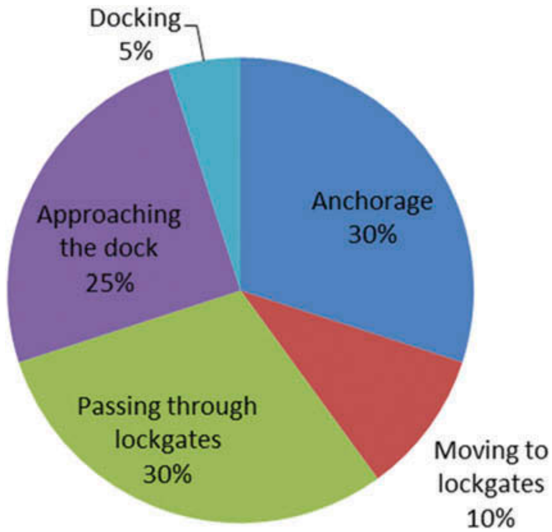
Ship type	−5%	Actual value	+ 5%
LNG Carrier	299632.5	315402.6	331172.7
LPG carrier	268281.3	282401.4	296521.5
Cement ship	652,456.7	686,796.5	721,136.3
PMS	1,232,787	1,297,670	1,362,554
General cargo vessel	873,788.2	919,777	965,765.9
Jet A-1	588,595.6	619,574.3	650,553
AGO	637,980.2	671,558.1	705,136
Container vessel	1,069,139	1,125,409	1,181,679
Passenger ship	289,989.5	305,252.1	320,514.7
Used vehicle carrier	813,705.5	856,532.1	899,358.7
Dry bulk carrier	291,248	306,576.8	321,905.6
Chemical products	357,035.7	375,827.1	394,618.5
Other chemicals	384,292.5	404,518.4	424,744.3

a part of the assessment, which may instigate a specific level of uncertainty. In spite of this, the calculation was performed to be the most illustrative for Lagos and Tin Can ports. To take care of the errors that must have occurred in course of the calculations, a ± 5% of the CO_2 emitted by each of the ship type was carried out and presented in Figure 3 as vertical bars on the value point.

5. Conclusion and recommendation

The CO_2 emissions at Lagos port and Tin Can port for the first and second quarter of 2017 was 8,167 t. The data obtained covered 6-months (January to June) in 2017. Extrapolation based on the result for the first and second quarter of 2017 indicates that approximately 16,335 t of CO_2 was

Figure 4. Percentage fuel consumption based on stage of movement.



produced in 2017. Around 773 t of CO_2 were produced and emitted during anchorage and while passing through lock gates movement, respectively. Also, 644 t of CO_2 was emitted through maneuvering to the dock movement. Consequently, these three movements account for 85% of the total CO_2 emission from Lagos and Tin Can ports. Whereas maneuvering to the lock gates movement shows an emission of 258 t, and 129 t of emissions for the docking stage. As a result, if provisions are made for electricity from land about 5% of the estimated emissions docking handling can be avoided.

Acknowledgements
The authors are grateful to the NPA for making available the data on vessels characteristics, movements and call on their website. We also appreciate the members of the pilot association, Damen Shipyards Group and Appledore Shipbuilders for making available some coded information that led to the success of this work. The management of Covenant University is also appreciated for providing an enabling environment in doing the report of this research work.

Funding
The authors received no direct funding for this research.

Author details
David O. Olukanni[1]
E-mail: david.olukanni@covenantuniversity.edu.ng
ORCID ID: http://orcid.org/0000-0001-8156-2619
Charles O. Esu[1]
E-mail: charles.esu@cu.edu.ng
[1] Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria.

Citation information
Cite this article as: Estimating greenhouse gas emissions from port vessel operations at the Lagos and Tin Can ports of Nigeria, David O. Olukanni & Charles O. Esu, *Cogent Engineering* (2018), 5: 1507267.

References
Chang, C., & Wang, C. (2012). Evaluating the effects of green port policy: Case study of Kaohsiung harbor in Taiwan. *Transportation Research Particle D*, *17*, 185–189. doi:10.1016/j.trd.2011.11.006
Chang, Y., Younghun, S., & Younghoon, R. (2013). Assessing greenhouse gas emissions from port vessel operations at the Port of Incheon. *Transportation Research Particle D Transport and Environment*. doi:10.1016/j.trd.2013.06.008
Corbett, J. J., Wang, H., & Winebrake, J. J. (2009). The effectiveness and costs of speed reductions on emissions from international shipping. *Transportation Research Particle D: Transport and Environment*, *14*, 593–598. doi:10.1016/j.trd.2009.08.005
European Environment Agency. (2002). *ENEP/CORINAIR emission inventory guidebook*.
Eyring, V., Isaksen, I., Berntsen, T., Collins, W., Corbett, J., Endresen, O., … Stevenson, D. (2009). Transport impacts on atmosphere and climate: Shipping. *Atmos Environment*, 44. doi:10.1016/j.atmosenv.2009.04.059
IMO, 2016a. *Marine environment*. International Maritime Organization. Retrieved from: http://www.imo.org/en/OurWork/Environment/Pages/Default.aspx. Assessed 01/ 02/2018
Matthias, V., Bewersdorff, I., Aulinger, A., & Quante, M. (2010). The contribution of ship emissions to air pollution in the North Sea regions. *Environment Pollution*, *158*. doi:10.1016/j.envpol.2010.02.013
Ng, S. K. W., Loh, C., Lin, C., Booth, V., Chan, J. W. M., Yip, A. C. K., … Lau, A. K. H. (2013). Policy change driven by an AIS-assisted marine emission inventory in Hong Kong and the Pearl River Delta. *Atmos Environment*, *76*. doi:10.1016/j.atmosenv.2012.07.070
NPA. (2017). Nigeria Port Authority: Ports statistics. Nigeria Port Authority website Retrieved from: http://nigerianports.gov.ng. Accessed 10/ 02/2018.
Olukanni, D. O., & Adebiyi, S. A. (2012). Assessment of vehicular pollution of road side soils in ota metropolis, Ogun State, Nigeria. *International Journal of Civil & Environmental Engineering*, *12*(4),40-46.

Olukanni, D. O., Adejumo, T. A., Adedeji, A. A., & Salami, A.W. (2016). Assessment of jebba hydropower dam operation for improved energy production and flood management. *ARPN Journal of Engineering and Applied Sciences, 11*(3), 8450-8467.

Olukanni, D. O., & Aremu, O. D. (2017). Provisional evaluation of composting as priority option for sustainable waste management in South-West Nigeria. *Pollution*, Publisher: University of Tehran *3*(3), 417–428.

Saraçoğlu, H., Deniz, C., & Kiliç, A. (2013). An investigation on the effects of ship sourced emissions in Izmir port. *Turkey Sciences World Journal*, 2013. doi: 10.1155/2013/218324

Song, S. K., & Shon, Z. H. (2014). Current and future emission estimates of exhaust gases and particles from shipping at the largest port in Korea. *Environment Sciences Pollution Researcher, 21*. doi:10.1007/s11356-014-2569-5

Villalba, G., & Gemechu, E. D. (2011). Estimating GHG emissions of marine ports the case of Barcelona. *Energy Policy, 39*, 1363–1368. doi:10.1016/j.enpol.2010.12.008.

Williams, A. B., & Nsikak, B. U. (2010). Interseasonal hydrological characteristics and variabilities in surface water of tropical estuarine ecosystems within Niger delta, Nigeria. *Environ Monit Assess, 165*, 399–406.