EVALUATING THE CONTRIBUTION OF SHIP EXHAUST GAS EMISSIONS TO AIR POLLUTION AND THE URBAN CARBON FOOTPRINT: A CASE STUDY OF DURBAN PORT

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DURBAN

2014

PREFACE

Research work described in this dissertation was carried out in the School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Durban, under the supervision of Dr L.F. Ramsay.

The study represents original work compiled by the author and has not been submitted to any other tertiary institution or published previously. Where use has been made of the work of others, it has been duly acknowledged and referenced in the text.

Nkosinathi Michael Manqele

Ramsay

Dr Lisa Frost Ramsay (Supervisor)

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to the following people for all their support and contribution

Dr Lisa Frost Ramsay for her unmatched support and supervision. Her commitment to this work was outstanding despite her many other commitments and progressions in her life. I am very grateful to have been your protégé and without your special guidance and excellent supervision, this work would not be possible.

My wife Lindiwe and my daughter Zamaduyaza for all the sacrifices they have made and the encouragement they have given me throughout this study. I am fortunate to have you in my life and my love for you is unparalleled.

Vusimuzi Manqele, my cousin, and Mmeli Majola my friend for helping me to collect the online technical data of ships that visited Durban Port during the study period. Thanks Duyaza and Macingwane for your brotherly support.

All the Transnet National Port Authority (TNPA) staff at Durban Port who assisted me during my search for data about ships and harbour crafts operations. The following people are particularly acknowledged: Justin Adams, the deputy harbour master, for providing times of arrival and departure of all ocean going vessels during the study period; Aubrey Baloyi, the marine pilot, for providing the manoeuvring characteristics data of various ships during the docking operation in port; and Peter Phillips, the Marine Technical Manager, for providing monthly engine hours of all harbour crafts during the study period. Without the operational data provided by the TNPA staff, no detailed marine mobile port inventory would be possible.

The staff at my work, Durban University of Technology (DUT) who were involved with financial support, technical support, and even moral support. A special thanks to the previous and the current Executive Deans of the Faculty of Applied Science (Prof Lorton and Prof Singh), the previous and the current Heads of Maritime Studies Department (Capt Johnsen and Leon Govender) and all the staff of the Department of Maritime Studies. Thanks to the staff from the Higher Education Employee Assistance Scheme (HEEAS), DUT library and the printing services who provided assistance during the compilation of this thesis. Thank you all for your support.

ABSTRACT

The Durban Port in South Africa is the busiest port in Africa and has the second largest container terminal in the southern hemisphere. Approximately 60% of the country's exports and imports pass through this port. It is one of the few ports in the world that is in close proximity to the central business district (CBD). This proximity has a positive spin-off in terms of tourism, recreation and accessibility to transport and other business activities. However, it also has a negative impact to the city's population due to air pollution resulting from the port activities, particularly from the marine mobile sources. Like many other ports globally, Durban Port suffers from the lack of proper quantification of emissions resulting from ships in the port. The aim of this study was therefore to calculate the pollution from ships in Durban Port between the 1st of April 2012 and the 31st of March 2013 (one year).

The activity-based method was utilized to estimate ships emissions of sulphur dioxide (SO_2), oxides of nitrogen (NO_X), particulate matter (PM_{10}), hydrocarbons (HC) and carbon dioxide (CO_2). This method uses emission factors for specific engines, the types of activities (also known as modes of operation) in the port, the time spent on each activity and the load factors per activity. The types of activities considered were manoeuvring, hoteling and loading/unloading. The types of vessels studied were ocean going vessels (OGVs) and harbour crafts.

The results indicate that OGVs (particularly container ships) emit higher levels of pollutants than the harbour crafts in Durban Port. This is explained by the higher number of OGVs relative to harbour crafts, and the higher emissions per OGV per operational hour relative to those of harbour crafts. Auxiliary engines accounted for a higher proportion of emissions of NO_X and HC when compared to propulsion engines and boilers, while the boilers emitted higher levels of SO_X, PM_{10} and CO_2. This is because both the auxiliary engines and the boilers remain operational in all three activities studied. The emissions inventory for Durban Port was compared with other ports globally including JN Port in India, the Port of Los Angeles in the United States and the Port of Copenhagen in Denmark.

Cambridge Environmental Research Consultants' (CERC) Atmospheric Dispersion Modelling System (ADMS) was used to model ambient concentrations of NO_X, SO_2, and PM_{10} from ships in port. The results were compared with and found to be below the South African National Ambient Air Quality Standards (NAAQS) published in line with Section 9 of the National Environmental Management: Air Quality Act 39 of 2004. However, the results indicate that emissions from ships are significant and should not be ignored in cumulative air quality assessments and the calculation of the urban carbon footprint.

Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AE	Auxiliary Engine
CO_2	Carbon Dioxide
DPM	Diesel Particulate Matter
ECA	Emission Control Area
EF	Emission Factor
GT	Gas Turbine
HC	Hydrocarbons (e.g. CH_4 – Methane)
HFO	Heavy Fuel Oil
HSD	High Speed Diesel
LF	Load Factor
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
ME	Main Engine or Main Propulsion Engine
MGO	Marine Gas Oil
MSD	Medium Speed Diesel
Mt	Mega-tonnes
NO_X	Nitrogen Oxides, refers to NO and NO_2 but calculated as NO_2
PM_{10}	Fine Particulate Matter with diameter 10 µm or less
RO	Residual Oil
SANAS	South African National Accreditation System
SDCEA	South Durban Community Environmental Alliance
SDB	South Durban Basin
SDMPP	South Durban Multi-Point Plan
SFC	Specific Fuel Consumption
SO_X	Sulphur oxides, refers to SO_2 and SO_3 but calculated as SO_2
SSD	Slow Speed Diesel
ST	Steam Turbine
TNPA	Transnet National Port Authority
TSP	Total Suspended Particulates
USEPA	United States Environmental Protection Agency

DEFINITIONS

Berth	A place where a ship is fastened alongside while loading or off-loading cargo
Call	One entrance and one clearance of a vessel in the port area.
Cold Ironing	An electrical connection made between the vessel and the terminal to provide full or partial operational power during hotelling periods.
Cold shift	This occurs when a vessel changes berths by being towed from one to the other using tugs without starting up the main engines.
Docking	The bringing of a ship alongside a pier/wharf/dock (PWD). However, it may also refer to a ship that is already alongside, for instance a ship that is docking or is docked at Pier A.
Emission Factor	A number specific to an engine or system that describes the amount of a pollutant that is generated per unit of activity.
Flue gas	A gas exiting to the atmosphere via a flue, which is a pipe for conveying exhaust gases from a furnace, boiler or steam generator.
Hot shift	This occurs when a vessel uses its main engines to shift from one berth to another.
Hotelling	Hotelling is the time at PWD when the vessel is operating auxiliary engines only or is cold ironing. Auxiliary engines operate at some load conditions the entire time the vessel is manned, but peak loads will occur after the propulsion engines are shut down. The auxiliary engines are then responsible for all onboard power or are used to power off-loading equipment, or both. Cold ironing uses shore power to provide electricity to the ship instead of using the auxiliary engines. Hotelling needs to be divided into cold ironing and active to accurately account for reduced emissions from cold ironing.
Loading/Unloading	The time when the vessel uses its own cranes/gantries or equipment to load and off-load the cargo. All general cargo ships and all container ships berthing at Pier B, C, D and E will use their own equipment for loading and off-loading.
Manoeuvre	Time in port between the breakwater and the PWD. Manoeuvring within a port generally occurs at the speed of 5 to 8 knots, with slower speeds maintained as the ship reaches its PWD. Even with tug assist, the propulsion engines are still in operation.

1. INTRODUCTION

1.1 BACKGROUND

South Africa made significant strides in aligning with international trends since its re-acceptance into the international community. This is also true for environmental management issues. In 2004, South Africa launched a Climate Change Response Strategy that provided a forward-thinking framework for the management of climate change. All sectors of government at national, provincial and local levels are required to have adaptation and/or mitigation plans for climate change and representatives from each sector form part of an inter-departmental committee on climate change (DEAT, 2005).

The National Environmental Management: Air Quality Act 39 of 2004 provides standards that regulate air quality monitoring and management by all spheres of government for the purposes of protecting human health. National ambient air quality standards (NAAQS) were published in 2009 in line with Section 9 of this Act. Minimum emissions standards (MES) for various installations have been published in terms of Section 21 of the same Act (RSA, 2010). Emission standards for various categories of motor vehicles, including passenger vehicles, buses, light duty vehicles (LDV) and trucks have been implemented (SAPIA, 2008). Industrial emissions are controlled by the National Air Quality Officer who issues the Atmospheric Emission License (AEL) to industries detailing permitted emission levels for specific pollutants by each industry or installation (DEAT, 2010). Emissions must then be monitored and reported by the holders of AEL. Despite emission standards being set for these various sectors, the shipping industry has remained immune to such measures and it is largely unregulated in terms of emissions.

Several initiatives including the South Durban Basin Multi-Point Plan (SDBMPP) were developed by various sectors to assess and address air pollution in South Africa. The Durban Port forms part of South Durban Basin although the emissions from the port have not been quantified or directly managed. According to DEAT (2005), one of the objectives of the SDBMPP was to identify gaps in ambient air quality monitoring systems, particularly for pollutants of sulphur dioxide (SO_2), oxides of nitrogen (NO_X) and volatile organic compounds (VOCs). The lack of research on ships emissions from the port is one such gap and this study is aimed at addressing this gap.

On a global context, the International Maritime Organization (IMO) made proposals aimed at addressing the emissions of priority pollutants and GHGs. These proposals are based on monitoring, reporting and verification (MRV) of emissions as the first step towards reducing emissions from ships (EC, 2013). The European Union (EU) and its Member States are actively engaged in the IMO's recent initiative for a stepped approach as the foundation of any further mitigation measures. Once adopted, the proposal would set the legal framework for collecting and publishing the verified annual data on priority pollutants and GHG emissions from large ships that visit EU ports, irrespective of the ship's country of registration (EC, 2013)

On a regional context, neither the African Union (AU) nor the Southern African Development Community (SADC) has made any engagements to adopt the proposed measures aimed at monitoring ships emissions in the region. There is no evidence of marine mobile pollution inventory being conducted in the African ports including South Africa. This is an oversight that may create difficulties in regulating the emissions from ships visiting the region. Durban Port can therefore set precedence for the African ports by establishing marine mobile emissions monitoring system.

Emissions in port mostly arise from mobile sources. These mobile sources can be categorized as either marine-based emission sources or land-based emission sources. The marine-based sources include the ocean going vessels (OGVs) and harbour crafts (*Table 1.1*). The OGVs are all foreign vessels because according to the South African Maritime Safety Authority (SAMSA), not a single merchant vessel is listed in the South African register (IOL, 2013). On the contrary, the harbour crafts are all locally registered vessels.

Table 1.1: Classifications of Harbour vessels

Category	Examples
Ocean going vessels (OGV)	Container ships Bulk carriers Tankers General cargo ships Car carriers Others including (passenger ships, reefers, supply ships, yachts, Ro-Ro, ocean tugs, survey ships, fishing trawlers etc.)
Harbour crafts	Tugboats Workboats Barges Ferries Pilot boats

The land-based sources include cargo-handling equipment (CHE) such as terminal tractors, cranes, container handlers, forklifts, heavy-duty trucks and locomotives operating within the port (USEPA, 2009). Land-based emission sources can be simply calculated from vehicular emission factors (USEPA, 2009). The focus of this study however, are in-port marine-based emissions where the primary sources of emissions are diesel engines that provide propulsion for ships and supply electrical power to ships systems.

The major pollutants of marine diesel engines include NO_X, SO_X, particulate matter (PM), hydrocarbons (HC) and carbon dioxide (CO_2). It is important that these pollutants are quantified since without an inventory of the port, it is impossible to adequately assess opportunities for reduction and chart progress in achieving ambient air quality and greenhouse gas mitigation goals. The port emission inventory can assist in assessing the impacts of port development projects and growth in marine activity (USEPA, 2009). It is well known that Durban has a busy and growing port (TNPA, 2010).

1.2 PROBLEM STATEMENT

Emissions from ships calling into Durban Port require close monitoring and control by relevant authorities (IMO, 2002). Currently shipping pollution is not directly regulated and there are no statistics available to indicate the relative significance of the emissions of the shipping industry to pollution in the City of Durban. Emissions from the petrochemical industries are recorded and monitored by government and legislation and local policies regulate their performance. Ship pollution is not well understood and its contribution to ambient pollution and greenhouse gas inventories has not been effectively estimated for Durban. This problem is not peculiar to South Africa alone. In the EU, international maritime transport accounts for 4% of GHG emissions and remains the only transport mode not included in the EU's GHG emissions reduction commitment (EC, 2013).

According to USEPA (2004), port emission inventories produced by national and local agencies are historically less accurate than those from other sectors due to limitations of methodologies utilized for port inventories. This is despite the increase of commercial shipping around the world, the data are still relatively scarce on the contribution of shipping emissions to ambient air particularly in harbor and urban environments (Viana et al., 2009). Wang et al. (2009) agreed that the study of air emission in maritime transportation is new, but the recognition of its importance has been rising in the recent decade. Therefore most pollution inventories in coastal cities suffer from poor quantification of port emissions and may significantly underestimate total emissions if port emissions are ignored (such as the calculation of Durban's Carbon Footprint by ASSAf, 2011).

Marine emissions primarily arise from diesel engines which are prime movers and power generating sources for marine vessels. It is believed that these emissions from marine diesel engines surpass all other land-based mobile sources in most ports (*Figure 1.1*) USEPA (2009). Their quantification is thus vital for correct emission inventory estimation. Unfortunately available emission factors for OGVs have been developed from very limited datasets and may not be accurate in themselves (USEPA, 2009). Some ports resort to stream-lined approach to prepare emission inventories whereby external data from other port inventories are interpolated to suit the port in question (USEPA, 2009). This is not considered the best practice and the accuracy of the results is limited by the availability of suitable proxies for extrapolation. Without accurate emission inventories, it is difficult to assess opportunities for emission reduction and implement and monitor reduction strategies in the port environment as is done in other sectors (USEPA, 2009). Therefore, conducting a proper port inventory of ships emissions provide opportunities to create and implement mitigation strategies and to measure performance over time. Furthermore continuously updated emission inventories are necessary to assess the impacts of port improvement projects or port growth as is the case with Durban Port (USEPA, 2009).

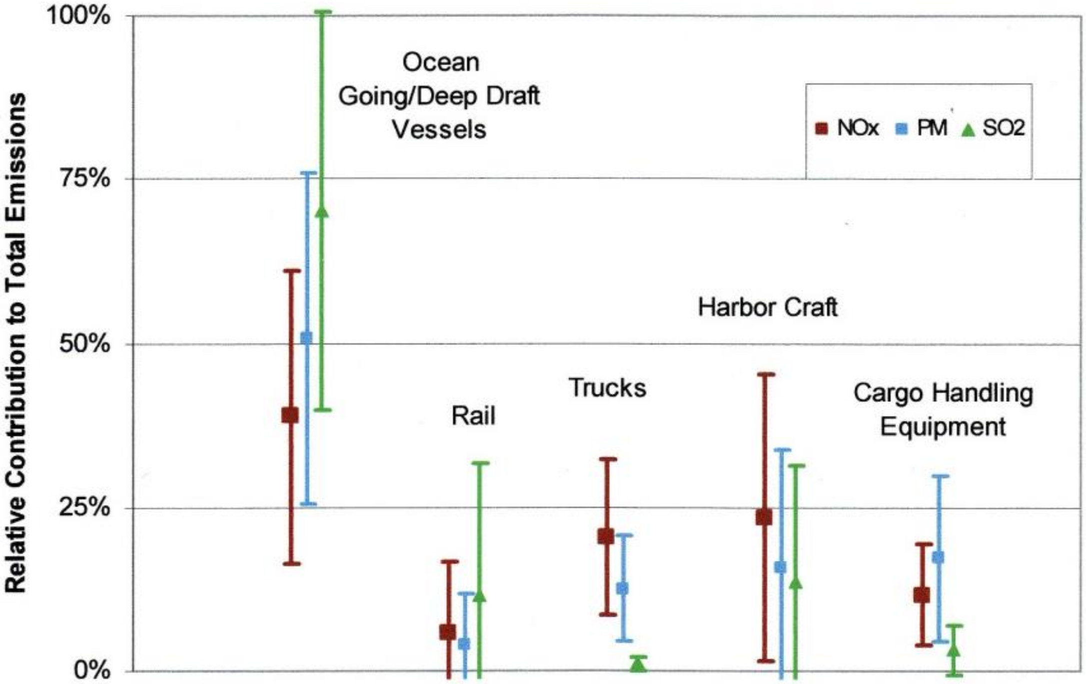

Figure 1.1: Relative contribution to ambient pollution from vehicle types (USEPA, 2009)

1.3 AIM AND OBJECTIVES

The aim of this study is to calculate the ships exhaust gas emissions of NO_X, SO_X, CO_2, HC and PM_{10} in Durban Port with the following objectives:

- To determine the contribution of specific ships categories to the pollution in the Port between container ships, bulk carriers, tankers, general cargo ships, car carriers, other types and harbour crafts.
- To determine the most polluting engine type from ships within the Port between the main engines, the auxiliary engines and the boilers.

- To compare pollution from ships in Durban Port with pollution from ships in other ports around the globe.
- To compare the emissions of certain pollutants by ships in the Port with the emissions by other sectors, specifically the industrial and vehicular emissions in the vicinity of Durban Port.

2. BACKGROUND TO STUDY SITE

2.1 BOUNDARIES OF THE STUDY

Ambient air pollution does not obey clearly defined property boundaries (USEPA, 2009). This is particularly true for mobile polluters such as ships because the source can pollute both inside and outside the study area. Nevertheless, the physical boundaries of a study area must be clearly defined to ensure that the study is feasible and clearly contained, and to allow results to be interpreted appropriately. The study boundaries in this case are based upon the purpose of the study and the available data. The aim of this study is to calculate the pollution each ship emits while in the Port. Only while in the Port is the ship considered to be part of the Port's emission inventory. Thus the study boundaries include the region to the north and south breakwaters (*Figure 2.1*). The study area is thus bound by the following geographical coordinates:

29° 51' 00"S	030° 59' 28"E
29° 54' 16"S	030° 59' 28"E
29° 51' 00"S	031° 04' 00"E
29° 54' 16"S	031° 04' 00"E

The calculation of each ship's emission commences only once the ship enters this space and it ends when the ship clears this space. According to USEPA (2009), boundaries may include the point where the marine pilot boards the vessel inbound. According to the marine pilot in Durban Port, Aubrey Baloyi (pers. comm., 2013) the pilot will normally board at four nautical miles north-east of south breakwater. However, since the exact time of boarding is not recorded this could not be used further for this study. The vessel traffic control station (VTS) in Durban records the times when the vessel arrives 12 nautical miles from the breakwater and when the ship crosses the breakwater into the Port. Not all ships reporting at 12 nautical miles will receive a pilot to proceed to berth. Some ships will spend hours and even days anchored outside before being cleared to enter the Port. When the ship leaves Port, the VTS records the time of departure as the time when the ship crosses the breakwater outbound. As such, the *turnaround time* from the breakwater inbound and outbound was considered the most appropriate data for this study.

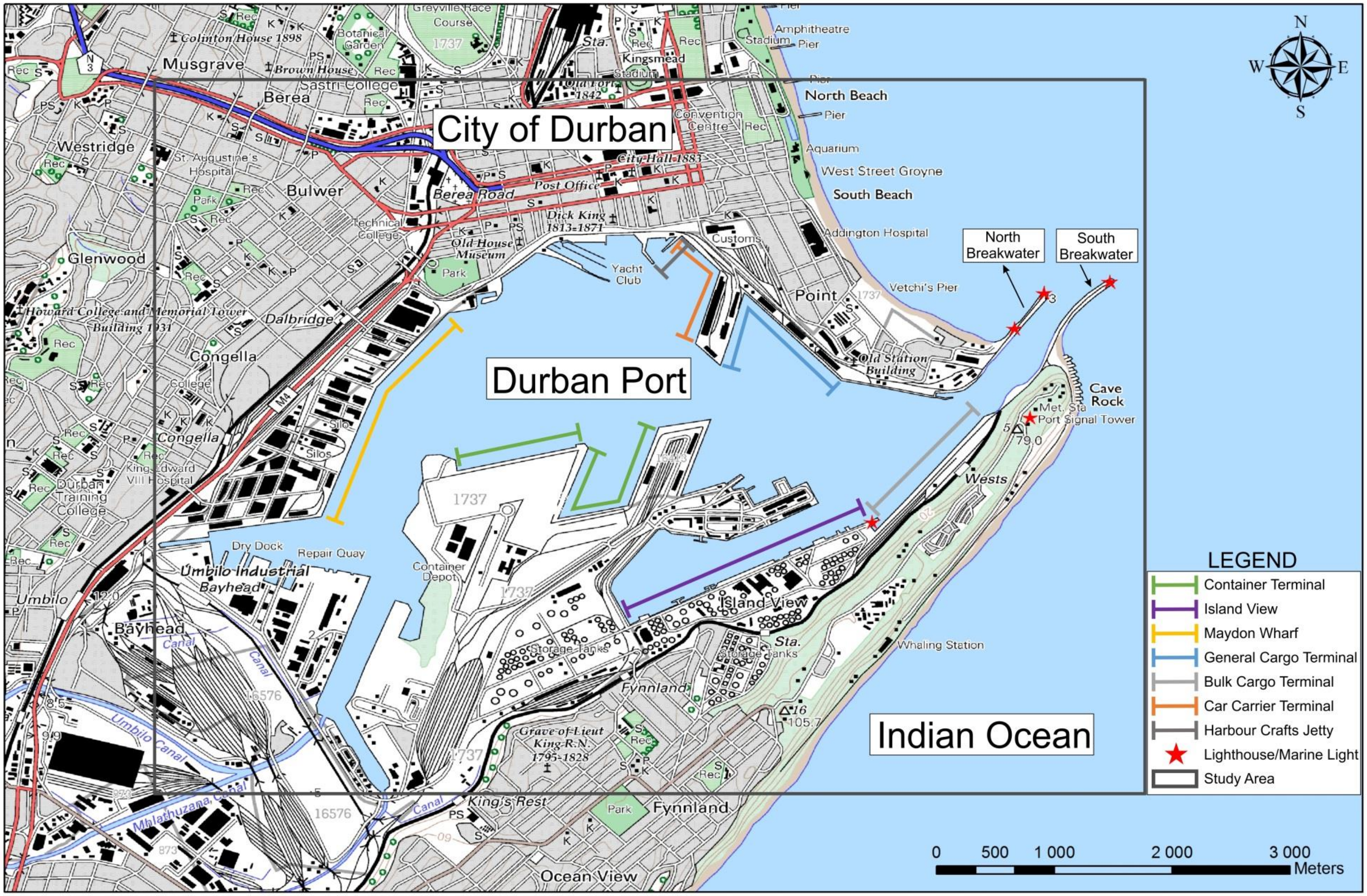

Figure 2.1: Boundaries of the Durban Port Study

2.2 ENVIRONMENTAL CONTEXT

The City of Durban is situated on the eastern seaboard of South Africa. Durban is the second largest coastal city in the country, the city with the busiest port on the African continent and has the second largest container terminal in the southern hemisphere (AAPA, 2013). The terminal handles 61% of all containerized cargo in the country while 40% of South Africa's break-bulk cargo passes through this Port. Durban is the premier trade gateway between South Africa and the Far East, Europe, USA, and East and West Africa. An estimated 25% of South Africa's imports and exports pass through Durban Port. More than 4,000 commercial vessels call in at the Port each year and a total cargo of over 31 million tonnes worth more than R50 Billion is handled each year. More than 6,000 people work within the premises of the Port (TNPA, 2010).

Pollution in Durban results from a variety of activities. Apart from emissions from ships, pollution sources include the petrochemical industrial hub in the South Durban Basin (SDB), the chemical storage facility at Island View, manufacturing hubs in Pinetown and Phoenix (as examples) and vehicular emissions. According to the South Durban Community Environmental Alliance (SDCEA, 2011), the SDB has the largest concentration of petrochemical industries in the country. The SDB was defined in the South Durban Multi-Point Plan (SDMPP) as stretching the 24 km in length from the Durban CBD in the north to Umbogintwini in the south, and extending inland for 4 km. This region covers an area of approximately 100 km^2 and Durban Port is entirely contained within this area (*Figure 2.2*). The SDB is considered to be the economic hub of KwaZulu-Natal due to high density of industries within this district. The key industries include two oil refineries (SAPREF, owned jointly by BP and Shell, as well as Engen owned by Petronas), the paper and pulp plant (Mondi), sugar refinery (Tongaat-Hullett), chemical industries, the port and some 600 other smaller industries. The oil refineries, the paper producer and sugar refinery are said to be responsible for 80% of SO_2 pollution load (DEAT, 2007). The basin also contains a variety of huge residential areas housing over 200,000 people.

Figure 2.2: South Durban Basin (Brooks et al., 2010)

There is high congestion of vehicles in the SDB, where major transport routes converge. The north-south N2 connects with the M4 highway, South Coast Road and M7 Edwin Swales Drive. These routes carry road traffic heading to and from the city (DEAT, 2007). Traffic and the various industries are said to emit "Durban poison" since studies have shown that the health (particularly the respiratory health) of South Durban residents is impacted by these emissions (UKZN, 2007). In addition, impacts include environmental stress and the costs of health care and time off work or school due to personal illness or the illness of other family members who require care.

According to TNPA (2010), Durban is one of the few cities in the world where the port is in close proximity to the central business district (CBD). This means that any emissions from ships have the potential to disperse from the port to the busiest economic locale of the city and the most densely populated residential zones. The two petrochemical plants are situated within 5 km off the port and benefit greatly from its proximity. However, this means that emissions from the Port supplement an existing 'pollution cloud'. It is impossible to distinguish the Port's contributions to ambient levels detected at the local monitoring stations. As such, it is necessary to compile an emissions inventory for this source to estimate its particular impact. A further consideration relates to greenhouse gas emissions (GHG). In the study conducted by ASSAf (2011), the transport sector accounted for 25% of GHG emissions within the City of Durban and is one of the highest contributors to air pollution. This is equivalent to 5.56 million tonnes of carbon dioxide emission per annum. This figure includes emissions from aviation transport and road transport but excludes rail and marine transports. According to ASSAf (2011), pollution from transport is predominantly road-based and the major attractor is the Port especially for road-freight.

This pollution from transport sector is on an increasing trajectory owing to the rapid economic growth and development of the city and the port. Robinson et al. (2004) described three kinds of cities based on their growth path. The first one is the *city coping with informal hyper-growth*. This kind of city represent many cities in Sub-Saharan Africa, Indian subcontinent, Muslim Middle East, Latin America and the Caribbean. It is characterized by rapid population growth and an economy heavily dependent on informal sector. The second kind is the *city coping with dynamic growth*. It is characterized by the middle-income rapidly developing economy represented by much of East Asia, Latin America, Caribbean and Middle East. In this city, the basic problems of the first kind of city are beginning to be solved. The third kind of city is the *mature city coping with ageing*. The North America, Europe, Japan, Australasia and parts of East Asia represent this city. It is characterized by stable or declining population, ageing and slow economic growth (Robinson et al., 2004). South African cities such as Durban are considered to be in the second category, which is the *city coping with dynamic growth*. Cities in this category undergo rapid transition and typically go through various stages of economic development at once (Robinson et al., 2004). However, some of these economic development stages have negative impacts embedded in them such as the increase in urban air pollution due to industrial and port developments.

The Port is undergoing a series of renovations and upgrades. These developments will have a significant multiplier effect on the economy of the city and its environs (TNPA, 2010). However, as much as this will have a positive spin off in the economy of the city, it also means that there will be an increase of pollutive emissions due to increases in the number of ships calling into the port.

2.3 CLIMATE

Durban falls within a sub-tropical climate zone and is characterised by warm to hot and humid weather. This climatic region is one of the wettest areas within southern Africa with the average annual rainfall of 1,009mm, and falling predominantly in the summer months due to atmospheric instability (DEAT, 2007). The region's winter rainfall is generally associated with frontal systems, moving from the south-west to the north-east along the South African coastline. However, winter weather is typically drier and is influenced by dominant high pressure systems (*Figure 2.3*). The coastal high pressure cells tend to move landward in winter, while all three dominant cells intensify in winter (Preston-Whyte and Tyson, 1988).

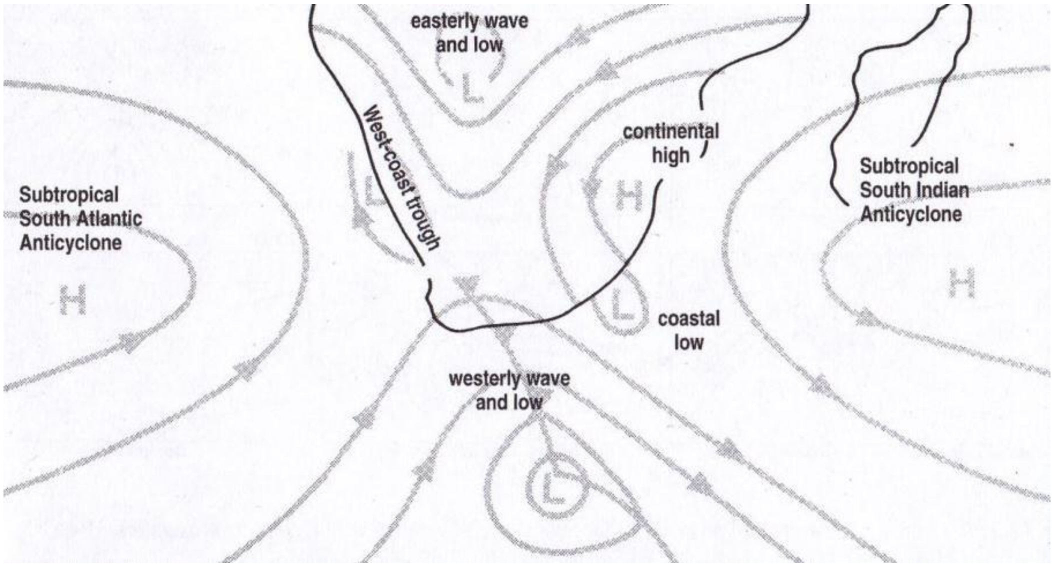

Figure 2.3: Major pressure cells influencing South African climate (Preston-Whyte and Tyson, 1988)

2.3.1 Regional Wind Patterns

The prevailing north-north-easterly winds are typically associated with high atmospheric pressure and regional geostrophic flow and bring fine weather. The south to south-westerly winds, associated with the passage of coastal low pressure systems and cold fronts, are generally stronger and may be accompanied by rainfall. The easterly and westerly components generally are calmer topographical winds, induced by discrepancies in temperature between land and ocean and facilitated by flow up or down local river valleys. These winds reveal a clear diurnal cycle. A gentle northerly wind component is evident (*Figure 2.4*), which is a wind rose for DSB generated using the Atmospheric Dispersion Modeling System (ADMS) software and hourly wind field data from South African Weather Services (SAWS) extracted from the weather station in old Durban International Airport. In both summer and winter months, wind velocities generally are greatest in the afternoon, while on average, wind velocities in winter are lower than in summer (DEAT, 2007).

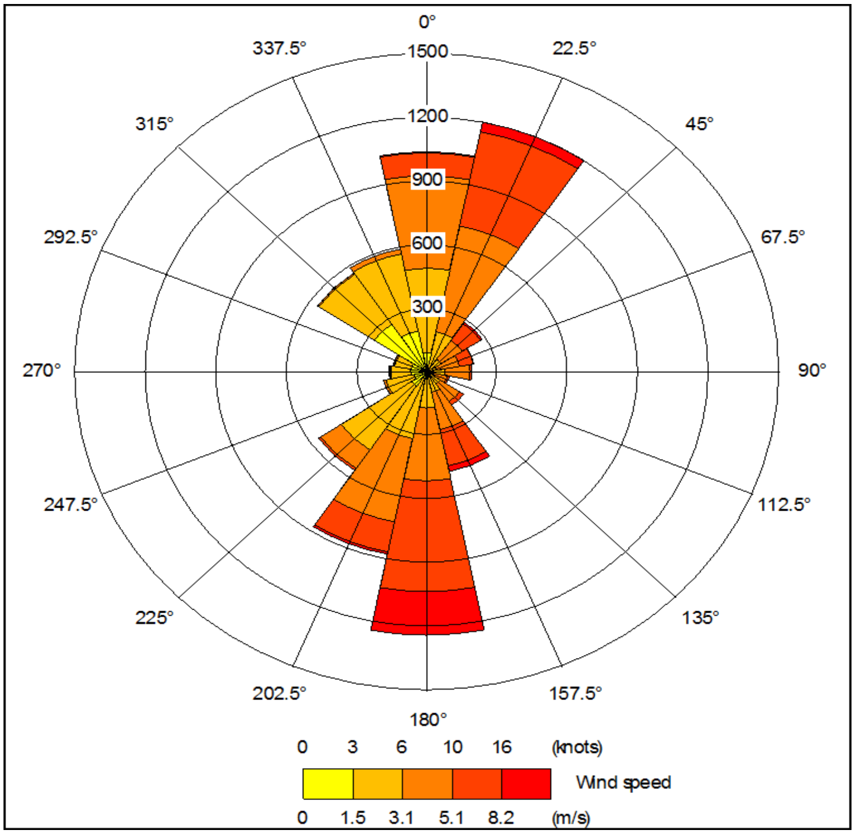

Figure 2.4: Annual wind rose for South Durban using 2012 wind field data

2.3.2 Local Wind Patterns

Preston-Whyte and Diab (1980) described localised airflow in South Durban as a system of drainage winds that flow down the Umbilo and the Umhlatuzana valleys at night, across the alluvial flats at the head of the bay to dam up against the Bluff ridge (*Figure 2.5*). From here, the air is diverted between the Bluff and Berea ridges as gentle south-westerly winds towards Durban's central business district (CBD). The accumulation of cold air in the DSB may lead to valley inversions at night, limiting vertical dispersion of air pollution. This local wind pattern is regularly disrupted by the passage of coastal lows and westerly wave frontal systems that clear the boundary layer every three to five days during the winter months (Preston-Whyte and Diab, 1980). The direction of predominant winds parallel to the coast and the topography results in channelling of pollutants within the basin (DEAT, 2007).

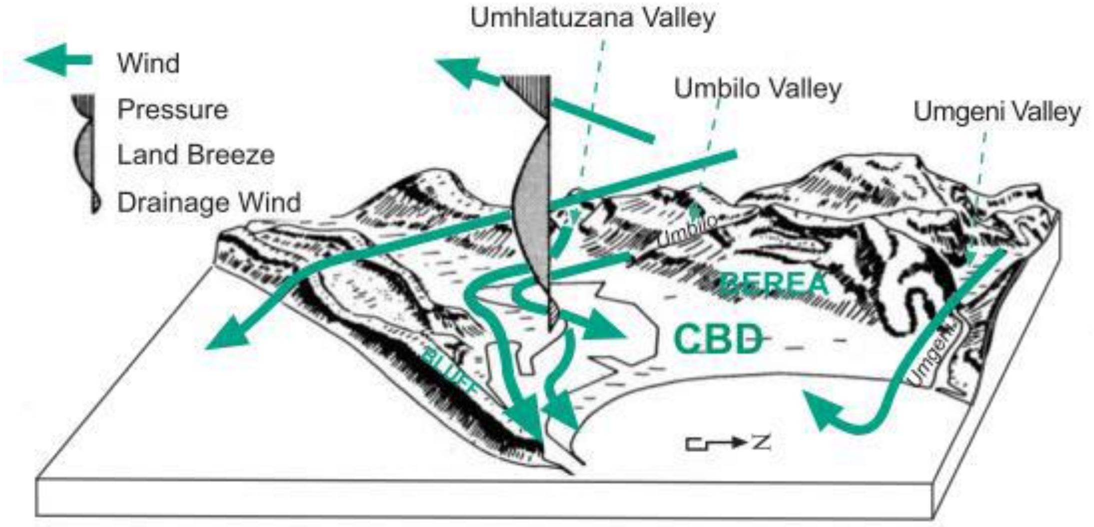

Figure 2.5: Nocturnal air circulations in Durban (Diab and Preston-Whyte, 1980)

2.4 SOUTH DURBAN MULTI-POINT PLAN (SDMPP)

The SDMPP was a project undertaken by the government after tireless complaints from the communities in the SDB regarding high pollution levels, odours, and chemical leaks in the region. It was officially launched on the 27th of November 2000 by the then Minister of Environmental Affairs and Tourism, Mr Valli Moosa. The SDMPP aimed to improve understanding of the environment in the region and to use available information to address environmental concerns, particularly those related to air pollution. The intention was to focus on information collection and problem identification as the basis for air quality management planning. The eThekwini Municipality became the implementing agency for the multi-point plan (MPP) and the plan was funded by Norwegian Agency for Development Cooperation (NORAD) through the Department of Environmental Affairs and Tourism (DEAT, 2007).

In September 2005, the National Environmental Management: Air Quality Act 39 of 2004 (NEMAQA) came into effect. This act stipulated that Air Quality Management Plans (AQMP) are developed and implemented by national, provincial and local governments. The eThekwini Municipality embarked on various strategies to implement an AQMP (eThekwini Municipality, 2010). The aim of the local AQMP was to improve air quality management and reporting to support the role of the national department. For eThekwini Municipality, the experience gained from the MPP facilitated the implementation of the AQMP and these projects progressed in parallel. A network of pollution measuring stations containing sophisticated measuring instruments focusses on air pollution monitoring in South Durban, but also with scattered stations in other parts of eThekwini. The network was designed by the team of experts from eThekwini Health Department under the technical guidance of Norwegian Institute of Air Research (NILU) for three purposes: to quantify ambient air pollution concentrations, to gauge compliance with air quality standards and to provide verification for the dispersion model (eThekwini Municipality, 2010).

The implementation of MPP resulted in development of sophisticated local air quality monitoring system around South Durban. Under the MPP, 16 monitoring stations were installed covering the refinery valley south of the port, other industrial areas, the city centre and the outlying residential areas. Initially there were only four monitoring stations established in Wentworth, Southern Sewage Works, AECI and Athlone Park. These stations started measuring SO_2 in July 1996 and reported daily, weekly, monthly and annual readings. Ozone and NO_X analyzers were added later in Wentworth after recognizing the presence of other pollutants. In October 2000, a monitoring station was established in Settler's School measuring carbon monoxide and PM_{10} in addition to SO_2 and NO_X. There are now 16 stations in the network and an additional mobile station (DEAT, 2007).

The MPP report by DEAT (2007) listed eight key components or focus areas in a drive to control and monitor emissions. Vehicle emission standards were added to the list at a later stage and became the ninth focus area. However, ships were never included in this list. The key focus areas were: a health risk assessment; an epidemiological study; phasing out programme for dirty fuels; establishment of an Air Quality Management System (AQMS); controlling chemical and fugitive emissions; strengthening the inspectorate (auditing and permitting system); development of a local legal framework; reviewing of standards for priority pollutants; and reviewing standards for vehicle emissions.

Positive results developed from implementation of MPP. The key achievements of MPP were, *inter alia*, the installation of an improved air quality monitoring network with integrated data transfer and storage, an updated emission inventory and sampling of pollutants, creating awareness and encouraging the industry to use best practice technology, association of health problems such as asthma in children to the air pollution concentration, and multi-stakeholder involvement in reducing the impact of pollution which included the Government, community and industry (DEAT, 2007).

2.5 ENVIRONMENTAL PERFORMANCE OF INDUSTRIES ADJACENT TO THE PORT

The environmental performance reports from three major industries in the vicinity of the Port were obtained to contextualize their impact on ambient air quality in the region. The three industries considered were two refineries, SAPREF and Engen, and the pulp and paper manufacturer, Mondi. In accordance with the city's by-laws, all three companies operate under Scheduled Trade Permit and are required to provide the annual performance report to eThekwini Health Department (SAPREF, 2011). However, it must be noted that the environmental performance reports from the three companies were not the most recent but they were the latest obtainable reports. The refineries are protected under the National Key Point Act 102 of 1980, a piece of apartheid legislation that is yet to be repealed (Pothier, 2013). Under this Act, the refineries can refuse to release information on their activities. Ultimately, environmental reports for 2012 and 2013 were not available for the completion of this study despite requests to these industries but earlier reports were available online.

2.5.1 Engen Refinery's Annual Performance Report

Engen provides a performance report on annual emission of CO_2 and four criteria pollutant namely SO_2, NO_X, PM_{10} and VOCs. The SO_2 daily emission limits were reduced by the Department of Environmental Affairs in December 2009 from 20 to 16 tons per day (Engen, 2011). The 2010 daily average tonnage of SO_2 emissions from Engen refinery was 9.0 tons per day with the highest value being 11 tons per day but still below the daily limit (*Figure 2.6*). Engen's annual SO_2 emission for 2010 was 2,700 tons/year (*Table 2.1*).

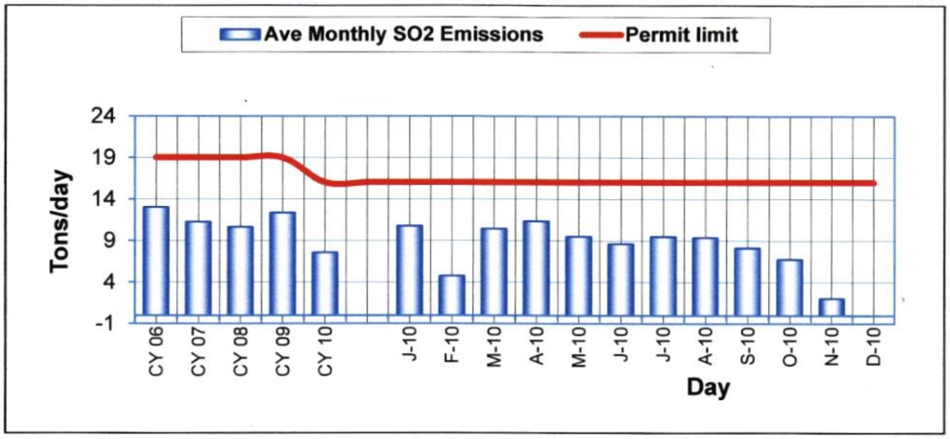

Figure 2.6: The 2010 daily average SO_2 compliance with the set limits (Engen, 2011)

In 2005, eThekwini Municipality set the NO_X emission limits to 8.0 tons per day in accordance to the city's Environmental Management Plan (Engen, 2011). The 2010 daily average NO_X emissions from Engen Refinery were 4.8 tons/day and were below the set limits (*Figure 2.7*). The total annual NO_X emissions in 2010 were 1,760 tons (*Table 2.1*).

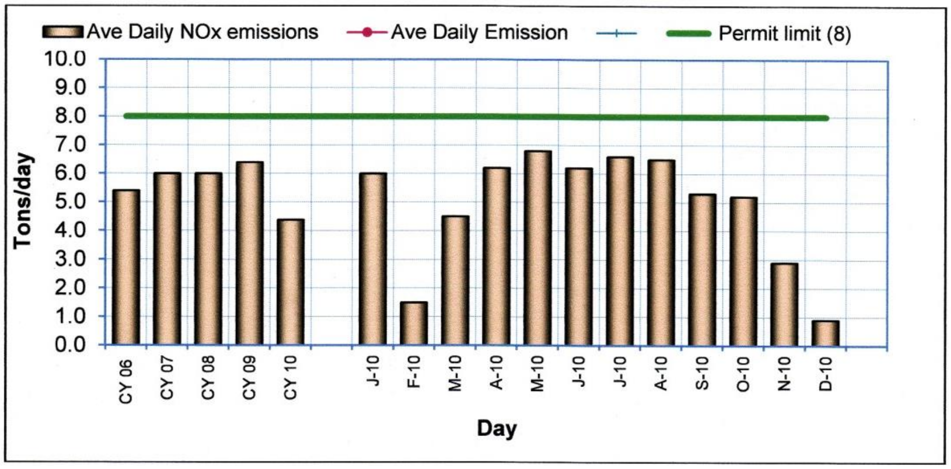

Figure 2.7: The 2010 daily average NO_X compliance with the set limits (Engen 2011)

The limits for PM emissions were reduced from 1.0 to 0.4 tons per day in December 2005 (Engen, 2011). Engen managed to stay below the set limit in its 2010 PM emissions (*Figure 2.8*). The total annual PM emissions in 2010 were 176 tons (*Table 2.1*).

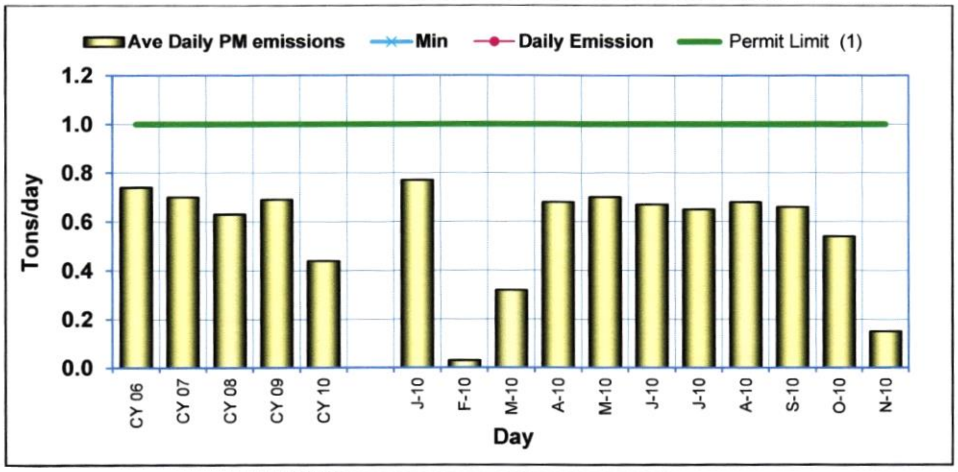

Figure 2.8: The 2010 daily average PM compliance with the set limits (Engen, 2011)

Benzene levels were assessed on the basis of ambient monitoring. South Africa introduced new NAAQS in December 2009 when the benzene limits were set to 10 µg/m^3 (Engen, 2011). No exceedance of benzene limits were reported in areas around Engen in 2010 (*Figure 2.9*).

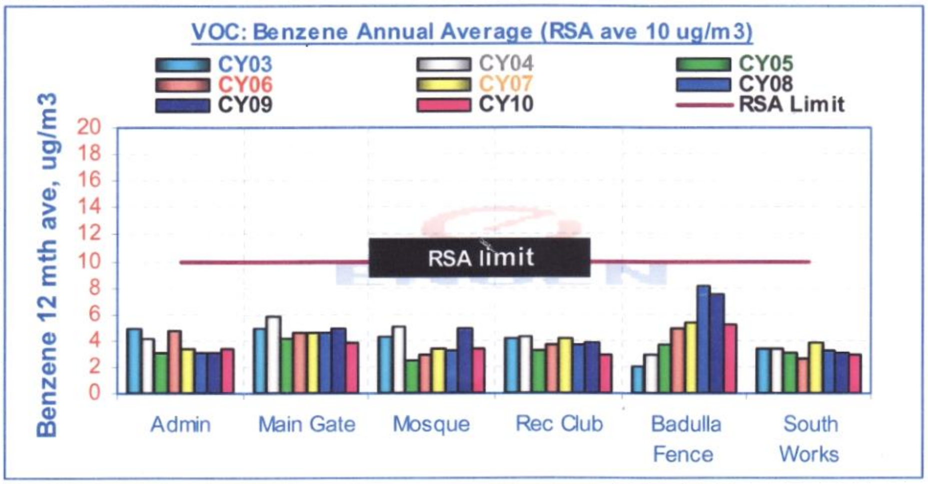

Figure 2.9: Ambient Benzene level by Engen in 2010 compared to NAAQS limits (Engen, 2011)

Engen is required to report the emissions of CO_2 as per Schedule Trade Permit. In 2010 Engen emitted 717,933 tonnes per year of CO_2 (*Table 2.1*), which is equivalent to the daily emissions rate of 1,966 tonnes (Engen, 2011).

Table 2.1: Engen's Annual emissions of criteria pollutants in 2010 (Engen, 2011)

Pollutants	Unit Tons/Annum	Annual Permit Quantity (Total)	Acute Emission	Process Emission	Actual Discharge Limits (Total)	Exceedances/Comments
SO_2	TPA	5,840	0.6	2,700	2,700	Acute emissions are from reportable flare event
PM	TPA	365	0	176	176	
NO_2 NO_X	TPA	2,825		1,786	1,786	
VOC's	TPA	N/A		1,519	1,519	Based on emission survey done in 2009. 2009 emission survey included more sources than 2005 survey.
CO_2	TPA	N/A	0.5	717,933		Acute emissions are from reportable flare events

2.5.2 SAPREF's Annual Performance Report

SAPREF manages its annual emission of priority pollutants namely SO_2, NO_X, PM_{10} and VOC and the greenhouse gases, CO_2 and methane. The 2011 environmental performance report shows that SAPREF managed to keep its emissions within the set standard limits for all pollutants (SAPREF, 2011). The refinery emitted an annual average of 11 tonnes per day of SO_2 in 2011 (*Figure 2.10*). This was below the set limit of 18 tonnes per day, which was introduced in 2010 (SAPREF, 2011).

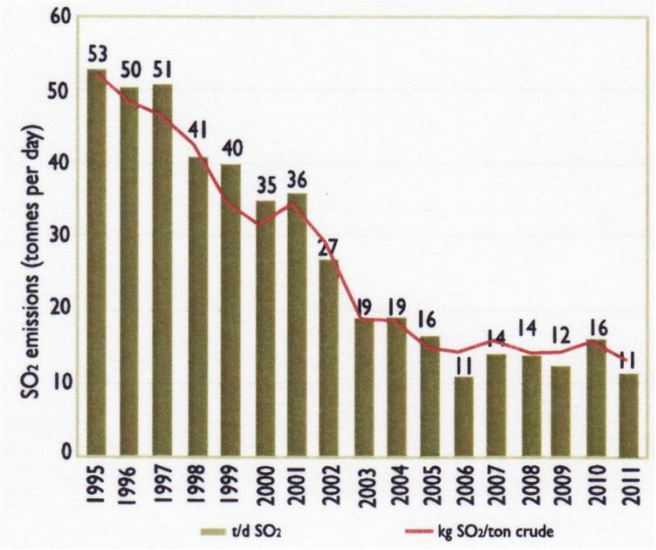

Figure 2.10: The average SO_2 emissions in tonnes per day from SAPREF (2011)

The SAPREF refinery emitted 3.4 tonnes of NO_X, which was within the set limit of 4.0 tonnes per day in 2011 (*Figure 2.11*).

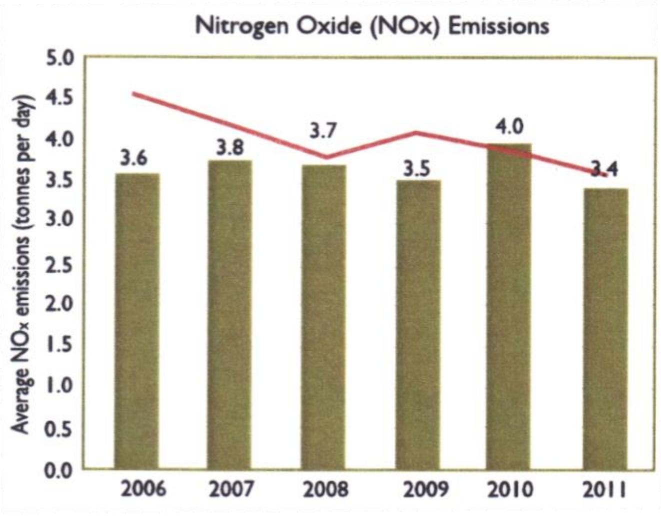

Figure 2.11: The average NO_X emissions in tonnes per day from SAPREF (2011)

SAPREF operated within the set limits of PM_{10} emissions in 2011 averaging 0.2 tonnes per day (*Figure 2.12*). The limits were set at one tonne per day since 2007 (SAPREF, 2011).

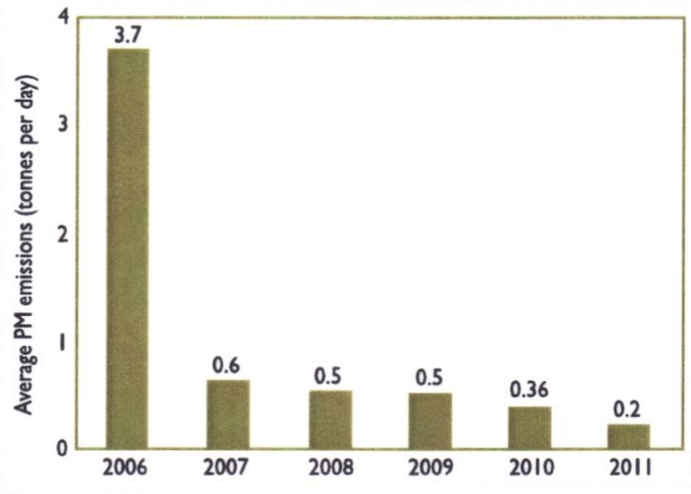

Figure 2.12: The average PM_{10} emissions in tonnes per day from SAPREF (2011)

The reported annual average ambient concentration of benzene in areas neighbouring the SAPREF refinery was 3.7μg/m^3 in 2011, which was well below the NAAQS of 10μg/m^3 (SAPREF, 2011). The annual VOC emissions of 3,158 tonnes per annum from SAPREF were reported in 2011 (*Figure 2.13*).

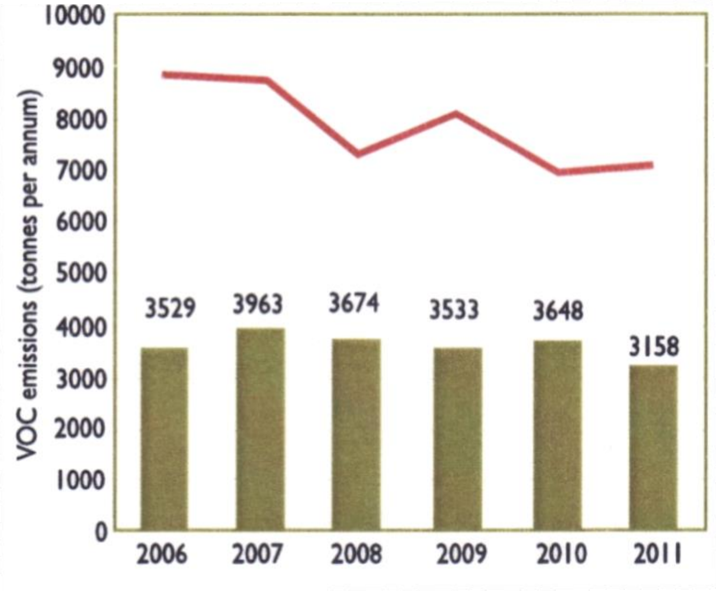

Figure 2.13: The VOCs emissions in tonnes per annum from SAPREF (2011)

Greenhouse gas emissions from SAPREF consist of CO_2 and methane. SAPREF reduced CO_2 emissions in 2011 through its initiative on energy efficiency (SAPREF, 2011). The emissions were reduced from 1,065 kilo-tonnes in 2007 to 866 kilo-tonnes in 2011 (*Figure 2.14*).

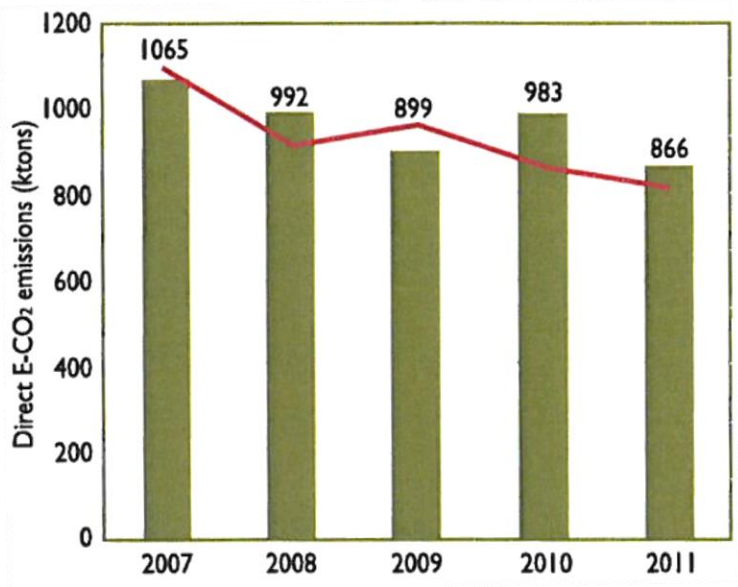

Figure 2.14: The CO_2 emissions in kilo-tonnes per annum from SAPREF (2011)

2.5.3 Mondi's Annual Performance Report

The Mondi's annual environmental performance reports are compiled as consolidated reports from all Mondi establishments around the world. The statistics for the emission of priority pollutants from the Durban paper mill were not publicly available, except those of SO_2. There was a declining trend in annual SO_2 emission from the Merebank mill, which is situated in the SDB, from 2004 to 2006 (*Figure 2.15*). The significant reduction from 2004 is attributed to the flue gas desulphurization equipment installed in the coal boilers in 2005 (Mondi, 2014).

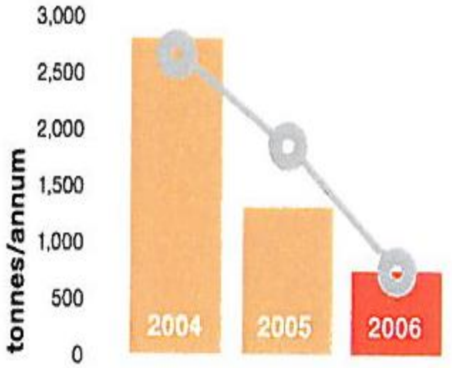

Figure 2.15: SO_2 emissions in tonnes per annum from Mondi Paper Mill (2014)

2.5.4 Vehicular CO_2 and SO_2 Emissions in South Durban

The transport sector is the second biggest GHG emitter in Durban and accounts for 25% of GHG emissions (ASSAf, 2011). However, the study by ASSAf (2011) only included two transport systems from this sector, namely the aviation transport and the road transport, and failed to include emissions from marine and rail transport. On per capita basis from this sector, Durban has 1.70 tCO_2e per capita, which is similar to New York, London and Mexico but lower than Bangkok at 3.53 tCO_2e per capita (ASSAf, 2011). Nevertheless, the transport sector is the fastest growing contributor of GHG emissions in South Africa (ASSAf, 2011). Vast arrays of potential interventions are being considered by eThekwini Municipality to make a significant contribution to carbon reduction from the transport sector. Some guidance on prioritization in this endeavor were provided by Thambiran and Diab (2011) who investigated the intervention in the road transport sector in Durban by calculating emission reduction from various scenarios using the road transport computer model (ASSAf, 2011). With these developments Durban can claim to be at the forefront of efforts to address climate change in South Africa (Ribbink, 2012).

The study conducted by Ramsay and Naidoo (2012) calculated a carbon footprint for Tara Road, which is a busy road passing through the SDB. This road connects three different suburbs, namely Merebank, Bluff, and Wentworth and incorporates an oil refinery, two shopping complexes and residential units (*Figure 2.16*). Ramsay and Naidoo (2012) highlighted the insufficient coverage of SDB as a carbon producer, particularly in the context of proposed industrial and port expansion. Ramsay and Naidoo (2012) showed that the vehicle sector contributed significantly to the pollution in the SDB.

In the study of Ramsay and Naidoo (2012), the vehicles were counted at key locations along both sections of the road. The counting took place over forty-five minutes duration on specific days of the week and included peak and off-peak hours. This was combined with fuel consumption data for passenger vehicles and heavy duty vehicles and converted to CO_2 emissions using standard emission factors for corresponding vehicles.

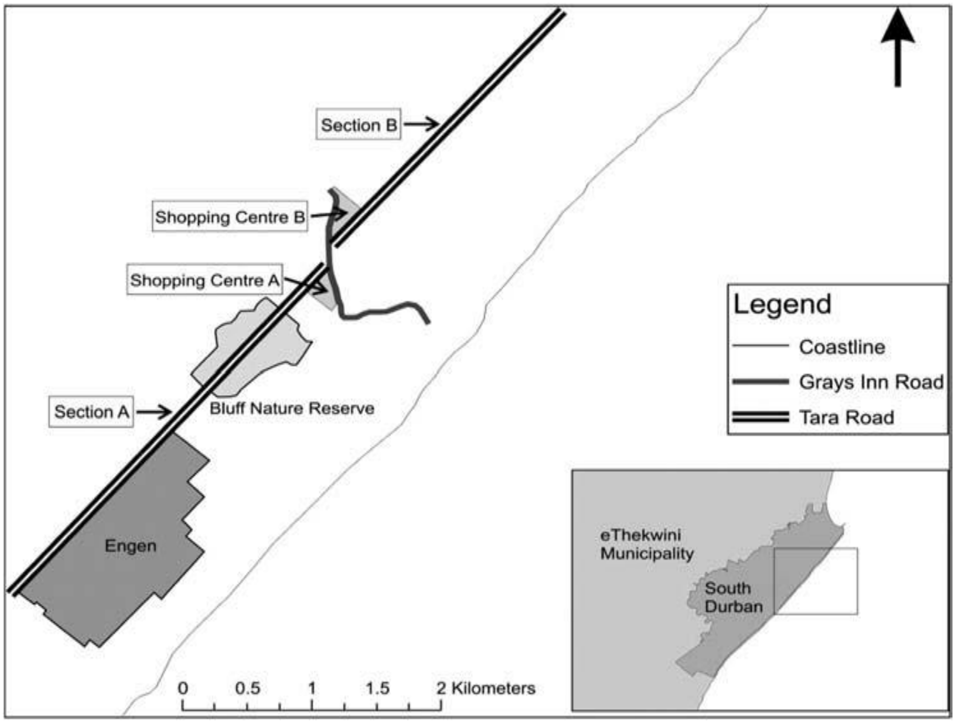

Figure 2.16: Tara Road in the study of vehicular emissions in SDB (Ramsay and Naidoo, 2012)

The results revealed that cars contributed 4,185 tCO_2 annually from this road and the results were compared with other emission sources within the same road, which included residential, commercial and industrial emissions (*Table 2.2*).

Table 2.2: CO_2 emissions along Tara Road in SDB (Ramsay and Naidoo, 2012)

Sector	Category	t CO_2	Percentage incl. industrial	Percentage excl. industrial
Transport	Sector total	4185.14	0.40	17.39
Residential	Electricity	1194.71	0.11	4.96
	Fires/barbeques	8.61	0.00	0.04
	Private transport	585.26	0.06	2.43
	Public transport	1.54	0.00	0.01
	Air travel	64.79	0.01	0.27
	Landfill waste	29.46	0.00	0.12
	Sector total	1884.37	0.18	7.83
Commercial	Electricity	17,976.09	1.70	74.69
	Landfill waste	22.39	0.00	0.09
	Sector total	17,998.47	1.70	74.78
Industrial	Stack emissions	1,032,417.00	97.72	–
Total	Incl. industrial	1,056,484.98	100	–
	Excl. industrial	24,067.98	–	100

In another study by Ramsay (unpublished), the sulphur dioxide emissions were calculated for the vehicle sector in the SDB. The traffic data for this study was provided by eThekwini Municipality and included major roads in SDB that were identified as likely to be more congested, namely N2, M1, M4, M7, R102, South Coast Road, Sarnia Road and Harry Gwala Road. The assumption made was that 90% of cars and minibus taxis used gasoline fuel and buses and heavy vehicles used gas oil fuel. The annual fuel usage was calculated using the fuel usage per vehicle type, the number of vehicles counted in each category over a certain period, the number of hours and the number of days in a year, all with special consideration to peak hours, week days, school holidays, public holidays and annual leave periods. The results indicated that 173,108,916.5 litres of gasoline and 92,533,700 litres of gasoil were used by vehicular traffic per annum in the study domain (*Table 2.3*). The emissions from this fuel usage were calculated using the mass balance approach, which assumes that all the sulphur in the fuel is emitted to the atmosphere in the form of SO_2. The total SO_2 emissions for the study area were 203,203,864 grams per annum (*Table 2.3*).

Table 2.3: SO_2 emissions from gasoline and gas oil in SDB (Ramsay, unpublished)

Scenario	Volume (l)	Fuel density (g/l)	Mass factor (R)	% sulphur by weight	SO_2 (g/annum)	SO_2 (g/s)
GASOLINE	173,108,917	747.5	2	0.0005	129,257,694	4.10
GASOIL	92,533,700	800.0	2	0.0005	73,946,170	2.34
				Total	**203,203,864**	**6.44**

The above studies reveal the limited investigation of the impact of mobile sources on ambient air quality and the carbon footprint of the SDB and the city. No study is yet to assess the impact of emissions from ships.

3. LITERATURE REVIEW

3.1 INTRODUCTION

The main exhaust gas emissions from ships are CO_2, SO_2, NO_X, HC and PM (Eyring *et al*., 2005). These pollutants can change the natural composition of the atmosphere, with implications for human health (SO_2, NO_X, HC and PM) or global warming (CO_2). Saxe and Larsen (2004) indicated that the emissions of SO_2 and NO_X from ships sailing around the coast of Denmark exceeded emissions from the combined effect of all shore-based activities which include amongst others the power stations, industries and road traffic. Eyring *et al.* (2005) compared emission from ships with other transport modes globally and found that although shipping was responsible for only 16% of total global fuel consumption (aviation 207 Mt, shipping 280 Mt, and road traffic 1,320 Mt), it contributed significantly to ambient air pollution because international marine emission regulations were not as strict as road traffic and aviation (*Figure 3.1*). For instance in 2000, the ocean going fleet produced 9.2 times more NO_X than aviation and due to high sulphur content in the marine fuel, ships produced 80 times more SO_X emissions. Ships also produced 1,200 times more particulate matter than aviation (Eyring *et al*., 2005).

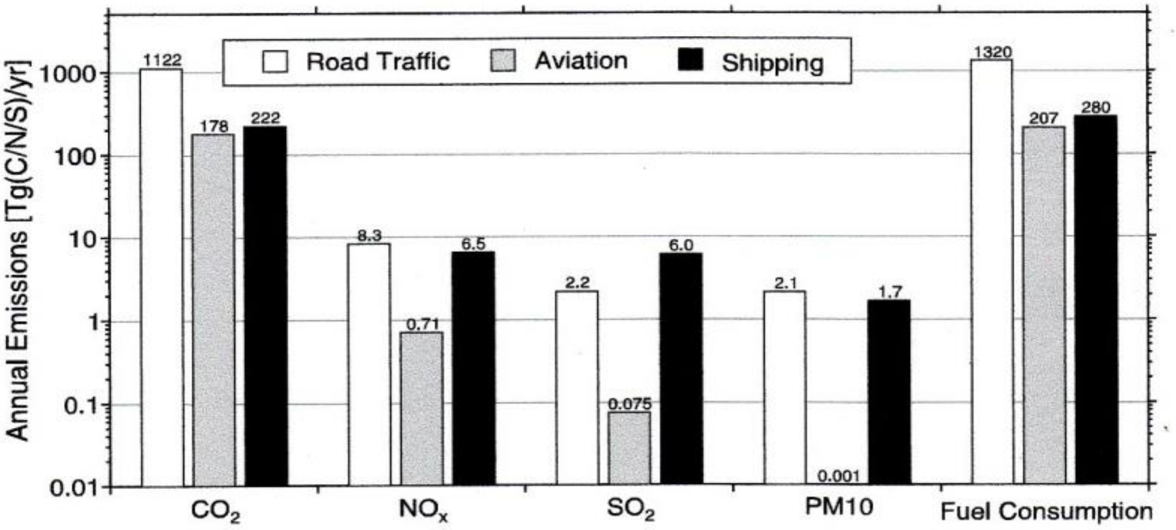

Figure 3.1: Global transport related annual emissions and fuel consumption in teragrams (Tg = 10^{12}; C = CO_2; N = NO_X; S = SO_2) over the last 50 years (Eyring *et al*., 2005)

According to Burgel (2007), Western European land based measures have reduced sulphur emission substantially, which leave ships as the remaining major source of such emissions. As mentioned previously, research on and management of pollution emissions from ships has lagged behind other sectors. At times inaccuracies in shipping emission inventories result due to certain methodologies used. For instance some published emission inventories for shipping suggest a total annual fuel burn of 289 Mt for ships greater than 100 GT, which was nearly twice as much as the fuel consumption published by the international marine bunker industry at the time. Such discrepancies highlight the degree of uncertainty in some emission estimates which may lead to overestimation of emissions. (Richter et al., 2004).

The international MARPOL (Maritime Pollution) Convention Annex IV which regulates exhaust gas emissions from engines (initially SO_2 and NO_X) entered into force only in May 2005. According to the briefing document by the European Environmental Bureau *et al*. (2004), the pollutants from land-based sources are gradually decreasing whilst those from shipping show a continuous increase.

Joseph *et al.* (2009) highlighted that recent studies show that ship emissions occur predominantly in port. Ports that are often located close to urban areas may be at the root of problems related to atmospheric pollution in the city. The ports that are in close proximity to urban areas produce a combined environmental effects due to the juxtaposition of port related sources with those related to urban activities (Joseph *et al.*, 2009). Hence it is essential to have systematic collection and collation of detailed information on ship emissions in ports to assess cumulative air pollution impacts.

The above highlights the importance of a study that assesses pollution from shipping in areas such as Durban Port. This chapter provides theoretical background to such a study. Included in this literature review are summaries of similar studies conducted at other ports. The methodologies applied in these studies guided the calculations for Durban, and their particular methodological limitations or advantages were used to refine the methodology followed in this study. In addition to these case studies, the intergovernmental shipping regulations concerning emission of fumes are presented, together with a discussion of the key pollutants of concern.

3.2 INTERNATIONAL CONVENTION FOR PREVENTION OF POLLUTION FROM SHIPS (MARPOL 73/78 ANNEX VI)

MARPOL (MARine POLlution) is the International Convention for the prevention of pollution by ships and the protection of marine environment. It formulates rules and regulations that are followed primarily by ships, which operate under the flag of the International Maritime Organization (IMO) member states. If the ship operates under another authority but transits in waterways of a member state, that ship still must comply with MARPOL regulations (VDMA, 2011).

According to MARPOL 73/78 (IMO, 2002), there are regulations put in place to control and monitor the air pollution from ships visiting ports and areas of Parties to the Convention. Annex VI of MARPOL 73/78 defines all substances emitted by ships that need to be regulated which include ozone depleting substances such as halons and chlorofluorocarbons (CFCs), SO_2, NO_X, and volatile organic compounds (VOCs).

Regulation 5 of Annex VI specifies that ships of 400 gross tonnage (GT) and above are subject to the specified surveys as a regulating measure to determine if they comply with pollution regulations and must be issued with a certificate of compliance. However, ships of less than 400 GT are subject to regulation by the local administration (IMO, 2002). It is therefore the responsibility of the Party State to detect and monitor any violation of pollution regulation and the enforcement of the provision of Annex VI of MARPOL. The ships to which this Annex applies are subjected to inspection by the administration of the Party State to determine whether the ship has emitted any substances in violation of Annex IV. However, the regulation does not specify the method of detection or collection of evidence for any alleged violation (IMO, 2002).

This regulation did not initially include greenhouse gasses (GHG) such as CO_2. MARPOL is currently in the process of including these GHGs. Studies commissioned by the IMO (2013) in 2009 showed that the annual CO_2 emissions from ships will decrease by 151.5 million tonnes in the year 2020 owing to the implementation of Energy Efficiency Design Index (EEDI) for new ships and the Ship's Energy Efficiency Management Plan (SEEMP) for all ships in operation. The EEDI and the SEEMP programs were launched on 14th of November 2011 ahead of the United Nation Climate Change Conference in Durban with a proposed 13% reduction in CO_2 emissions by 2020 and 23% by 2030 (IMO, 2013). The mandatory treaty provisions to reduce GHG emissions from international shipping were adopted by IMO in July 2011. The adopted measures added a new chapter to MARPOL Annex VI entitled "Regulation on energy efficiency for ships" making mandatory the EEDI and SEEMP. The EEDI is a control measure for design and construction of new ships to minimize emissions of GHGs. This is achieved by allocating benchmark values and indices that become the design parameters. SEEMP focuses on regulating the management and operation of ships for energy efficiency and thus reduction in emissions (DMA, 2011). The EEDI and SEEMP control measures entered into force on the 1st of January 2013 (IMO, 2013). With this new control measures, ships are expected to improve efficiency by 10% and attain 20% CO_2 emissions reduction per tonne/kilometer (ICS, 2014).

In view of the growth projections of the world trade and the corresponding transport demands, the MEPC recognised that the technical (EEDI) and operational (SEEMP) measures would not be sufficient to satisfactorily reduce the GHG emissions from international shipping (IMO, 2014). It was therefore proposed that the market-based measure (MBM) is needed as part of the comprehensive package of measure for the effective regulation of GHG emissions from international shipping. The MBM places the price on GHG emissions and provides economic incentive for reduction of GHG emissions from fuel consumption reduction (IMO, 2014).

3.2.1 NO_X Emission Regulation

The MARPOL 73/78 Regulations dictate that all vessels fitted with diesel engines with a power output of more than 130 kW which were installed or underwent major conversion on or after 1st January 2000 must comply with the regulation in Annex VI regulation 13 (IMO, 2002). Regulation 13 paragraph (3) (a) specifies the NO_X emission level that is acceptable for the operation of each engine as follows:

a) The operation of engine is only permitted when the NO_X emissions are within the following limits:

  i) 17 g/kWh when n is less than 130 rpm.

  ii) 45 x $n^{-0.2}$ g/kWh when n is 130 rpm or more but less than 2000 rpm.

  iii) 9.8 g/kWh when n is 2000 rpm or more.

  Where n is the rated engine speed in crankshaft revolution per minute (IMO, 2002). Such limits fell under the *Tier 1* technology category. The *Tier 2* category came into effect on 1st of January 2011 as planned by IMO (2002). This Tier brought more stringent limits to NO_X emissions from ships (Wright, pers. comm., 2012). The more stringent limits termed *Tier 3* are planned for 2016 onwards (*Figure 3.2*).

b) Exceptions to the rules include; Emergency diesel engines, engines installed in life boats and devices intended for emergencies; Engines installed on ships that are solely engaged in voyages within the sovereignty of the flag state provided that such engines are fitted with alternative NO_X control measures authorized by the Administration of that flag state. However, the flag state may still allow exclusion from application of this regulation to any engine that is installed or undergoes major conversion before the date of entry of the protocol provided that the ship is operating solely within the territories of the flag state (IMO, 2002).

c) Adjustment must be made by engine manufacturers and operators to compensate for various *Tier* structure developments. These adjustments must be met by the specified deadlines (*Figure 3.2*).

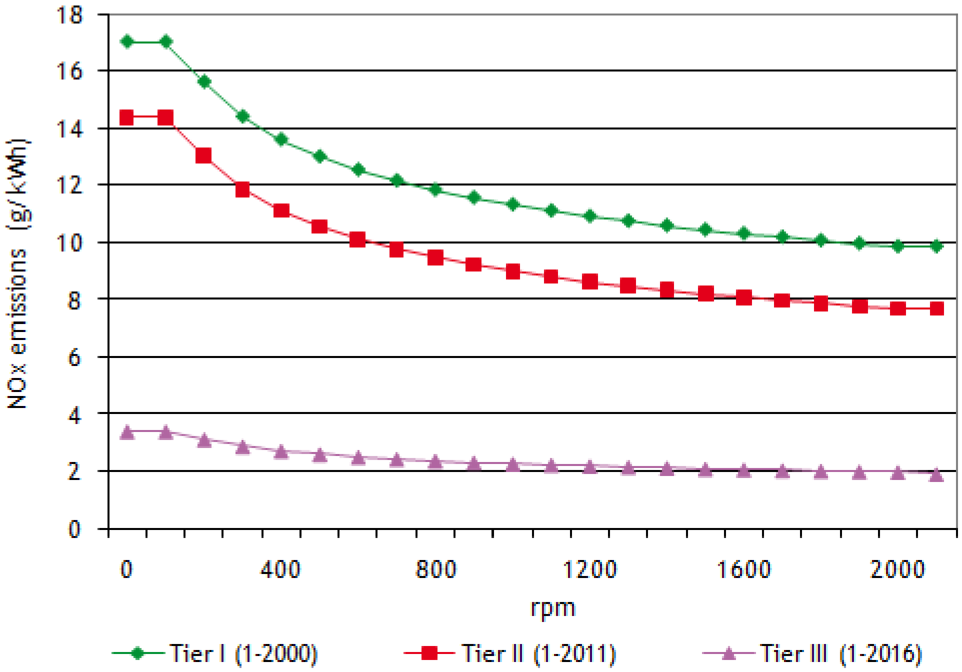

Figure 3.2: NO_X Emission limits as a function of engine speed, MARPOL Annex VI (2002)

3.2.2 SO_X Emission Regulation

There are two methods for controlling sulphur emissions by ships. The first method is the reduction of the sulphur content of marine fuel oil at the refinery. The IMO (2002) stipulates that any fuel oil used by ships must not exceed 4.5% of sulphur content. By 2007 the average sulphur content of residual oil (also called heavy fuel oil) became even more stringent at 3% (Burgel, 2007). In sulphur emission control areas (SECA) the fuel used by ships transiting in those areas must not exceed 1.5% of sulphur content. This limit remained in force until 2010 when new limits were set at 1% sulphur content (*Figure 3.3*). The supplier of the fuel oil must be able to verify that the fuel complies with these requirements as set out by the regulations and this must be documented when the fuel is purchased from the supplier by the ship (IMO, 2002). South Africa is not yet a SECA and therefore it is expected that ships visiting Durban Port will mostly be controlled by 3.5% sulphur content limit, which came into effect on the 1st of January 2012 (*Figure 3.3*). The second method of sulphur control is the use of the exhaust gas cleaning system onboard ships. In this case IMO (2002) stipulates that the exhaust gas cleaning system fitted onboard ships must reduce the total emission of sulphur oxides from both main engines and auxiliary engines to 6 g/kWh or less.

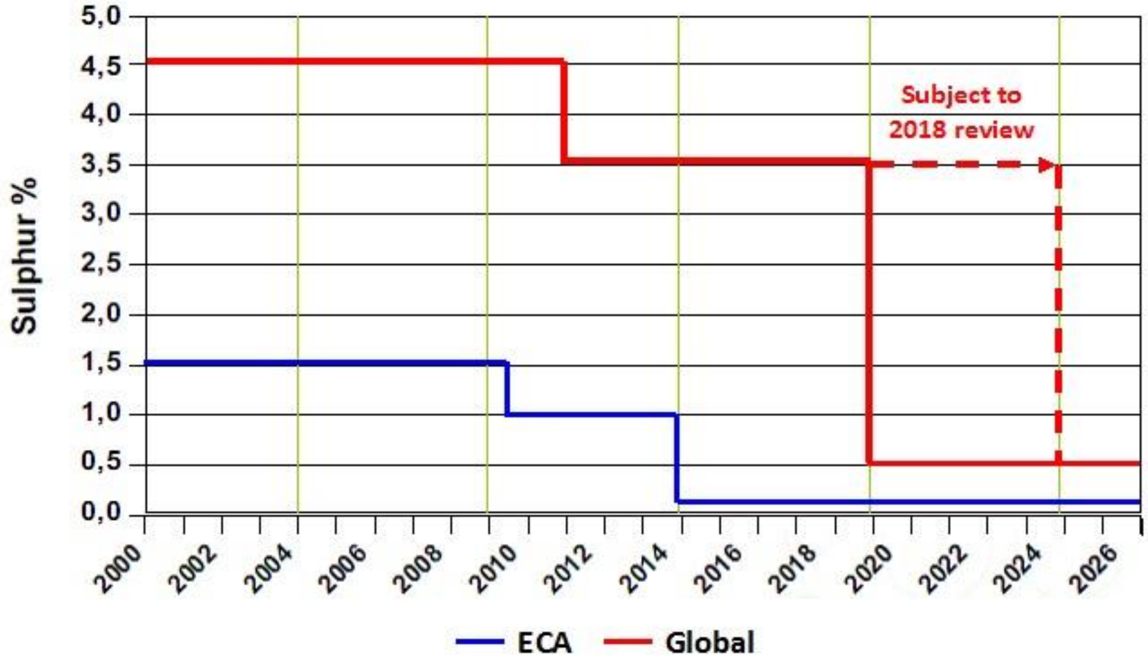

Figure 3.3: Sulphur Emission control limits, MARPOL Annex VI (Kittiwake, 2014)

3.3 ICF REPORT ON CURRENT METHODOLOGIES FOR PREPARING MOBILE SOURCE PORT-RELATED EMISSION INVENTORY

There has been much debate on how ports emission inventories should be prepared. In the past, the methodologies used in port inventories were less refined than other sectors because they were based on limited data. Port inventories tend to vary according to the purpose of inventory, the available time and according to who is conducting the inventory. In most cases, simplified inventories are prepared based upon fuel used (USEPA, 2005). This top-down approach in which fuel-based emission factors are multiplied by fuel sales for an area containing the port is no longer recommended. The method based on fuel sales often resulted in overestimation of fuel consumption and inflated emission figures. This is because ships can store fuel in large tanks and the shipping agent will generally purchase fuel based upon the lowest price and not necessarily where the ship is docked. Also ships burn only a fraction of fuel in a given port and the rest is burnt en-route to their destination thousands of miles away from where fuel was purchased. The newer method is a bottom-up approach that relies on operational data also termed activity-based approach (USEPA, 2004)

In 2009, the United States Environmental Protection Agency (USEPA) released a document outlining methodologies for preparation of port inventory. These methods can be utilized by the port authorities, by those doing business in port, the state and local air quality agencies and researchers interested in understanding and quantifying the air quality impacts of port operations and their changes over time. The focus of USEPA document was emissions resulting from mobile sources such as ocean going vessels, harbour crafts and land-based sources such as cargo handling equipment (CHE) which include cranes, locomotives and high-way vehicles coming into the port. The report was a continuation of previous documents that address problems encountered in conducting port related inventories and to encourage ports to be proactive in addressing air quality issues (USEPA, 2009). In the report, emission factors and load factors of SO_X NO_X HC and PM_{10} were changed and greenhouse gas emission inventory was included for the first time. The methodologies of port inventory are continuously changing and approaches improving.

USEPA (2005) highlighted three different approaches for performing port pollution inventories and they include:

a) A *detailed approach* where each ship is considered individually and each trip in and out of port is quantified. This approach provides a thorough calculation of emissions and it is the best practice if all the data is readily available.

b) A *mid-tier approach* where each ship's trip is averaged according to the ship type and tonnage. The mid-tier approach may be appropriate for ports that lack the resources for detailed approach but do have operational data by ship type. If resources are still insufficient for mid-tier approach, then the stream-lined approach may be utilized.

c) A *stream-lined approach* is where ship emissions are estimated from another port's detailed inventory. This means that when the inventory and activity patterns of one port are known, it can be utilized to estimate emissions in another port using the activity ratio between the ports (USEPA, 2005).

3.3.1 Detailed Approach

The detailed approach involves a detailed account of every activity by individual ships within the port, it is therefore necessary to include the definition of port boundaries and the characteristics of each vessel. To achieve this, access to data from various sources is required and these sources must include vessel traffic system (VTS), port control, pilot data and Lloyd's Register of Ships. The VTS Station provides data on the vessel movement in port. This mostly comes in an electronic format and generally includes the vessel's name, date and time of arrival and date and time of departure (USEPA, 2009).

The data from the harbour pilot is invaluable in that it provides the time for different modes of operation in the port. Every OGV entering or leaving the port requires the services of the harbour pilot. The harbour pilot takes over from the ship's pilot or the navigator and coordinates with the tugs to bring the ship alongside during the docking. During this time, the approach speed is critical which determines the amount of time spent in this mode of operation termed *manoeuvring* mode. The data provided by the harbour pilot and the VTS Control is therefore used to calculate emissions for the time spent in each mode (USEPA, 2009).

The Lloyd's Register-Fairplay Ltd offers the largest database of global merchant ships and their characteristics in various formats (USEPA, 2009). According to USEPA (2009) this data is available at a cost of $2,950 (Sea-Web for ships over 100GT) and $1,450 (Internet Ships Register for ships over 299GT). Without information from the VTS Control, the harbour Pilot and Lloyd's Register of Ships, the detailed approach is not possible.

3.3.2 Mid-Tier Approach

When dealing with a mid-size port or in the context of limited time and skills resources, a mid-tier approach can be utilized as a simplified version of a detailed approached by averaging the vessel characteristics and the operational data by ship type. This is typically so when the dead weight tonnage (DWT) ranges are known. The load factors and emission factors can be applied to average vessel characteristics for a given ship type and DWT range and multiplied by the number of calls that all vessels in a given type and DWT range made over the period concerned in that port. Each call must be divided into various modes of operation and each mode averaged for the vessel type and DWT range. Therefore by combining vessels in each type and DWT and summing all the calls, the total emission can be determined from each category of ship and this reduces the amount of time and information needed to produce the inventory (USEPA, 2009).

3.3.3 Stream-Lined Approach

As mentioned earlier, the stream-lined approach may be applied when insufficient data is available to follow the mid-tier approach or when time or skill is limited. In this case an existing emission inventory from another similar port may be used by either scaling the emissions up or down according to the ratio of vessels between the two ports (USEPA, 2009). However care should be taken that the two ports are compatible in terms of size of the ports and types of vessels visiting the ports.

According to USEPA (2005) the type of approach to use will depend on the following factors:

- The purpose of inventory;
- Financial resources available to conduct the inventory;
- The location of the port;
- The geographical size of the port;
- The current and projected number of vessels calling at the port and;
- The complexity of the port owner/operator relationship.

3.4 CASE STUDIES

3.4.1 Jawaharlal Nehru (JN) Port in Mumbai, India, 2006

The study of Jawaharlal Nahru (JN) Port in Mumbai, India, was chosen because it shares certain similarities with Durban Port. According to Balachandran (2012), JN Port is India's largest container port, which is the similar case with Durban Port in South Africa. The study of JN Port took place while the port operations and construction activities were running in parallel throughout the year in 2006. Durban Port is currently engaged in the same development where renovations of roads leading to the port are taking place and the expansion of the port is underway. Although the construction phase in Durban Port does not form part of this study, it is likely to impact on other activities including the shipping activities within the Port. The area of study in JN Port is contained between latitude 18°53' 23''N to 18°57'47''N and longitude 72°56' 17''E to 73°01' 43''E. This area size is calculated to be 23.5 square nautical miles. The area of study of the Durban Port is 14.8 square nautical miles. Therefore both these study areas were restricted to within the port limits. Lastly, the study of Durban Port follows similar methodology utilized in the study of JN Port.

Joseph *et al.* (2009) compiled the detailed emission inventory of total suspended particulate (TSP), respirable particulate matter (PM_{10}), SO_2 and NO_X for JN Port for 2006. In the JN Port study, the emission inventories comprised three different activities namely road transport, shipping, and construction with the purpose of identifying major pollution sources and assist in decision-making and the development of control strategies.

The three activities in JN Port were tracked and inventories created to determine the contribution of each to the total emissions. For shipping activity, the study made use of the following formula approved by Intergovernmental Panel on Climate Change (IPCC) to estimate the emission of any pollutant from a single marine mobile pollution source:

$$E = P \times LF \times EF \times T$$

Where: E = *emissions for a given pollutant (grams)*

P = *maximum power output of engine (kW) also known as maximum continuous rating (MCR)*

LF = *load factor for an engine, as a fraction of maximum installed power capacity, dimensionless (expressed as percentage of engine's maximum power)*

EF = *emission factor (pollutant specific) in mass emitted per work output of the engine in different operation modes (g/kWh)*

T = *time for each activity in hours* (Joseph *et al*., 2009)

However, the calculation of marine emissions in JN Port only included ships in the hotelling mode and did not include the manoeuvring activity. Therefore, all emissions were assumed to be developing from the auxiliary engines and none from the main engines or boilers. The emission factors for auxiliary engines using residual oil having sulphur content of 2.7% were therefore adopted from ICF International[1] to complete the study (Joseph *et al*., 2009). These emission factors were given as follows:

PM_{10} = 1.14 g/kWh

SO_2 = 11.1 g/kWh

NO_X = 14.7 g/kWh

The load factors, which are expressed as percentages of maximum engine power output were based on the data from Starcrest Consulting Group[2] produced in 2004 (Joseph *et al*., 2009). The load factors for auxiliary engines below were used in the JN Port study (*Table 3.1*).

Table 3.1: Load Factors for auxiliary engines used in the study of JN Port for each type of vessel (Joseph *et al*., 2009)

Vessel Type	Load Factor
Bulk	22%
Container	17%
General	22%
Barges	24%
Tankers	67%

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[1] ICF (2014) International is the energy and environmental policy consulting firm based in Virginia, USA, founded as Inner City Fund in 1969. It addresses issues related to energy, environment, economic, health and social challenges of inner cities and beyond.

[2] Starcrest Consulting Group is an environmental management, air quality, climate and sustainability consulting company established in 1997 to provide technical, policy and business service support to state regulatory agencies, port authorities, private industry and federal services in the United States of America and internationally. Starcrest has done port inventories for the ports of Los Angeles, Long Beach, New York, Houston, Puget Sound and International Association of Ports and Harbours.

The vessel movement within the port for the period January to December 2006 was used for compilation of the emission inventory. The total number of vessels that took berth in the port during the study period were 2,841 (Joseph *et al*., 2009). The percentage distribution of these vessels indicate that 72.9% were container ships, 1.6% bulk cargo ships, 10.6% tankers, 3.5% general cargo ships and 11.4% were barges (*Figure 3.4*).

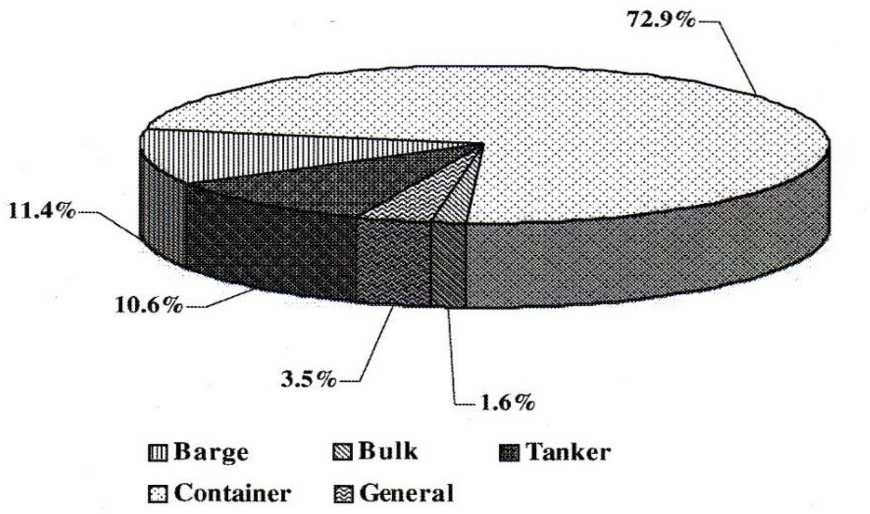
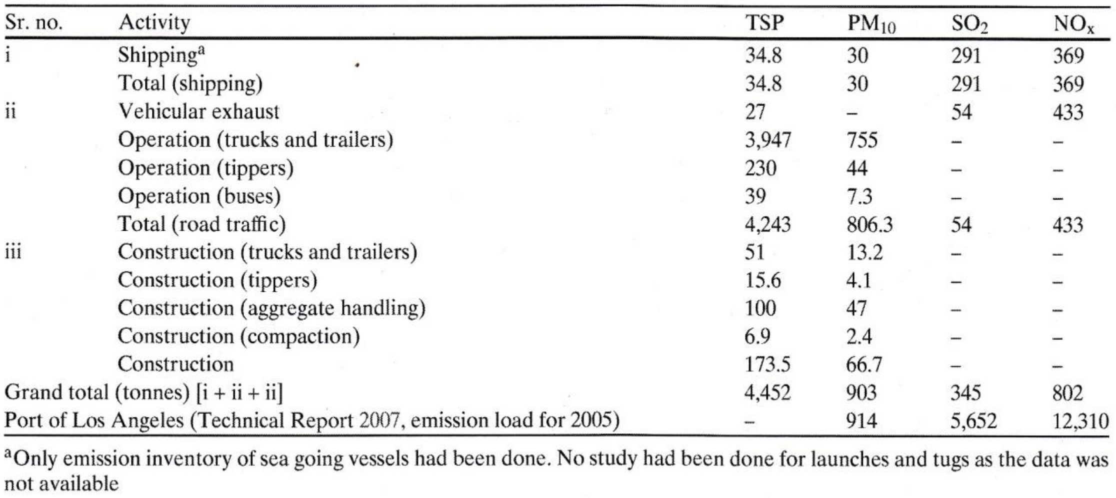


Figure 3.4: Percentage distribution of vessel types in JN Port, Mumbai, in 2006 (Joseph *et al*., 2009)

Shipping dominated the emissions of SO_2 and almost contributed half of NO_X emissions (*Table 3.2*). The shipping sector contributed 16.4% of the total TSP, 3.3% of PM_{10}, 84.3% of SO_2, and 46% of NO_x (Joseph *et al*., 2009). The total emissions were then compared with the results from the study of the Port of Los Angeles conducted by Starcrest Consulting Group for 2005 emissions (*Table 3.2*). It must be noted that the study of JN Port included OGVs only and omitted emissions from harbour crafts due to lack of data (*Table 3.2*).

Table 3.2: Total emissions (tonnes) from three port activities in JN Port, Mumbai in 2006 (Joseph *et al.*, 2009)



Sr. no.	Activity	TSP	PM_{10}	SO_2	NO_x
i	Shipping[a]	34.8	30	291	369
	Total (shipping)	34.8	30	291	369
ii	Vehicular exhaust	27	–	54	433
	Operation (trucks and trailers)	3,947	755	–	–
	Operation (tippers)	230	44	–	–
	Operation (buses)	39	7.3	–	–
	Total (road traffic)	4,243	806.3	54	433
iii	Construction (trucks and trailers)	51	13.2	–	–
	Construction (tippers)	15.6	4.1	–	–
	Construction (aggregate handling)	100	47	–	–
	Construction (compaction)	6.9	2.4	–	–
	Construction	173.5	66.7	–	–
Grand total (tonnes) [i + ii + ii]		4,452	903	345	802
Port of Los Angeles (Technical Report 2007, emission load for 2005)		–	914	5,652	12,310

[a] Only emission inventory of sea going vessels had been done. No study had been done for launches and tugs as the data was not available

3.4.2 The Port of Los Angeles (POLA), United States of America (USA), 2005

POLA is situated in the west coast of USA and together with the Port of Long Beach (POLB), they share San Pedro Bay and comprise a significant national economic hub. These San Pedro Bay ports handle more than 40% of containerized trade in the USA. POLA conducted its first activity-based port inventory of maritime related emissions in 2004, which documented the activity levels for 2001. The San Pedro Bay ports subsequently adopted the Clean Air Action Plan in 2006, which was designed to reduce air emissions and health risks while allowing the port developments to continue. The detailed annual activity-based port inventory became a critical component to the success of Clean Air Action Plan (Starcrest, 2007). The report discussed in this section is based on the 2005 activity levels for POLA for priority pollutants (i.e. NO_x, SO_x, PM_{10} and HC) and the 2007 GHG emission inventory. This port was also chosen because of its similarity to Durban Port. It handles the highest number of containerised cargo in the USA (Starcrest, 2011), which is a similar situation with Durban Port in South Africa. The methodology used in POLA study is similar to Durban Port study. The major difference between the two studies is the size of the study area. POLA study covered an area of more than 4,025.6 square nautical miles while Durban Port study covered only 14.8 square nautical miles, which is 272 times less than POLA study area.

On 20th June 2004 the POLA's container terminal at berth 100 became the world's first container terminal to use Alternative Maritime Power (AMP). This system allowed for ship's auxiliary engines to be shut down when the ship is alongside at berth (POLA, 2015). This translated to a substantial reduction in emissions from ships whilst docked alongside in port.

The emissions from OGVs and harbour crafts in POLA included four vessel activities, namely the transit within the study area, manoeuvring in port, hotelling in port, and hotelling at anchorage. The 2005 POLA study recorded 2,341 inbound vessels (those arriving in the port), 2,312 outbound vessels (those departing from the port) and 777 shifts (inter-port, intra-port and anchorage shifts), with the total sum of 5,430 vessel movements over one year. The majority of inbound vessels were container ships as represented in *Figure 3.6* (Starcrest, 2007).

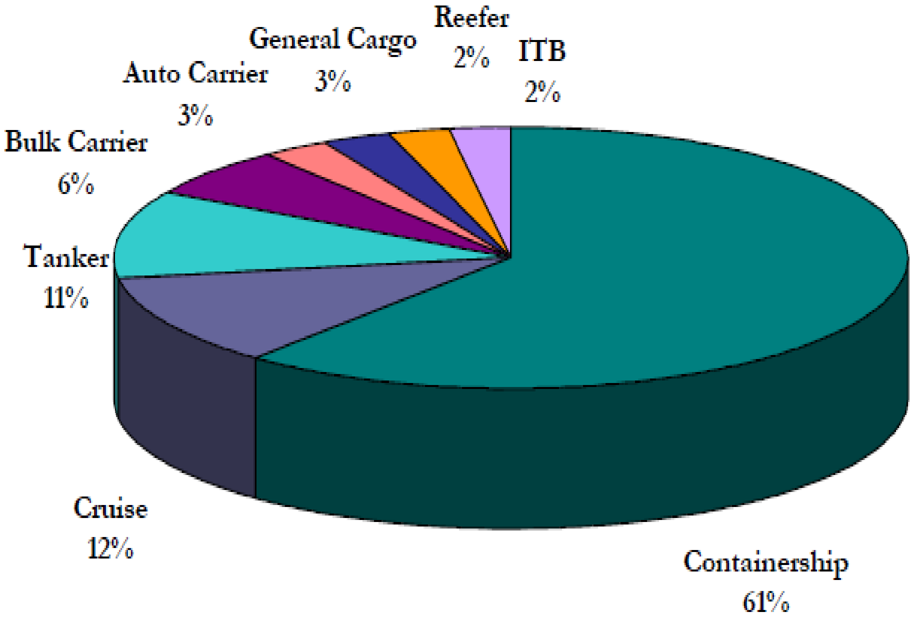


Figure 3.5: Percentage distribution of inbound vessel types in POLA (Starcrest, 2007)

The methodology used by Starcrest (2007) in the study of POLA was a detailed approach. The study involved collecting data on movement of each vessel and vessel characteristics. The study was based on the estimation of emission as a function of vessel power demand in kilowatts-hour (kWh), multiplied by emission factors in grams per kWh (g/kWh) as represented in the equation below (Starcrest, 2007).

$$E = Energy \times EF$$

The vessel power demand is the function of energy output of an engine in kilowatts (kW) over a period of time in hours multiplied by load factor. The emissions were calculated using the equation:

$$E = MCR \times A \times LF \times EF$$

Where: E = *emissions (grams)*

MCR = maximum continuous rating (kW)

A = activity (hours)

LF = load factor (unit less)

EF = emission factor (g/kWh)

The MCR power is defined as the manufacturers tested engine power. The load factor for main propulsion engines is the ratio the actual speed for the mode of activity to the maximum speed of the vessel. This load factor can be expressed in the equation:

$$LF = \left(\frac{AS}{MS}\right)^3$$

Where: LF = load factor, percent

AS = actual speed, knots

MS = maximum speed, knots

The main propulsion engine emission factors used were extracted from the ENTEC (2002) study and older vessels were assumed to have been built prior to 1999 and used residual fuel oil with average sulphur content of 2.7% (Starcrest, 2007). The emission factors used for this category were in accordance with the vessel technologies for SSD, MSD, GT and ST (*Table 3.3*).

Table 3.3: Emission factor (g/kWh) for OGV main engines built prior to 1999 used in the study of POLA (Starcrest, 2007)

ENGINE	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC
Slow speed diesel	1.5	1.2	1.5	18.1	10.5	1.4	0.6
Medium speed diesel	1.5	1.2	1.5	14.0	11.5	1.1	0.5
Gas turbine	0.05	0.04	0.0	6.1	16.5	0.2	0.1
Steam turbine	0.8	0.6	0.0	2.1	16.5	0.2	0.1

Newer models of main engines assumed to have been built after 2000 were allocated revised emission factors (*Table 3.4*). The calculations for emissions from auxiliary engines were similar to main propulsion engines with a slight difference in load factors. Load factors for main propulsion engines were calculated based on speed factors. However, for auxiliary engines, the load factors were estimated from reports in the technical literature and from discussions with ships engineers.

Table 3.4: Emission factors (g/kWh) for OGV main engines for 2000 used in the study of POLA (Starcrest, 2007)

ENGINE	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC
Slow speed diesel	1.5	1.2	1.5	17.0	10.5	1.4	0.6
Medium speed diesel	1.5	1.2	1.5	13.0	11.5	1.1	0.5

The total power and the load factors were then summarised and used as defaults for the types of vessels studied. Container ships were divided into eight categories based on their container carrying capacity from 1,000 containers to 8,000+ containers (*Table 3.5*).

Table 3.5: Auxiliary engine power and load defaults for OGVs used in the study of POLA (Starcrest, 2007)

Vessel Type	Total Aux Eng Power (kW)	Load Defaults (%)			Load Defaults (kW)		
		Sea	Maneuvering	Hotelling	Sea	Maneuvering	Hotelling
Auto Carrier	2,850	15%	45%	26%	428	1,283	741
Bulk – General	2,850	17%	45%	10%	428	1,283	285
Container – 1000	2,090	13%	50%	18%	272	1,045	376
Container – 2000	4,925	13%	43%	22%	640	2,118	1,084
Container – 3000	5,931	13%	43%	22%	771	2,550	1,305
Container – 4000	7,121	13%	50%	18%	926	3,561	1,282
Container – 5000	11,360	13%	49%	16%	1,477	5,566	1,818
Container – 6000	13,501	13%	50%	15%	1,755	6,751	2,025
Container – 7000	13,501	13%	50%	15%	1,755	6,751	2,025
Container – 8000	13,501	13%	50%	15%	1,755	6,751	2,025
Cruise	na	Na	na	na	na	na	na
General Cargo	1,776	17%	45%	22%	302	799	396
Ocean Tug	600	17%	45%	22%	102	270	134
Miscellaneous	1,776	17%	45%	22%	302	799	396
Reefer	3,900	15%	45%	32%	585	1,755	1,248
Ro/Ro	2,850	15%	45%	26%	428	1.283	741
Tanker - General	1.911	24%	33%	26%	459	631	497
Tanker – Chemical	1,911	24%	33%	26%	459	631	497
Tanker –Crude - Aframax	2,544	24%	33%	26%	611	840	661
Tanker – Crude - Handyboat	1,911	24%	33%	26%	459	631	497
Tanker – Crude Panamax	2,520	24%	33%	26%	605	832	655
Tanker – Oil Products	1,911	24%	33%	26%	459	631	497
Tanker – (Diesel/Electric)	1,985	24%	33%	26%	476	655	516

The calculations from boilers were different from the main propulsion and auxiliary engines. Instead of using default emission factors, data was collected from 50 vessels during the vessel boarding program (VBP), which focused on gathering specific vessel characteristics and operational data from ships visiting the port. The values obtained from VBP were used for specific types of vessels. The boiler fuel consumption was converted to equivalent kilowatts using specific fuel consumption (SFC) extracted from the ENTEC report. An average SFC for residual fuel is 305 grams of fuel per kWh and thus the average values were obtained using the equation:

$$Average\ kW = ((daily\ fuel/24) \times 1{,}000{,}000)/305$$

This calculation provides the boiler energy default values (*Table 3.6*).

Table 3.6: Boiler energy defaults used in the study of POLA (Starcrest, 2007)

Vessel Type	Boiler Energy Defaults (kW)		
	Sea	Maneuvering	Hotelling
Auto Carrier	0	371	371
Bulk – General	0	109	109
Container – 1000	0	506	506
Container – 2000	0	506	506
Container – 3000	0	506	506
Container – 4000	0	506	506
Container – 5000	0	506	506
Container – 6000	0	506	506
Container – 7000	0	506	506
Container – 8000	0	506	506
Cruise	0	1,000	1,000
General Cargo	0	106	106
Ocean Tug	0	0	0
Miscellaneous	0	371	371
Reefer	0	464	464
Ro/Ro	0	109	109
Tanker - General	0	371	3,000
Tanker – Chemical	0	371	3,000
Tanker –Crude - Aframax	0	371	3,000
Tanker – Crude - Handyboat	0	371	3,000
Tanker – Crude Panamax	0	371	3,000
Tanker – Oil Products	0	371	3,000
Tanker – (Diesel/Electric)	0	346	346

The data for harbour crafts inventory was obtained from the crafts' records and by interviewing the craft operators. The emission factors were developed from review of literature and discussions with regulating agencies. Emissions were calculated by multiplying the emission factors with annual hours of operation (activity) of each engine. The vessels were divided into the following categories (Starcrest, 2007):

- Assist tugboat
- Towboats and push boats
- Ferries
- Excursion vessels
- Crew boats
- Work boats
- Government vessels
- Commercial fishing vessels
- Recreational vessels

The emission factors for various categories of harbour crafts were assigned using a Tiered approach. Engines built prior to 2009 fall under Tier 0, Tier 1, or Tier 2. Tier 0 is the baseline where engines used pre-controlled technology. Tier 1 technologies include the first round of standards for NOx only, beginning in 2000. For instance, the engines with maximum power output of 560 kW and built after 1st January 2000 must not emit more than 10 grams of pollutants per kWh of power usage (see *Table 3.7*). Tier 2 includes the second round of standards for NOx, HC and PM commencing between 2004 and 2007, depending on engine displacement (USEPA, 2009). Most harbour crafts engines are Category 1 (engines with power output of 1,000 kW or less) and few are Category 2 (engines with power outputs greater than 1,000 kW). The emission factors used in the POLA study of 2005 were assigned in accordance with these Tiers and Categories (*Table 3.7*).

Table 3.7: Harbour crafts emission factors used in the study of POLA (Starcrest, 2007)

			Tier 0 engines g/kW-hr		
min. kW	**NO_X**	**CO**	**HC**	**PM**	**SO_2**
37	11.0	2.00	0.27	0.90	0.15
75	10.0	1.70	0.27	0.40	0.15
130	10.0	1.50	0.27	0.40	0.15
225	10.0	1.50	0.27	0.30	0.15
450	10.0	1.50	0.27	0.30	0.15
560	10.0	1.50	0.27	0.30	0.15
1,000	13.0	2.50	0.27	0.30	0.15
Category 2 engines	13.2	1.10	0.50	0.72	0.15
			Tier 1 engines g/kW-hr		
min. kW	**NO_X**	**CO**	**HC**	**PM**	**SO_2**
37	9.8	2.00	0.27	0.90	0.15
75	9.8	1.70	0.27	0.40	0.15
130	9.8	1.50	0.27	0.40	0.15
225	9.8	1.50	0.27	0.30	0.15
450	9.8	1.50	0.27	0.30	0.15
560	9.8	1.50	0.27	0.30	0.15
1,000	9.8	2.50	0.27	0.30	0.15
Category 2 engines	9.8	1.10	0.50	0.72	0.15
			Tier 2 engines g/kW-hr		
min. kW	**NO_X**	**CO**	**HC**	**PM**	**SO_2**
37	6.8	5.00	0.27	0.40	0.15
75	6.8	5.00	0.27	0.30	0.15
130	6.8	5.00	0.27	0.30	0.15
225	6.8	5.00	0.27	0.30	0.15
450	6.8	5.00	0.27	0.30	0.15
560	6.8	5.00	0.27	0.30	0.15
1,000	6.8	5.00	0.27	0.30	0.15
Category 2 engines	9.8	5.00	0.50	0.72	0.15

The emission results from the study of POLA for 2005 activity levels for OGVs show that the particulate matters were divided into three, namely $PM_{2.5}$, PM_{10} and DPM (*Table 3.8*).

Table 3.8: The 2005 OGVs emissions by vessel type from POLA (Starcrest, 2007)

Vessel Type	PM$_{10}$	PM$_{2.5}$	DPM	NO$_X$	SO$_X$	CO	HC
Auto Carrier	7.1	5.7	6.6	72.9	5.8	6.2	2.8
Bulk – General	28.6	22.9	26.8	285.4	237.9	23.2	9.8
Bulk – General	0.3	0.2	0.2	2.7	2.3	0.2	0.1
Bulk – General	0.6	0.5	0.5	5.9	5.1	0.5	0.2
Total Bulk Vessels							
Container – 1000	22.4	17.9	17.9	195.3	227.5	16.2	7.0
Container – 2000	33.1	26.5	28.4	331.5	289.4	27.6	12.4
Container – 3000	61.4	49.1	55.5	691.9	475.8	59.6	28.5
Container – 4000	105.1	84.1	97.0	1,086.2	832.9	98.3	47.5
Container – 5000	83.0	66.4	75.0	868.8	662.0	79.4	38.0
Container – 6000	47.9	38.3	43.8	590.5	322.5	58.0	27.3
Container – 7000	27.3	21.8	25.8	260.0	237.4	25.2	11.7
Container – 8000	0.5	0.4	0.5	4.5	3.7	0.5	0.3
Total Containership	**380.7**	**304.5**	**343.8**	**4,028.8**	**3,051.3**	**364.7**	**172.6**
Cruise	**115.5**	**92.4**	**112.2**	**1,065.2**	**84.5**	**84.5**	**34.5**
General Cargo	**11.9**	**9.5**	**9.8**	**110.0**	**8.8**	**8.8**	**3.8**
Ocean Tugboat	**4.3**	**3.4**	**4.3**	**40.0**	**3.1**	**3.1**	**1.4**
Miscellaneous	**0.6**	**0.5**	**0.5**	**5.7**	**0.4**	**0.4**	**0.2**
Reefer	**11.8**	**9.4**	**10.4**	**109.3**	**8.7**	**8.7**	**3.7**
Ro/Ro	**0.5**	**0.4**	**0.4**	**3.3**	**0.4**	**0.4**	**0.2**
Tanker - General	23.1	18.5	11.6	147.2	325.7	12.5	5.5
Tanker – Chemical	7.4	6.0	4.1	51.5	98.9	4.4	1.9
Tanker –Crude - Aframax	2.1	1.7	1.5	16.5	24.0	1.4	0.6
Tanker – Crude - Handyboat	5.3	4.2	2.5	33.9	75.9	2.8	1.3
Tanker – Crude Panamax	4.2	3.4	2.3	28.7	57.9	2.4	1.1
Tanker – Oil Products	29.6	23.7	14.4	197.3	436.0	16.1	7.1
Total Tankers	**71.8**	**57.5**	**36.4**	**475.1**	**1,018.3**	**39.5**	**17.4**
TOTAL	**633.6**	**506.9**	**552.0**	**6,205.6**	**5,609.3**	**540.2**	**246.7**

The container ships contributed more than 60% of all pollutants in the POLA study (*Figure 3.6*). The main propulsion engines had the highest emissions in all pollutants except SO$_X$ (*Table 3.9* and *Figure 3.7*).

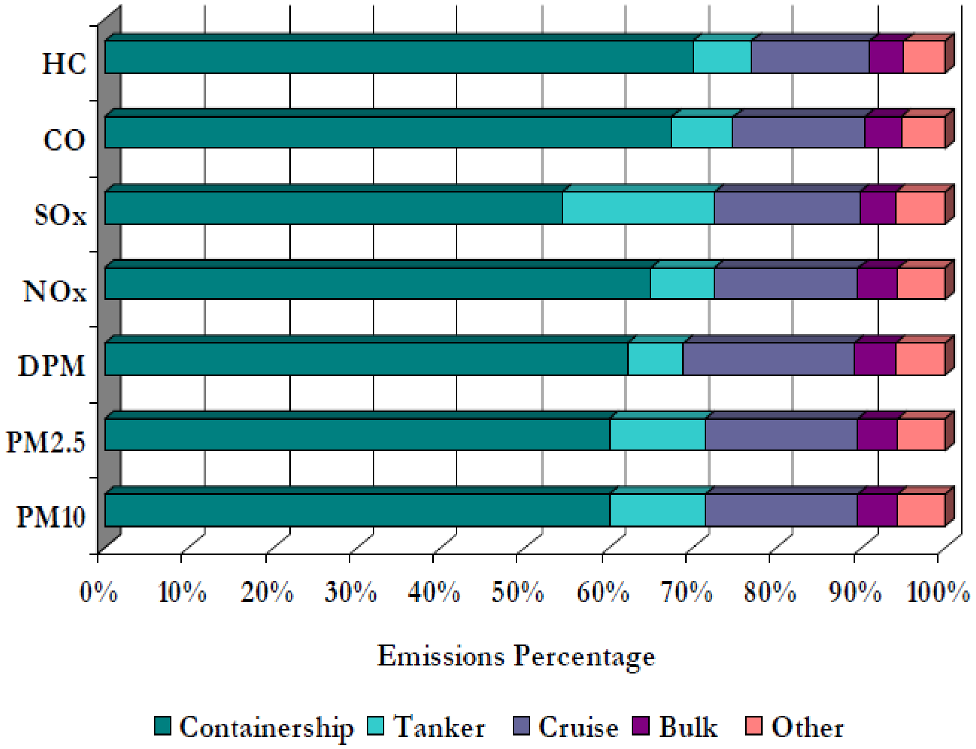


Figure 3.6: Percentage distribution of emissions from OGVs by vessel types in POLA in 2005 (Starcrest, 2007)

Table 3.9: The 2005 OGVs emissions (tpy) by engine type from POLA (Starcrest, 2007)

ENGINE TYPE	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC
Auxiliary Engine	263.8	211.0	263.8	2,858.4	1,997.0	230.0	83.6
Auxiliary Boiler	78.7	63.0	0.0	209.1	1,615.9	20.0	10.0
Main Engine	291.2	232.9	288.0	3,138.2	1,996.4	290.2	153.1
TOTAL	**633.6**	**506.9**	**552.0**	**6,205.6**	**5,609.3**	**540.2**	**246.7**

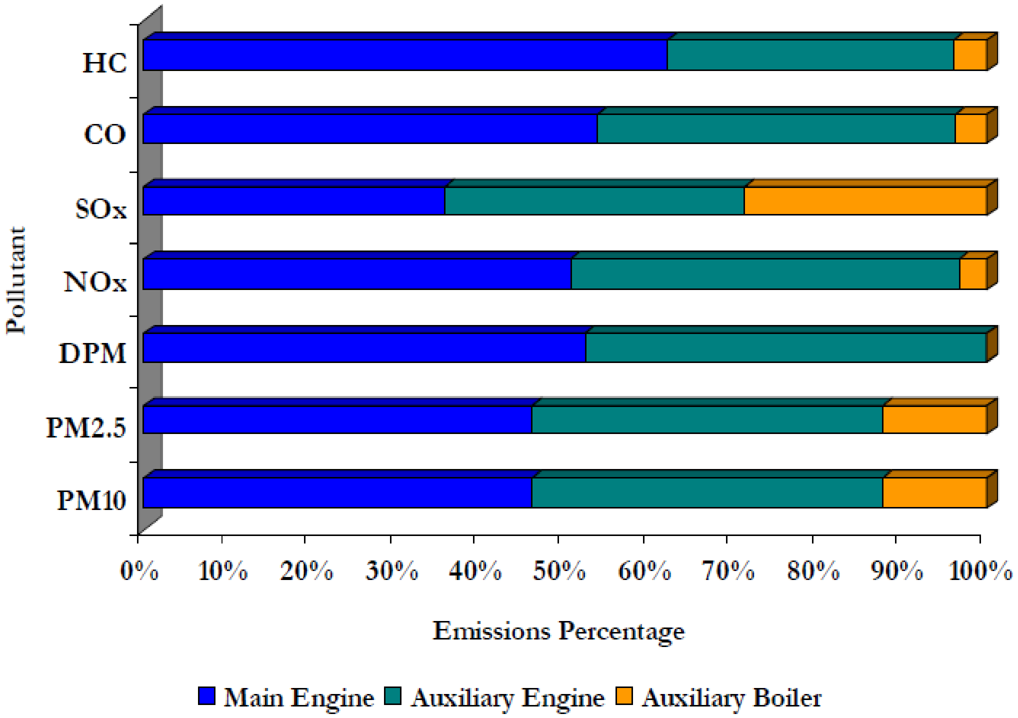


Figure 3.7: Percentage distribution of emissions from OGVs by engine types in POLA in 2005 (Starcrest, 2007)

The assist tugs were the highest emitters of all pollutants in the harbour crafts category (*Table 3.10*). Nevertheless the harbour crafts produced fewer emissions than the OGVs (refer to *Table 3.8*).

Table 3.10: The 2005 harbour crafts emissions by vessel type from POLA (Starcrest, 2007)

Vessel Type	Engine Type	PM_{10}	$PM_{2.5}$	DPM	NO_X	SO_X	CO	HC
Assist Tug	Auxiliary	0.7	0.6	0.7	19.4	0.1	4.4	0.4
	Propulsion	9.0	8.3	9.0	283.8	1.4	53.7	5.5
Assist Tug Total		9.7	8.9	9.7	303.2	1.5	58.1	5.9
Commercial Fishing	Auxiliary	1.3	1.2	1.3	24.0	0.1	7.4	0.5
	Propulsion	3.6	3.3	3.6	116.2	0.7	22.1	2.5
Commercial Fishing Total		5.0	4.6	5.0	140.3	0.8	29.5	3.0
Crewboat	Auxiliary	0.2	0.1	0.2	4.3	0.0	0.7	0.1
	Propulsion	0.7	0.7	0.7	23.5	0.1	6.0	0.5
Crewboat Total		0.9	0.8	0.9	27.7	0.2	6.8	0.6
Excursion	Auxiliary	0.6	0.6	0.6	8.9	0.1	1.9	0.2
	Propulsion	5.4	5.0	5.4	208.8	1.2	37.7	4.5
ExcursionTotal		6.1	5.6	6.1	217.6	1.3	39.5	4.7
Ferry	Auxiliary	0.1	0.1	0.1	1.7	0.0	0.3	0.03
	Propulsion	5.8	5.4	5.8	200.4	1.4	101.9	5.0
Ferry Total		5.9	5.4	5.9	202.1	1.4	102.2	5.1
Government	Auxiliary	0.0	0.0	0.0	0.8	0.0	0.1	0.02
	Propulsion	0.7	0.7	0.7	29.6	0.0	5.4	0.6
Government Total		0.7	0.7	0.7	30.4	0.0	5.5	0.6
Ocean Tug	Auxiliary	0.1	0.1	0.1	1.3	0.0	0.3	0.0
	Propulsion	1.1	1.0	1.1	39.4	0.2	6.3	0.6
Ocean Tug Total		1.2	1.1	1.2	40.7	0.2	6.5	0.7
Tugboat	Auxiliary	0.4	0.4	0.4	7.8	0.0	1.7	0.2
	Propulsion	8.0	7.4	8.0	270.5	1.4	44.4	5.0
Tugboat Total		8.4	7.8	8.4	278.4	1.4	46.1	5.2
Workboat	Auxiliary	0.1	0.1	0.1	1.4	0.0	0.3	0.0
	Propulsion	0.4	0.4	0.4	17.4	0.1	2.8	0.4
Workboat Total		0.5	0.5	0.5	18.8	0.1	3.1	0.4
Harbour Vessel Total		38.4	35.3	38.4	1,259.2	7.0	297.5	26.1

The tugs showed higher percentage of NO_X and SO_X emissions (*Figure 3.9* and *Figure 3.10*). There are more emissions from harbour crafts within the port because the tugs and other vessels mostly operate within the port limits (*Figure 3.10*).

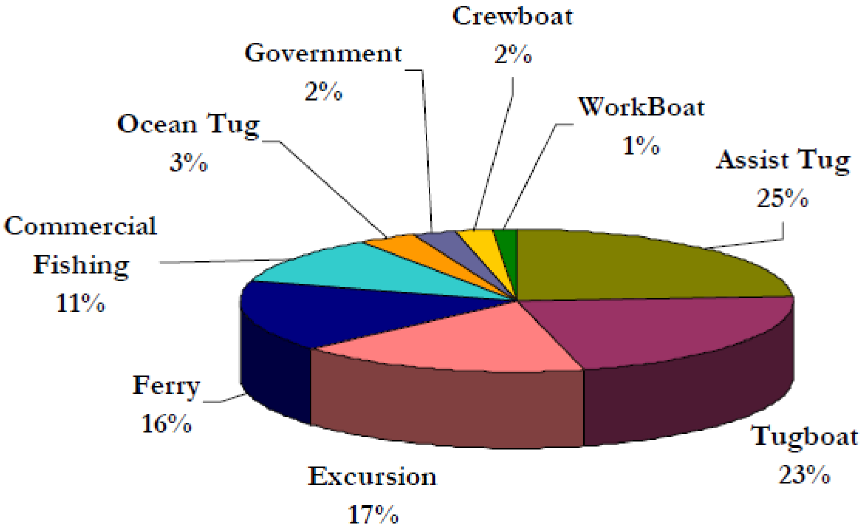


Figure 3.8: Percentage distribution of NO_X emissions from harbor crafts by vessel types in POLA in 2005 (Starcrest, 2007)

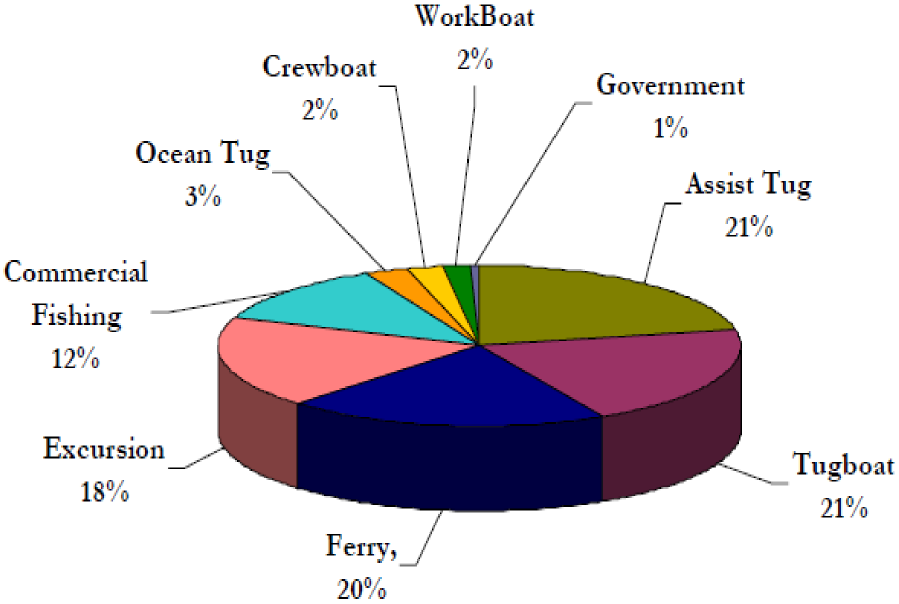


Figure 3.9: Percentage distribution of SO_X emissions from harbor crafts by vessel types in POLA in 2005 (Starcrest, 2007)

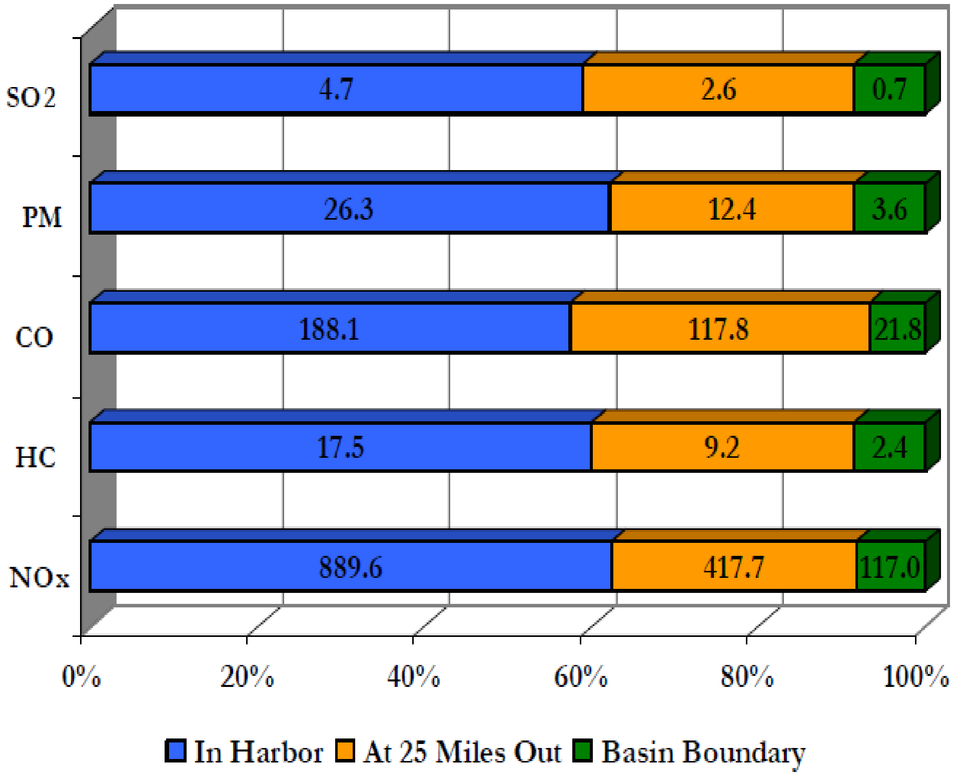


Figure 3.10: Percentage distribution of pollutants by area of operation from harbor crafts in POLA in 2005 (Starcrest, 2007)

Starcrest expanded the port inventories to include GHG emissions and involved emission estimates from regional, national and international levels of activities. This meant that the distance travelled by OGVs from the last port of call to the next port of call became part of inventory for each port. Such an approach allows for determination of impacts of ports on a global scale and assists in quantifying the anthropogenic GHG emission influences of the port in a global domain (Starcrest, 2010). The study domain for OGVs can be reduced from a much broader global scale to narrower national and regional subdomains for closer analysis, as done in the study of POLA (Starcrest, 2010).

There were 2,493 inbound and 2,449 out-bound vessels for POLA in 2007, which made the total of 4,942 vessel movements over the study period in 2007 (*Table 3.11*).

Table 3.11: Total OGVs movement in POLA in 2007 (Starcrest, 2010)

Vessel Type	Arrival (In-Bound)	Departure (Out-Bound)
Auto Carrier	67	69
Bulk	98	85
Bulk – Heavy Load	2	2
Bulk – Wood Chips	3	3
Container – 1000	237	238
Container – 2000	104	104
Container – 3000	127	127
Container – 4000	537	534
Container – 5000	328	313
Container – 6000	160	160
Container – 7000	80	80
Container – 8000	4	1
Cruise	**254**	**253**
General Cargo	**105**	**104**
ITB	**65**	**61**
Reefer	**46**	**45**
Ro/Ro	**0**	**1**
Tanker – Aframax	3	3
Tanker – Chemical	135	127
Tanker – Handyboat	86	88
Tanker – Panamax	52	51
TOTAL	**2,493**	**2,449**

The emission factors used for the main propulsion engines included three greenhouse gases namely CO_2, CH_4 and N_2O (*Table 3.12*).

Table 3.12: GHG emission factors for OGVs main propulsion engines for the 2007 POLA study (Starcrest, 2010)

ENGINE	Model Year	CO_2	CH_4	N_2O
Slow speed diesel	<=1999	620	0.012	0.031
Medium speed diesel	<=1999	683	0.010	0.031
Slow speed diesel	2000+	620	0.012	0.031
Medium speed diesel	2000+	683	0.010	0.031
Gas turbine	All	970	0.002	0.08
Steamship	All	970	0.002	0.08

The emission factors used for the auxiliary engines were for the medium speed engine using residual oil (*Table 3.13*).

Table 3.13: GHG emission factors for OGVs auxiliary engines using residual oil in the 2007 POLA study (Starcrest, 2010)

ENGINE	CO_2	CH_4	N_2O
Medium speed	683	0.008	0.031

The GHG emissions for the 2007 study of POLA from the OGVs were measured in mega-tonnes (*Table 3.14*). The table shows only the domain that is comparable to the study of Durban Port, which is the zone termed "Outside 24nm/Inside SoCAB". This is because it is the domain that defines only the emissions from the marine sources (i.e. OGVs) and no land based sources (Starcrest, 2010). The total annual CO_2 emissions from OGVs within the SoCAB domain were 11,340 mtons (*Table 3.14*).

Table 3.14: 2007 GHG emissions from OGVs in POLA (Starcrest, 2010)

Domain	2007 Total OGV Emissions			
	CO_2 (mtons)	N_2O (mtons)	CH_4 (mtons)	CO_2E (mtons)
Annual Inventory (Outside 24 nm/Inside SoCAB)	11,340	1	0	11,527

3.4.3 Air Pollution from Ships in Three Danish Ports, 2001

In a study conducted by Saxe and Larson (2004) the operational meteorology air quality model (OML) was used to calculate the urban dispersion of air pollutants originating from ships in three Danish ports, namely Copenhagen, Elsinore and Køge. Although three ports were studied by Saxe and Larson, more attention will be given to the Port of Copenhagen because of its similarity to Durban Port, specifically regarding the types and the amount of ships inventoried. The study of Danish Ports modelled the dispersal of NO_X, SO_2 and PM resulting from ships in ports in 2001. Saxe and Larson (2004) argued that the emissions of SO_2 and NO_X from ships sailing along the coast of Denmark exceeded emissions from all land-based sources combined, which included power stations, industry and road traffic (*Figure 3.11*). This study was chosen as it provides the procedure for modeling the ambient concentrations of pollutants from ships emission. The model results from the two ports i.e. Copenhagen and Durban ports will be compared.

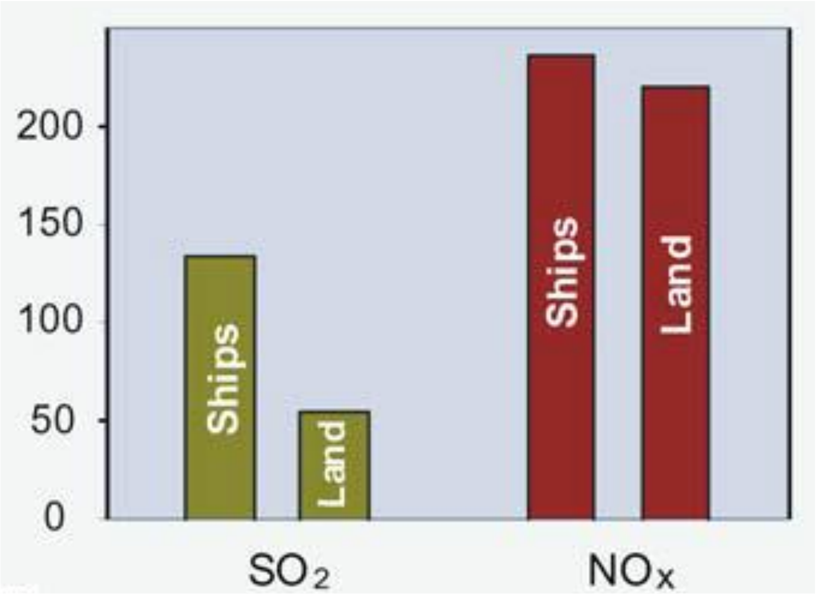


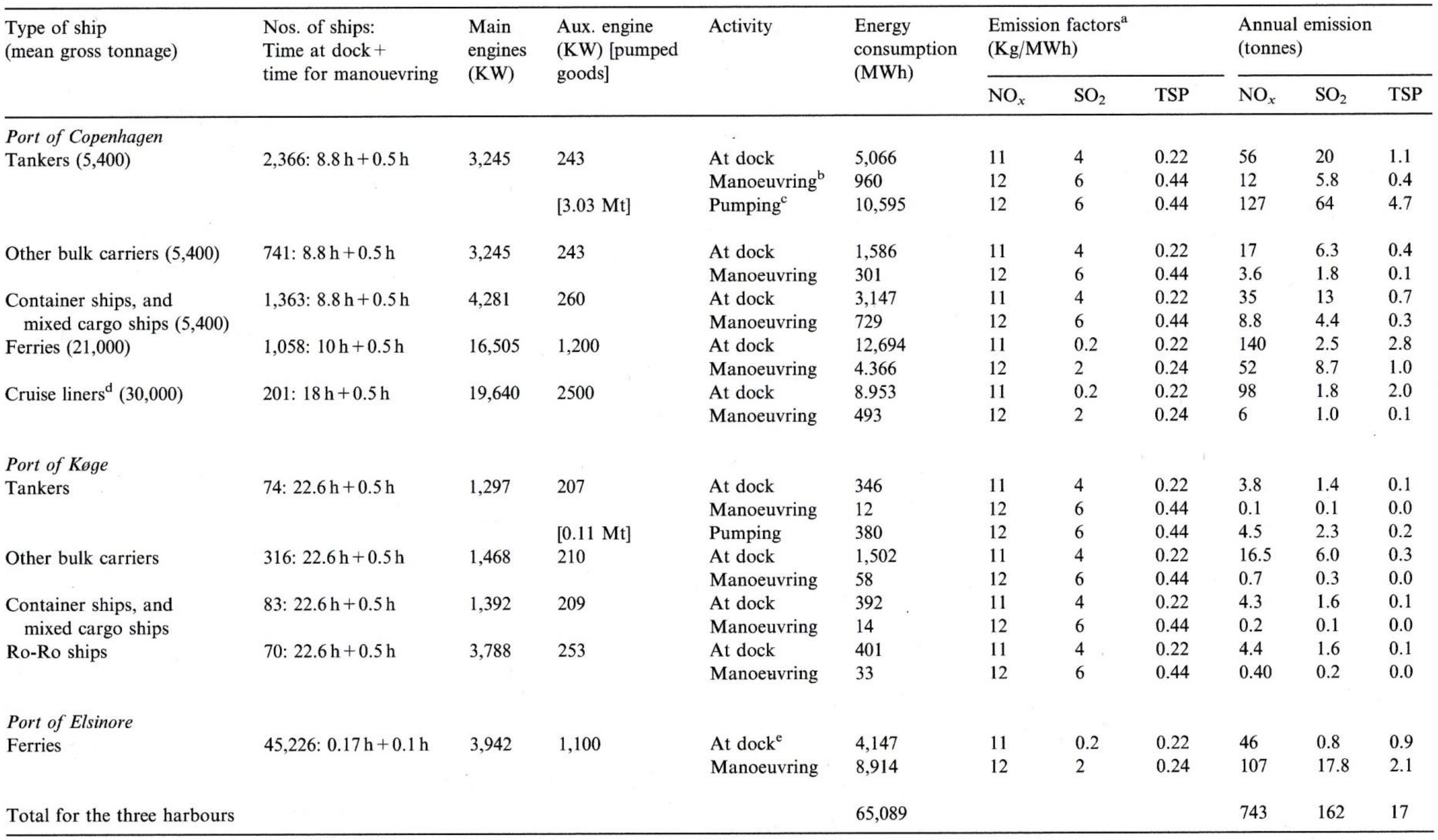
Figure 3.11: Air pollutant emissions in (tpy) from all land-based sources combined compared to emissions from ships sailing around Denmark (Saxe and Larson, 2004)

Saxe and Larson (2004) obtained details on the capacity of main propulsion engines and auxiliary engines of all ferries from the owners, and applied them in the calculations for each vessel. The data on the main propulsion engines for cargo ships were estimated based on information of 466 ships described by Seapress, which shows the illustrated list of Danish ships (Saxe and Larson, 2004).

For modelling purposes, Saxe and Larson (2004) determined the average size of the types of cargo ships and made an assumption that all ships within a particular category were of equal size. For ferries, the size was based on the knowledge of ships sailing regularly between Danish ports and the adjacent countries of Germany, Norway, Sweden and Poland. The time spent by ships in Copenhagen was provided by the port authorities from register entries and for ferries, the service providers supplied the timetables. The port authorities in Copehagen also provided the information on the size and duration of visits of each cruise liner. The ferries and the cruise liners remained on average 10 hours and 18 hours alongside in Copenhagen and they spent 30 minutes manoeuvring in the port (*Table 3.15*). The information on the auxiliary engine capacity of one third of cruise liners revealed a linear correlation between the auxiliary engine capacity and the gross tonnage. This information was used to calculate the engine capacities of unknown auxiliaries for cruise liners based on the gross tonnage.

The emission factors used by Saxe and Larson (2004) were derived from the report by Oxbøl and Wismann (*Table 3.15*). The emissions from cargo ships' main propulsion engines were based on average emission factors for medium speed engines. The load factors of main propulsion engines during manoeuvring in port were assumed to be between 25% and 50% of the maximum power output depending on the type of ship. The ferries were assumed to manoeuvre at half-power and all other ships at quarter-power. The results in the study of the Port of Copenhagen were obtained by considering the maximum continuous ratings of engines, taken as average for specific ship type, and multiplying by the number of hours spent in each activity and by the number of ships in the port. This gave the total energy consumption in MWh from all ships in the type category per mode of operation. The total energy consumption multiplied by the emission factor for the specific pollutant resulted in the amount of emissions of each pollutant.

Table 3.15: The energy consumption and emissions by ships in the Ports of Copenhagen, Elsinore and Køge in 2001 (Saxe and Larson, 2004)



Type of ship (mean gross tonnage)	Nos. of ships: Time at dock + time for manouevring	Main engines (KW)	Aux. engine (KW) [pumped goods]	Activity	Energy consumption (MWh)	Emission factors[a] (Kg/MWh)			Annual emission (tonnes)		
						NO_x	SO_2	TSP	NO_x	SO_2	TSP
Port of Copenhagen											
Tankers (5,400)	2,366: 8.8 h + 0.5 h	3,245	243	At dock	5,066	11	4	0.22	56	20	1.1
				Manoeuvring[b]	960	12	6	0.44	12	5.8	0.4
			[3.03 Mt]	Pumping[c]	10,595	12	6	0.44	127	64	4.7
Other bulk carriers (5,400)	741: 8.8 h + 0.5 h	3,245	243	At dock	1,586	11	4	0.22	17	6.3	0.4
				Manoeuvring	301	12	6	0.44	3.6	1.8	0.1
Container ships, and mixed cargo ships (5,400)	1,363: 8.8 h + 0.5 h	4,281	260	At dock	3,147	11	4	0.22	35	13	0.7
				Manoeuvring	729	12	6	0.44	8.8	4.4	0.3
Ferries (21,000)	1,058: 10 h + 0.5 h	16,505	1,200	At dock	12,694	11	0.2	0.22	140	2.5	2.8
				Manoeuvring	4.366	12	2	0.24	52	8.7	1.0
Cruise liners[d] (30,000)	201: 18 h + 0.5 h	19,640	2500	At dock	8.953	11	0.2	0.22	98	1.8	2.0
				Manoeuvring	493	12	2	0.24	6	1.0	0.1
Port of Køge											
Tankers	74: 22.6 h + 0.5 h	1,297	207	At dock	346	11	4	0.22	3.8	1.4	0.1
				Manoeuvring	12	12	6	0.44	0.1	0.1	0.0
			[0.11 Mt]	Pumping	380	12	6	0.44	4.5	2.3	0.2
Other bulk carriers	316: 22.6 h + 0.5 h	1,468	210	At dock	1,502	11	4	0.22	16.5	6.0	0.3
				Manoeuvring	58	12	6	0.44	0.7	0.3	0.0
Container ships, and mixed cargo ships	83: 22.6 h + 0.5 h	1,392	209	At dock	392	11	4	0.22	4.3	1.6	0.1
				Manoeuvring	14	12	6	0.44	0.2	0.1	0.0
Ro-Ro ships	70: 22.6 h + 0.5 h	3,788	253	At dock	401	11	4	0.22	4.4	1.6	0.1
				Manoeuvring	33	12	6	0.44	0.40	0.2	0.0
Port of Elsinore											
Ferries	45,226: 0.17 h + 0.1 h	3,942	1,100	At dock[e]	4,147	11	0.2	0.22	46	0.8	0.9
				Manoeuvring	8,914	12	2	0.24	107	17.8	2.1
Total for the three harbours					65,089				743	162	17

The results of Copenhagen study indicate that ferries had the highest contribution of NO_X emissions followed by tankers and cruise liners (*Figure 3.12*). Most of NO_X emissions in Copenhagen were associated with hotelling activity when ships were alongside. In Køge Port, bulk carriers contributed 49% of NO_X emissions while docked alongside. Although shore-power supply is provided in Køge, it is rarely used. At Elsinore Port, ferries contributed 73% of NO_X during manoeuvring in port. Approximately 50% of 130 tonnes of SO_2 emissions from ships in Copenhagen Port resulted from loading and unloading of tankers (Saxe and Larson, 2004).

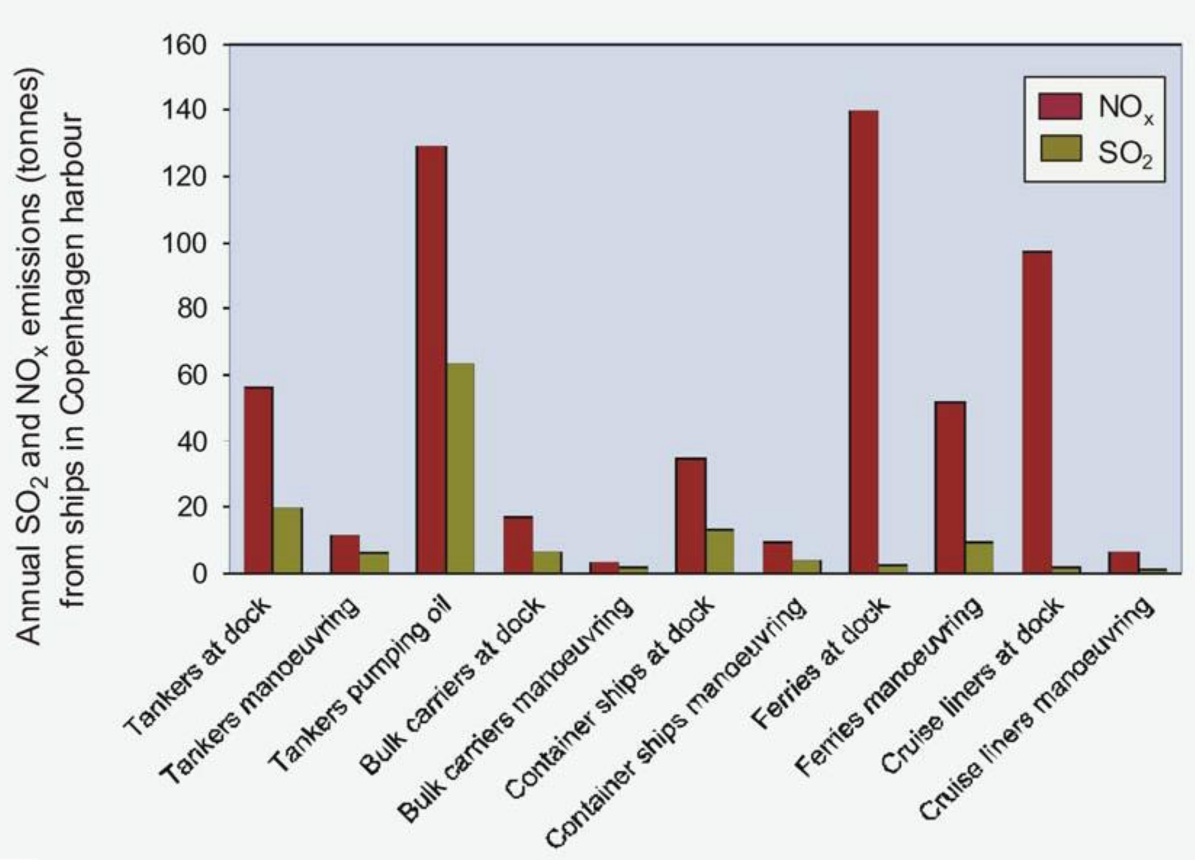


Figure 3.12: NO_X and SO_2 emissions resulting from ships in the Port of Copenhagen in 2001 (Saxe and Larson, 2004)

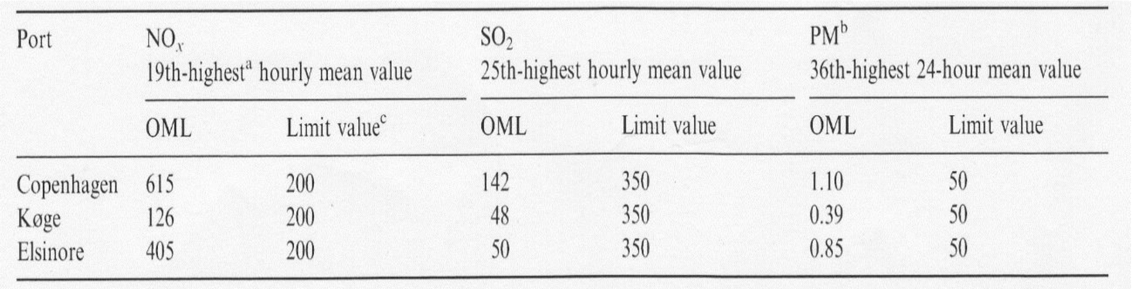
The results from the three ports were then used to model the urban dispersion of NO_X, SO_2 and PM from ships in each port. For large ports such as Copenhagen, ships dock at four different sections of the port according to vessel type, namely cargo ships, tankers, cruise liners, and ferries. In each section, the emissions are assumed to originate from one or two central points. Emissions from arriving, departing and docked ships were all allocated to these points in accordance with type of ship. On average, the points of emission were defined as 30 m above sea-level for cruise liners, and 20 m for all other ships. In Køge and Elsinore, the points of emission were all defined as 20 m above the sea level. Flue gases were assumed to be emitted at a rate of 30 ms^{-1} for all ship types. Flue gas temperature was estimated at 350°C. The roughness parameter was set at 0.3 m, as the terrain of interest was mostly urban (Saxe and Larson, 2004).

The OML originally was developed to calculate the contribution of stationery sources such as tall chimneys with a constant rate of emission, to the concentration of air pollutants in the surrounding area (Saxe and Larson, 2004). To allow for dispersion modeling, the authors developed fixed points representing the average locations and emissions from manoeuvres and docks for cruise liners, ferries, cargo ships and tankers. Seven points were assigned for Copenhagen and one point was assigned for the smaller Ports of Elsinore and Køge (Saxe and Larson, 2004). The OML model could not be used for variable emissions. For instance the emissions from cruise liners were converted to flux values assumed to occur evenly over all the hours of the year. This method was applied to all other types of ships.

Meteorological input comprised one full year of data from Copenhagen. Modeling ships in port is more complicated than modeling stationery sources with constant emissions. In the town of Køge, where the built-up area around the harbour has low-rise, the pollutant concentrations were calculated at 1.5 m above sea-level. This is the level where people, who are the prime receptors, are expected to breathe the air. In Elsinore, the buildings near the harbour are taller, so pollutant concentrations were calculated at 5 m above sea-level. In Copenhagen, concentrations were calculated at 7 m above sea-level, since the buildings there are taller than in Elsinore (Saxe and Larson, 2004).

The model showed that emissions of NO_X by ships in the Port of Copenhagen caused a peak hourly averaged concentration of 615 $\mu g/m^3$, which exceeded the legal limit of 200 $\mu g/m^3$ (*Table 3.16*). These exceedances contributed significantly to the overall NO_X pollution in Copenhagen and would have had serious impact on human health if most of NO were transformed into NO_2. The emissions of PM by ships in Copenhagen contributed 8 to 15% of that of urban road traffic and caused neighbourhood concentrations equivalent to only 0.2 – 0.4% of European Community's legal annual mass based limit values for protection of human health. The low activity in Køge Port meant that ships did not significantly affect the urban air quality (Saxe and Larson, 2004).

Table 3.16: Maximum concentrations of air pollutants (μgm^{-3}) in and around the Danish ports caused by ships in ports calculated by OML and compared to some of the European Commission's limit values for protection of human health (Saxe and Larson, 2004)



Port	NO_x 19th-highest[a] hourly mean value		SO_2 25th-highest hourly mean value		PM[b] 36th-highest 24-hour mean value	
	OML	Limit value[c]	OML	Limit value	OML	Limit value
Copenhagen	615	200	142	350	1.10	50
Køge	126	200	48	350	0.39	50
Elsinore	405	200	50	350	0.85	50

3.5 NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS) FOR COMMON POLLUTANTS

The air quality standards are the thresholds that serve to indicate what levels of exposure to pollution are generally safe for human inhalation including the very young and the elderly. The World Health Organization (WHO) provides scientific guidance on the levels of pollution that adversely affect human health. As a result countries formulate their own legal standards based on these guidelines (DEAT, 2014).

The South African NAAQS were introduced based primarily on guidance offered by two sets of standards, namely the South African National Standards (SANS 69:2004 and SANS 1929:2005). SANS 69:2004 provides the framework for implementing NAAQS. It makes provision for the establishment of air quality objectives for the protection of human health and the environment. These air quality objectives include limit values, alert thresholds and target values. SANS 1929:2005 provides limits for common pollutants. The limit values presented in this standard are intended to guide air quality management. The NAAQS only become enforceable as revised under Government Notices (GN 1210 of 2009 and GN 486 of 2012). The NAAQS have specific averaging periods, compliance dates, and allowable frequencies of exceedence and reference methods (RSA, 2009).

The criteria pollutants for South African air quality limits include sulphur dioxide, nitrogen dioxide, particulate matter, carbon monoxide, lead, ozone, benzene, and the deposition of dust (RSA, 2009). The pollutants of focus in this study are SO_2, NO_2, CO_2, HC, and PM_{10}. All GHGs, including the CO_2 were recently declared as priority air pollutants by the Minister of Water and Environmental Affairs (RSA, 2014). Prior to this declaration, CO_2 did not feature as a criteria pollutant in the South African air quality standards because it has no health impact on humans except that it is a major pollutant responsible for global warming and climate change. Other GHGs included under this declaration involves methane (CH_4), nitrous oxide (N_2O), hydroflurocarbons (HFCs), perflurocarbons (PFCs), and sulphur hexafluoride (SF6). However, this study will focus only on CO_2 as a GHG emitted by ships.

3.5.1 Nitrogen Oxides (NO_2)

Nitrogen oxides form a group of reactive gases containing several components including nitrogen dioxide (NO_2), nitric oxide (NO) and nitrous oxide (N_2O). NO_2 is often used as an indicator for the larger group because of its abundance in the atmosphere. NO_2 is emitted by cars, power plants and off-road equipment (USEPA, 2013).

NO_2 contributes to the formation of ground-level ozone and it is linked to many adverse effects of respiratory system. Current evidence show that exposure of 30 minutes to 24 hours can have adverse respiratory impacts including inflammation of airways in healthy people and increased respiratory symptoms in people with asthma. NO_x react with ammonia, moisture and other compounds to form small particles, which can penetrate deep into the lungs and cause or worsen respiratory disease such as bronchitis. It can also aggravate heart disease. Children, elderly and people with lung disease such as asthma are at risk from adverse effects of NO_2 (USEPA, 2013).

In this study, all NO_X from ships exhaust gas emissions are assumed to be NO_2. This will allow comparison between ship emissions and the NAAQS (*Table 3.17*).

Table 3.17: National Ambient Air Quality Standards for NO_2 (RSA, 2009)

Averaging Period	Concentration	Frequency of Exceedence	Compliance Date
1 hour	200µg/m^3 (106 ppb)	88	Immediate
1 year	40µg/m^3 (21 ppb)	0	Immediate
The reference method for the analysis of NO_2 shall be ISO 7996			

3.5.2 Sulphur Dioxide (SO_2)

Sulphur dioxide forms part of the larger group of highly reactive gases known as oxides of sulphur (SO_x). SO_2 is of greatest concern from a health perspective, it is used as an indicator for the larger group of sulphur oxides. Other components of the group such as SO_3 are found in much lower concentration than SO_2. The larger percentage of SO_2 emission is from fuel combustion in power plants (73%) and other industrial facilities (20%). A smaller percentage comes from burning of high sulfur containing fuels by locomotives, ships and non-road equipment (USEPA, 2013).

Current studies show that exposure to SO_2 for 5 minutes to 24 hours can have an array of respiratory problems. These range from bronchoconstriction to asthma symptoms. Such effects can be short term visits to emergency departments to long term hospital admissions for respiratory illnesses. SO_X can react with other compounds in the atmosphere to form small particles that can cause or worsen respiratory disease such as bronchitis. They can also aggravate heart disease leading to prolonged hospital admission and premature death (USEPA, 2013).

The NAAQS published in the Government Gazette dated 24 December 2009, in line with Section 8 of NEMAQA, sets out the SO_2 ambient concentration (*Table 3.18*). In the study of Durban Port, all SO_X emissions from ships are assumed to be in the form of SO_2. This will allow comparison with the NAAQS (*Table 3.18*).

Table 3.18: National Ambient Air Quality Standards for SO_2 (RSA, 2009)

Averaging Period	**Concentration**	**Frequency of Exceedence**	**Compliance Date**
10 minutes	500µg/m^3 (191 ppb)	526	Immediate
1 hour	350µg/m^3 (134 ppb)	88	Immediate
24 hours	125µg/m^3 (48 ppb)	4	Immediate
1 year	50µg/m^3 (19 ppb)	0	Immediate
The reference method for the analysis of SO_2 shall be ISO 6767			

3.5.3 Particulate Matter with an Aerodynamic Diameter Less than 10 Micrometers (PM_{10}) and Less than 2.5 Micrometers ($PM_{2.5}$)

Particulate matter is the mixture of suspended solid particles and liquid droplets. It is made up of a number of components including acids, metals, and soil or dust particles. The size of particles is linked to its potential to cause health problems. Of main concern are particles of less than 10 micrometers in diameter or smaller because those particles can generally pass through the throat and nose and enter the lungs. These particles can affect the heart and lungs and cause serious respiratory problems. $PM_{2.5}$ can pass through the alveolar capillaries and into the bloodstream to be laid down as plaques in the cardiovascular system. (USEPA, 2013).

According to USEPA (2013) various scientific studies link particulate matter exposure to a variety of health problems that include:

- Premature death in people with heart or lung disease
- Heart attacks
- Irregular heartbeat
- Aggravated asthma
- Decreased lung function
- Respiratory symptoms such as coughing, difficulty breathing and throat irritation.

The current NAAQS for PM_{10} and $PM_{2.5}$ will be replaced with more stringent levels on the 1st January 2015 for PM_{10} and 1st January 2016 for $PM_{2.5}$ (*Table 3.19* and *3.20*). Further stringent levels will be introduced on the 1st January 2030 for $PM_{2.5}$ (*Table 3.20*).

Table 3.19: National Ambient Air Quality Standards for PM_{10} (RSA, 2009)

Averaging Period	Concentration	Frequency of Exceedence	Compliance Date
24 hours	120µg/m³	4	Immediate – 31 December 2014
24 hours	75µg/m³	4	1 January 2015
1 year	50µg/m³	0	Immediate – 31 December 2014
1 year	40µg/m³	0	1 January 2015
The reference method for the determination of PM_{10} shall be EN 12341			

Table 3.20: National Ambient Air Quality Standards for $PM_{2.5}$ (RSA, 2012)

Averaging Period	Concentration	Frequency of Exceedence	Compliance Date
24 hours	65µg/m³	4	Immediate – 31 December 2015
24 hours	40µg/m³	4	1 January 2016 – 31 December 2029
24 hours	25µg/m³	4	1 January 2030
1 year	25µg/m³	0	Immediate – 31 December 2015
1 year	20µg/m³	0	1 January 2016 – 31 December 2029
1 year	15µg/m³	0	1 January 2030
The reference method for the determination of $PM_{2.5}$ fraction of suspended particulate matter shall be EN 14907			

3.5.4 Hydrocarbons (HC)

Hydrocarbons are organic compounds consisting entirely of hydrogen and carbon. The majority of hydrocarbons occur naturally in crude oil. Hydrocarbons are the principle constituents of petroleum and natural gas. They serve as fuels and lubricants and become raw material in the production of rubber, plastic, explosives and industrial chemicals. Depending on the number of bonds between carbon atoms, hydrocarbons can be divided into alkanes (single bond), alkenes (double bonds), alkynes (triple bonds) and aromatic hydrocarbons (rings). Methane (CH_4), a green-house gas is one example of hydrocarbon that develop naturally as well as from human activities (Elmhurst College, 2013).

Organic compounds that exist as gases in the atmosphere are referred to as volatile organic compounds (VOCs). Benzene is an example of volatile organic compound found in vehicle and power plant emissions. Long term exposure to benzene can cause leukemia, blood disorder and damage to immune system (Miller & Spoolman, 2011).

The current NAAQS for benzene are in existence until December 2014. This means that the amount of ambient benzene concentration is expected to be halved by the beginning of 2015 (*Table 3.21*). For the purpose of this study, all hydrocarbons from ships exhaust gas emissions will be assumed to be benzene. This will allow comparison with the national ambient air quality standards set by the Department of Environmental Affairs.

Table 3.21: National Ambient Air Quality Standards for Benzene (RSA, 2009)

Averaging Period	Concentration	Frequency of Exceedence	Compliance Date
1 year	10µg/m³ (3.2 ppb)	0	Immediate – 31 December 2014
1 year	5µg/m³ (1.6 ppb)	0	1 January 2015
The reference method for the sampling and analysis of benzene shall either be EPA compedium method TO-14 A or method TO-17			

3.5.5 Carbon Dioxide (CO_2)

CO_2 is a greenhouse gas that occurs naturally as part of the earth's carbon cycle (natural circulation of carbon between plants, animals, atmosphere, oceans and soil). Other GHGs include water vapour (H_2O), CH_4, N_2O, and other fluorinated gases from industrial processes. The major impact of GHGs is climate change as they become concentrated in the atmosphere and slow the escape of outgoing terrestrial (heat) radiation. They are transparent to the Sun's short-wave ultra violet radiation but limit the long-wave infra-red radiation from the earth's surface from penetrating through into space. CO_2 does not have health impacts but impacts on climate change.

There is widespread agreement amongst scientists that humans have recently caused disturbance to the earth's natural carbon cycle by increasing CO_2 in the atmosphere and thereby affecting the natural sinks such as forests, which remove CO_2 from the atmosphere. Humans lead to emissions of CO_2 through the process of combustion of fossil fuels such as coal, natural gas and oil for energy generation and transportation (USEPA, 2013). The increase in the concentration of GHGs in the atmosphere has led to rapid global warming. Consequences of global warming amongst others would be hotter summers, long droughts, and reduction of water resources (Starcrest, 2011).

The Department of Environmental Affairs has recently released a Government Gazette dated 14 March 2014 declaring greenhouse gases as priority pollutants. This document states that all emitters of greenhouse gases in excess of 0.1 Megatonnes annually or measured as $CO_{2\text{-eq}}$ (CO_2 equivalent) are required to submit a pollution prevention plan (RSA, 2014).

3.6 SUMMARY

The port inventories are traditionally less accurate than other sectors because of limited data and methodologies to conduct port inventories (USEPA, 2004). There are not many ports in the world that have been inventoried for marine mobile sources, particularly using the detailed approach which requires many resources and more time. This scarcity of port inventories around the globe makes it difficult to find results of emissions to compare with the study of Durban Port. Some of the ports that have conducted similar studies, have huge discrepancies of scale in comparison to the Durban Port study area. For instance, The Port of Los Angeles (POLA), which is one of the few ports in the world where such a study was conducted, covered the study area of 4,025.6 square nautical miles around the port. This area is 272 times larger than the Durban Port study area of 14.8 square nautical miles.

Although limited data and other resources were available to conduct the detailed marine mobile inventory for Durban Port, however, they were not enough to cover the area size covered by the POLA study. This is particularly true because the Durban Port VTS station only records the arrival and departure times when the vessel crosses the breakwater or when the pilot is on-board on arrival. There is no record of vessels at anchorage or transiting within 24 nautical miles from the port or from the coastline as was the case in POLA. Nevertheless, due to fewer known ports globally that possess detailed published port inventory results, the POLA study was used for comparison with the Durban Port study by making use of area versus emission ratios between the two ports.

The types of ships operating within the Port of Copenhagen are not particularly similar to ships in Durban Port. There is high concentration of ferries, passenger ships and tankers in Copenhagen than in Durban whereas Durban experiences more container ships visits than other types of vessels. Nevertheless, the prominence of choosing the Port of Copenhagen was its value in modelling the ambient concentration of pollutants from ships emissions. The JN Port in Mumbai was the most compatible of the three to the Durban Port with regards to size and types of ships normally visiting the port.

4. THE RESEARCH DESIGN AND METHODOLOGY

This chapter provides an overview of the research approach, data collected, and how this data was used to address the research objectives. A case study approach was chosen to satisfy the objectives of this study with the use of secondary data analysis as discussed below.

4.1 RESEARCH DESIGN

Hofstee (2006) highlights the importance of choosing the correct research design to meet the study objectives and to arrive at a reliable and well supported conclusion. It is important that the design aligns with the methodology to produce sound results. This research will follow the case study approach supported by secondary data analysis.

4.1.1 Case Studies

According to Hofstee (2006), using a case study to conduct research requires that the researcher focuses on a single object, area or organization in a tightly structured way. This facilitates the identification of principles that can be extrapolated and applied to other similar cases. However, it is important to use more than one case study to ensure that one does not extrapolate from anomalies. This technique is useful when a detailed knowledge of a particular case is required. Mouton (2001) argues that the important strength of case study research is that the researcher develops a good understanding of the subject matter and the study area. Therefore, broader understanding of the Port and its activities will yield better results from the analysis and interpretation of data and will increase the knowledge base on Port emissions.

The limitation of this design is that generalization of results can be difficult in different areas (Mouton, 2001). The results obtained in the study of Durban Port may not necessarily apply to other areas around the country because of the uniqueness of the area in terms of size, traffic density, port activities and other activities in the vicinity of the Port.

The case study research technique was applied in the study of Durban Port to establish precedence for other ports in South Africa. Durban Port is ideally suited for this purpose as it is the busiest port in the country in terms of ship traffic density, the amount of cargo handled, the proximity of heavy industrial activities to the Port, and its proximity to the city centre and residential urban clusters.

4.1.2 Secondary Data Analysis

Secondary data analysis makes use of data that are collected by other researchers, government agencies and research institutions for further work and purposes since such data may have a broad range of uses and significance (Hofstee, 2006). Mouton (2001) describes use of secondary data from various sources to test or validate hypotheses. The importance of this data depends on whether it is appropriate for the envisaged study (Hofstee, 2006). The availability of secondary data was critical to meet the objectives of this study.

Three categories of secondary data were obtained from Transnet National Port Authority (TNPA) and Lloyd's Register of Ships. The first category of data came from the vessel traffic service (VTS) station of TNPA, which maintains daily record of all ocean going vessels (OGVs) that visit the Port throughout the year. This data includes the name of the ship, the time of arrival and departure, reason for visit and the name of the berth where the vessel was docked. According to Justin Adams (pers. comm., 2013), the VTS Manager in Durban Port, the Port uses this data for various purposes including the control and monitoring of shipping traffic and for future improvement and development plans for the Port. The second category of data comes from the Lloyd's Register of Ships, which is the sole originating authority for ships' IMO numbers and company numbers. Lloyd's has been continuously producing such data since 1764 and holds the largest maritime database in the world. This data is made available to any interested party at a specific cost. The data includes ship's name, size, year built, flag state and engine capacities (USEPA, 2009). The third category of data was provided by the engineering division of TNPA. This department maintains operational records of harbour crafts used for port services and includes the names of harbour crafts in operation, the types of vessels, the characteristics of machinery fitted and the monthly engine hours of operation. According to Peter Phillips, the Marine Technical Manager of TNPA in Durban Port (pers. comm., 2013), this data is used for operational and maintenance planning.

One important consideration regarding secondary data is the degree of its reliability. The VTS information on traffic density is easily verifiable through the monthly journal called *Ports and Ships*, which maintain records of all ships that were in South African ports on any given day (Hutson, 2012). Lloyd's register, as the sole assigning authority for IMO numbers for all merchant ships, is expected to have the most reliable dataset on OGVs. Both sources are therefore considered the most reliable sources of the data concerned.

According to Mouton (2001), secondary data analysis is time saving and less costly because it uses existing data. The data from the VTS station was available on request and was easy to manipulate and analyse due to its well organized format. However, data from the Lloyd's Register was costly and not user-friendly and data on each ship was extracted individually. Nevertheless the process was necessary because the collection of technical data from each ship visiting would have taken significantly longer.

The limitation of using secondary data in research is that data might not be sufficient to address all research objectives. For instance, not all technical data of ships studied were available in the Lloyd's Register of ships. Some of the ships searched in Lloyd's database had no information on auxiliary engines. In such cases assumptions, interpolation and averaging became necessary to complete the study. For instance, in April 2012 ninety eight container ships called into Durban Port. However, only seventy seven had data available on the Lloyd's Register and no technical data was found about the remaining twenty one vessels. Interpolation was therefore performed to obtain average maximum continuous ratings of main and auxiliary engines, engine RPMs, average speed and average gross tonnage from the known data and those average values were allocated to the twenty one vessels without data so as to estimate their emissions (refer to digital dataset provided as CD1).

4.2 METHODOLOGY

In line with the research design chosen for this study, the methodology must provide sufficient data of suitable quality and resolution, and the data must articulate with specific research questions and study objectives (Hofstee, 2006). In the study of Durban Port, vessels were grouped according to their types and the characteristic data for each vessel type were tabulated in a spreadsheet. This data included vessel name, IMO number, year built, gross tonnage, maximum speed, engine RPMs, maximum continuous rating of engines, arrival and departure times in port, and number of engines per vessel. The use of spreadsheet simplified the calculations of emissions using formulae for each of the three engine types, namely main propulsion engine, auxiliary engine and the boilers (refer to digital dataset provided as CD1). The emission results were systematically inserted in tables for analysis and interpretation. Graphs were then used for improved visual presentation. Emissions from OGVs were separated from the harbour crafts for comparison of results.

4.2.1 Ocean Going Vessels

Data Acquisition

The data on OGVs were collected from two sources: the TNPA and Lloyd's Register of Ships. The first dataset is the record of ships movement in Port from the 1st of April 2012 till 31st of March 2013. This data was compiled by the vessel traffic service (VTS) of TNPA and included the names of ships, the times of arrival and departure from the Port, the berthing place and the reason for visit (refer to digital dataset provided as CD1). Arrival time is the time that the vessel passes the breakwater on entering the Port and departure time is the time when the vessel passes the same breakwater on departure from the Port. The VTS refers to the total duration from entry till departure as the '*turnaround time*'. The *turnaround time* can therefore be taken as the total time spent by the vessel inside the port limits, which is inshore of breakwater. It is assumed to be the time during which the ship will emit its pollutants while in Port.

The second dataset comprised characteristic data of vessels that visited the Port during the study period. These data included names and types of ships, gross tonnages, capacity of the main engines and auxiliary engines in kilowatts (kW), the speed of main engines in revolutions per minute (RPM) and the type of fuel used. Vessel characteristic data were sourced from the Lloyd's Register of Ships. USEPA (2009) maintains that the ships' characteristic data is indispensable for a detailed emission inventory. Without this data, the reliability of results becomes questionable.

Data Collation

The information from TNPA and Lloyd's Register was collated and categorized for analysis. Vessels were divided into seven different types and were categorized as follows:

- Container Vessels
- Bulk Carriers
- Tankers (*Oil, Chemical, LPG and Product Tankers*)
- General Cargo vessels
- Vehicle Carriers
- Other (*fishing vessels, stern trawlers, dredgers, supply ships, yachts, survey ships, support ships, tugs , Ro-Ro, navy ships and passenger ships*)
- Unknown (*all ships for which characteristic data was not available and the types unknown*). Emissions from this category were not calculated but did not comprise a significant proportion of total shipping (<5%).

Data from both TNPA and Lloyd's Register were consolidated in one table (refer to digital dataset provided as CD1). Any data missing from the Lloyd's dataset were interpolated from the known parameters, particularly the maximum continuous ratings (kW) of auxiliary engines.

Average Calculations

The average values per ship type included gross tonnage (tonnes), the year built, maximum speed of vessels (knots), maximum revolutions per minute (RPM) for the main engines, maximum continuous rating (MCR) in kilowatts (kW) for main engines and auxiliary engines. The average values were obtained by adding the figures from known vessels and dividing by the number of known vessels in that category. The calculated average values were then assigned to ships of the same category whose data was unavailable (*Table 4.*1).

Certain criteria were used to identify ships whose category was unknown. From the VTS list, certain types of ships can be identified by virtue of their berthing place or by their reason for visit. Some information was obtained from other sources such as Bureau Veritas (BV), which is another classification society similar to Lloyd's Register. BV maintains a database of all ships under their register. Ships that could not be identified using these methods and sources were then classified as *unknown*. Less than 5% of OGVs were classified as unknown and no emissions were estimated from this category.

Table 4.1: Annual average values from all ship types in Durban Port between 1st of April 2012 and 31st of March 2013.

Type of OGV	Total No: of ships	Percentage distribution for ships	Total Gross Tonnage (T)	Average Year Built	Average Gross Tonnage (T)	Average Speed (kts)	Average RPM ME	Average MCR (kW) ME	Average MCR (kW) AE
Container ships	1,133	26.7%	39,246,521	2003	39,944	22.4	125	31,094	1,721
Bulk Carriers	765	18.1%	21,377,851	2005	28,158	15.2	126	8,091	549
Tankers	645	15.2%	12,382,423	2005	21,677	14.8	231	7,903	738
General Cargo	641	15.1%	7,421,258	1997	13,278	15.2	234	6,698	590
Vehicle Carriers	345	8.1%	17,651,572	2005	55,071	20.9	107	13,876	1,090
Others	508	12.0%	3,875,159	1990	8,887	15.3	657	6,529	552
Unknown	201	4.7%							
TOTAL	**4,238**	**100%**	**101,954,784**						

Emission Calculations

Engine emissions depend on four factors. These include the *maximum power output of the engine*, the *load factor*, the *emission factor* and the *time* spent on certain activity (also known as the mode of operation). The product of these four factors will give the emissions for a particular type of pollutant. The use of energy-based emission factors is considered the most appropriate method for calculating emissions (USEPA, 2009). The following formula approved by the International Panel on Climate Change (IPCC) was adopted and used to calculate the total emission of specific pollutants from each engine during a specific activity:

$$E = P \times LF \times EF \times T$$

Where: E = *emissions for a given pollutant (grams)*
P = *maximum power output of engine (kW) also known as maximum continuous rating (MCR)*
LF = *load factor for an engine, as a fraction of maximum installed power capacity, dimensionless (expressed as percentage of engine's maximum power)*
EF = *emission factor (pollutant specific) in mass emitted per work output of the engine in different operation modes (g/kWh)*
T = *time for each activity in hours*

The total emission from each engine for each type of pollutant during the ship's entire stay in the port was then given as a sum of emission from each activity and was calculated using the formula:

$$E_T = \sum_{j=1}^{n} E_j$$

Where: E_T = *total emission from one engine per visit (grams)*
E_j = *amount of emission from one engine per activity (grams)*
j = *activity number (e.g. first activity: j=1)*
n = *number of activities (1 to n).* (Joseph *et al.*, 2009)

All the calculations were conducted in Microsoft Excel for ease of data manipulation, analysis and presentation. The resulting emission estimates from the spreadsheets, which are in grams (refer to digital dataset provided as CD1), were then converted to tonnes for tables and graphs.

The four factors in the formula are dependent on characteristics, namely the ship's port activities and the type of engines. These four factors are discussed individually below.

Power Output

The USEPA (2009) classifies marine engines into three categories based on the maximum continuous rating (MCR) also known as maximum power output in kilowatts (*Table 4.2*). A Category 1 engine generally is used as a propulsion engine in small vessels such as harbour craft and fishing vessels. Category 2 engines are generally used for propulsion in tugboats or auxiliary engines in large ocean going vessels. Category 3 engines are used for propulsion in large OGVs (USEPA, 2009).

Table 4.2: Marine Engine Categories based on Power Rating (USEPA, 2009)

Category	**Displacement per Cylinder**	**Use**	**Approximate Power Ratings**
1	Displacement < 5 liters (and power ≥ 37 kW)	Small harbour crafts and recreational propulsion	< 1,000 kW
2	5 liters ≤ Displacement < 30 liters	OGV auxiliary engines, harbour crafts and smaller OGV propulsion	1,000 – 3,000 kW
3	Displacement ≥ 30 liters	OGV propulsion	> 3,000 kW

The USEPA (2009) also categorizes marine engines according to engine speed in revolutions per minute (*Table 4.3*). There are five main categories of engines in marine operations, namely slow speed diesel (SSD), medium speed diesel (MSD); high speed diesel (HSD), gas turbine (GT) and steam turbine (ST). These engines use one or more of the following three types of fuel: marine diesel oil (MDO); marine gas oil (MGO) and residual oil (RO). These fuel types differ primarily by their viscosity, ranging from more volatile marine distillate to heavier RO. The distillates are further classified into MDO and MGO. MGO is light and clean and contains no residual fuel oil while MDO is heavier and may contain some residual fuel oil (Cooper & Gustafsson, 2004).

The RPM data from ships that visited Durban Port during the study period were obtained from Lloyd's Register of Ships and categorized as slow, medium or high speed engines (*Table 4.3*) and were then allocated corresponding emission factors. The emission factors together with the maximum power ratings in kilowatts were then used to calculate the total emissions from each engine (refer to digital dataset provided as CD1).

Table 4.3: Marine Engine Speed Categories (USEPA, 2009)

Speed Category	Engine RPM	Engine Stroke Type
Slow	< 130 RPM	2
Medium	130 – 1,400 RPM	4
High	> 1,400 RPM	4

For a detailed inventory, it is important to obtain information on engine speeds and fuel types. Entec (2002) profiled the global fleet of ships that use certain categories of engines and provided a percentage breakdown per ship type (*Table 4.4.*). For the study of Durban Port, the average RPM values were calculated by adding the RPMs of known vessels in that category and dividing by the number of vessels. The subsequent values were then allocated to ships in that category where engine speed data was not available (*Table 4.5*).

Table 4.4: Percentage breakdown of engines used by certain types of ships profiled by Entec (2002)

	Chemical Tanker	Dry Bulk	General Cargo	Passenger	Container	Car Carrier		Chemical Tanker	Dry Bulk	General Cargo	Passenger	Container	Car Carrier
	MAIN ENGINE							**AUXILIARY ENGINE**					
SSD/MGO				0.06%									
SSD/MDO													
SSD/RO	67.21%	97.10%	59.53%	2.04%	92.11%	45.66%							
MSD/MGO			0.67%							0.20%	0.40%		
MSD/MDO													
MSD/RO	30.97%	2.29%	37.74%	87.15%	5.83%	49.70%		58%	58%	57.80%	57.60%	58%	58%
HSD/MGO			0.23%							0.10%	0.30%		
HSD/MDO													
HSD/RO		0.06%	1.42%	3.79%		1.68%		42%	42%	41.90%	41.70%	42%	42%
GT/MGO				0.60%									
GT/MDO													
GT/RO				0.30%									
ST/MGO													
ST/MDO													
ST/RO	1.82%	0.55%	0.41%	6.06%	2.06%	2.96%							
TOTAL	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*		*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

Table 4.5: Average speeds and power outputs of engines used to categorize types of engines in Durban Port

	MAIN ENGINE				AUXILIARY ENGINE	
Type of OGV	**Average Speed (kts)**	**Average RPM**	**Average MCR (kW)**	**Engine Type**	**Average MCR (kW)**	**Engine Type**
Container ships	22.4	125	31,094	SSD	1,721	MSD
Bulk Carriers	15.2	126	8,091	SSD	549	MSD
Tankers	14.8	231	7,903	MSD	738	MSD
General Cargo	15.2	234	6,698	MSD	590	MSD
Vehicle Carriers	20.9	107	13,876	SSD	1,090	MSD
Others	15.3	657	6,529	MSD	552	MSD

Time Factor

The activities of a ship within the port during each call can be divided into categories that describe their emission characteristics. A call in Durban Port involves three modes of operation and they are termed *manoeuvring, hotelling* and *loading/unloading*.

Each mode is associated with a particular engine speed and in turn with an engine load that has specific emission characteristics (USEPA, 2009). The emissions from each ship in port are determined by the time spent in one or a combination of these three activities using the time-in-mode calculation (Saxe and Larsen, 2004). The ship will have different fuel consumption rates in different modes and thus emissions will differ. A detailed inventory can be created by calculating emissions for each activity using the ship type, actual speed, engine power, load factor, emission factor and time in mode for propulsion and auxiliary engines and boilers (USEPA, 2009). If these parameters are weighted by time in mode, they produce the highest level of detailed inventory in contrast to the weighting by call method. The load factors and the emission factors are the function of engine speed, which depends on the mode of operation. Therefore the amount of time spent in each mode will determine the amount of emissions.

The VTS station records the total time spent by each vessel in the port and this is called the *turnaround* time. The time allocation for each activity in the port is a fraction of the *turnaround* time. According to the marine pilot in Durban Port, Aubrey Baloyi (pers. comm., 2013), different vessels will take variable amounts of time to come alongside from the pilot station depending on the type of vessel and the berthing place. The pilot station is the point where the marine pilot will embark and take charge of the vessel to direct it to its berthing place. In Durban Port, this point is situated about four nautical miles north-east of the breakwater. Ships transiting from the pilot station to the breakwater will proceed at various speeds (*Table 4.6*). The fastest ships such as container, general cargo, reefer, car carrier and passenger liners will proceed at 12 knots from the pilot station and then reduce speed to seven knots before crossing the breakwater. Slower ships such as bulk carriers and tankers will proceed at 10 knots and then reduce to five knots before crossing the breakwater. All ships within the port basin must proceed at not more than the official speed of seven knots when inside the port.

Table 4.6: Speed for transiting and manoeuvring within Durban port per ship type

Type of vessel	Transit Speed (Knots)	Manoeuvring Speed Inbound (Knots)	Manoeuvring Speed Inbound (Knots)
Container Vessel	12	7	8
Bulk Carrier	10	5	8
Tanker	10	5	8
General Cargo	12	7	8
Car Carrier	12	7	8
Reefer	12	7	8
Passenger Liner	12	7	8
Other	12	7	8

The passage from the pilot station to the breakwater can be referred to as *transit mode*. The movement between the breakwater and the berth is referred to as *manoeuvring*. The vessels take longer to manoeuvre when they are inbound from breakwater to the berthing place than when outbound due to the strict rules regarding the official speed of seven knots within the port for inbound vessels. However, for outbound vessels, the rules are slightly relaxed when reaching the open basin because the vessel must attain enough speed to counter the effects of tide and current when crossing the breakwater. Therefore, most vessels start increasing speed to about eight knots or more whilst still inside the port when outbound. This factor causes the manoeuvring time during departure to be less than the arrival time (*Table 4.7*).

It must also be noted that vessels such as bulk carriers, tankers and general cargo ships are recorded with variable times for manoeuvring in and out of the port (*Table 4.7*). This depends on whether the vessel is berthing on the starboard side or the port side onto the quay. When these ships proceed to berth in Maydon Wharf and lay port side onto the quay, an extra turning manoeuvre becomes necessary which results in more time being taken to berth the ship. It is not easy to know whether the ship was berthed onto the starboard or the port side and therefore the maximum time for berthing was used in all calculations during this study as this was the environmentally conservative approach.

Table 4.7: Time for transiting and manoeuvring within Durban Port to various berths per ship type

Type of vessel	Transit time	Berth	Manoeuvring time (Inbound)	Manoeuvring time (Outbound)
Container Vessel	20 minutes		45 minutes	30 minutes
Bulk Carrier	24 minutes	Pilot Station to Maydon Wharf		
		Berthing Starboard side	1hr 30min	1hr 15min
		Berthing Port side	2 hrs	1hr 45min
		Outer Berth/Breakwater (Coal/Iron Ore/Chrome)	1hr	45 minutes
Tanker	24 minutes	With turning manoeuvre	1hr 30min	1hr 15min
		Without turning manoeuvre	1 hr	45 minutes
General Cargo	20 minutes	Pilot Station to Maydon Wharf		
		Berthing Starboard side	1hr 30min	1hr 15min
		Berthing Port side	2 hrs	1hr 45 min
Car Carrier	20 minutes		45 minutes	30 minutes
Reefer	20 minutes		1hr	45 minutes
Passenger Liner	20 minutes		45 minutes	30 minutes
Other	20 minutes		45 minutes	30 minutes

The VTS Station records the time when the vessel crosses the breakwater inbound and outbound as the time of arrival and departure respectively. Therefore, for the purpose of this study, this is the time the vessel is considered to commence its port emissions on arrival and the time the vessel will end its emission on departure from the port. These times were included in the spreadsheet for all vessels that called in Durban Port over the study period (refer to digital dataset provided as CD1).

For the hotelling activity, the total time spent in this mode will be the turnaround time minus the manoeuvring time, provided that the ship did not use its own equipment to load and unload its cargo. The loading/unloading activity is valid only if the ship used its own equipment such as cranes and pumps to convey cargo to and from the quay. Justin Adams (pers. comm., 2013) stated that in Durban Port, all ships use port facilities to load and unload cargo except for all general cargo ships that comes into the port and the container ships that are berthing at Point B, C, D, E and F. Therefore all general cargo ships and all container ships that are berthed in Point B, C, D, E and F are allocated a zero time for hotelling and are allocated turnaround time minus manoeuvring time for loading/unloading activity. All other ships are allocated zero time for loading/unloading activity and turnaround time minus manoeuvring time for hotelling (refer to digital dataset provided as CD1).

Load Factors

Ships use different engine speeds during various activities or modes of operations. When the ship is docked in the port, its main engines are shut off and auxiliary engines are used for hotelling. In any case the load factor will be a fraction of the maximum capacity of the engine and is expressed as a percentage. This means that when the ship is alongside, the load factor for the main engines is zero because no equipment is drawing power from the main engines in this mode. However, the auxiliary engines will have a certain percentage of load factor from hotelling services such as lighting, air-conditioning, refrigeration and other smaller equipment.

Auxiliary engines will experience an increase in load factor during loading and unloading as heavy equipment such as pumps and cranes will draw more power from these engines. The emissions from the auxiliary engines are determined by amount of power being drawn from engine by equipment rather than the speed of the engine since auxiliary engines are governed to operate at same speed in different loads. This means that higher loads are compensated by higher fuel consumptions, which results in more emission at same speed. Durban Port does not supply shore electrical power to ships alongside and hence it is expected that ships will always rely on their auxiliary engines for hotelling services. Therefore auxiliary engines will be operational for the entire duration of the ship in Port and for the reasons mentioned earlier, all container ships docked at Point B, C, D, E and F and all general cargo vessels in the port will have higher load factors on auxiliary engines from loading and unloading (*Table 4.8*).

When the ship is manoeuvring in port the load factor from auxiliary engines will be higher due to more equipment drawing from the engines when the ship is underway. The main engines are also running during this mode and propulsion power is being consumed from them. Therefore the load factor for main engines will also increase from zero to some value. It is therefore critical to determine the load factors for each mode to estimate the emissions from each engine.

However, engine load assumptions come with high uncertainties that can have a significant influence on the calculated emissions (Entec, 2002). For instance, it is not correct to assume that every vessel docked at Point B, C, D, E, or F is loading throughout the entire period whilst alongside. Also, some ships may be operating their main engine at idle speed while alongside as opposed to shutting them down as expected. A tanker may have the main engine running at 20% load and auxiliary engines at loads > 40% whilst alongside. These values may fluctuate from ship to ship. Therefore, assumptions are necessary to bring the results to a reasonable approximation within the constraints of the study (Entec, 2002).

The load factor is the percentage of the ship's total main or auxiliary engine power. According to USEPA (2009) the load factor for the main engine at cruise speed is 83%. However at lower speeds, the propeller law should be used to estimate the ship's propulsion load which is based on the theory that propulsion power varies by the cube of speed ratio. The formula below indicates this relationship:

$$LF = \left(\frac{AS}{MS}\right)^3$$

Where LF = Load Factor (%)

AS = Actual Speed (knots)

MS = Maximum Speed (knots)

USEPA (2009) advises that the propulsion load factors should be calculated using this propeller law for every call, however load factors below 2% should be set at 2% as a minimum.

The auxiliary engine load factors will differ slightly from main engines because they vary by ship type and time-in-mode. Auxiliary engines are running all the time in all modes of operation. The largest load is during the manoeuvring mode as indicated in *Table 3.8*. An extra auxiliary engine may even be started in case it is required in an emergency. USEPA (2009) assigned a higher load factor for loading/unloading than for hotelling mode because heavy equipment is operated during this mode, especially when cold ironing is non-existent i.e. no shore electrical power supply and the ship depends on its own auxiliary engines for loading and for hotelling services. Therefore it is necessary to determine the auxiliary engine load factors for individual port based on the type of berth, the port infrastructure i.e. port facilities such as shore supply and shore gantries, as well as type of ship. This method is recommended for a detailed inventory of port pollutions (USEPA, 2009). However, from the data available, it was not possible to determine the load of each ship that called into Durban Port during the study period. Therefore, the values for mid-tier approach were used during the study of Durban Port (*Table 4.8*). These values were developed by Starcrest after conducting interviews with ship Captains, chief engineers, and harbour pilots during the vessel boarding programs (USEPA, 2009).

Table 4.8: Auxiliary Engine Load Factor assumptions derived from USEPA (2009)

Ship Type	Manoeuvring	Hotelling	Loading/Unloading (Berth B, C, D, E and F)
Auto Carrier	0.45	0.26	-
Bulk Carrier	0.45	0.10	-
Container ship	0.48	0.19	0.30
Cruise ship	0.80	0.64	-
General Cargo	0.45	0.22	0.30
Miscellaneous	0.45	0.22	-
OG Tug	0.45	0.22	-
RoRo	0.45	0.26	-
Reefer	0.67	0.32	-
Tanker	0.33	0.26	-

Emission Factors

The Emission factors are variables that convert the activity data into emission values (DEAT, 2009). The emission factor reflects the emissions that an engine produces when operating at a certain capacity over a period of one hour. One important influence on emissions is the type of fuel used and this should be determined for each type of engine. Most OGVs operate their main propulsion engines on RO. However, modern ships may have at least two tanks and a reserve one for either MDO or MGO. The MDO and MGO are clean and more refined fuel types and are mostly used for auxiliary engines and for propulsion in Emission Control Areas (ECA) and when navigating close inshore.

Each of the three port activities described above, correspond to modes of operation of the main engine and the auxiliary engine, which in turn correspond to emissions produced by each engine. Main engines are primarily used for propulsion when the ship is manoeuvring in port, whilst the auxiliary engines are used solely for electric power generation. The ship will therefore use only auxiliary engines when docked alongside or during loading and unloading operation and will use both the main engines and the auxiliary engines when manoeuvring in port. However, the power rating of auxiliary engines during manoeuvring will differ from when the vessel is docked alongside or when it is loading and unloading. Similarly the emission factors will be different during the three modes of operation.

USEPA (2009) acknowledges the scarcity of data on emission factors and the expenses in obtaining them. To obtain accurate emission data, tests must be conducted for each type of engine and fuel. A number of engines must be tested per type and the tests repeated in order to obtain unbiased results. This emission testing has proven to be a very costly and difficult undertaking for OGVs and thus not many tests have been undertaken. One of the recent analyses of emission data from OGVs was made by Entec in 2002. The Entec's analyses were based on tests conducted by Lloyd's Register Engineering Service in 1995 and IVL Swedish Environmental Research Institute in 2002. These tests included emission data from 142 propulsion engines where all five types of marine engines (SSD, MSD, HSD, ST and GT) and three types of fuel oils (RO, MDO and MGO) were tested. The emission factors derived from the Entec analysis (2002) are generally accepted as the most current (*Tables 4.9* and *4.10*).

According to Entec (2002), the main factor influencing ship emissions is the type of engine installed and the type of fuel used irrespective of the category and the type of vessel. After carefully examining data for different sizes of the same type of engines, Entec discovered that the size of the engine had limited effect on emissions. The emission factors were consequently derived based on engine type and fuel type and valid for all engine sizes (Entec, 2002).

Table 4.9: Marine Emission Factors and specific fuel consumption (SFC) of different types of Main Engines "in port" and "manoeuvring" derived from Entec (2002)

	NO_X	SO_2	CO_2	HC	PM	SFC
	g/kWh					
SSD/MGO	13.6	1.0	647	1.8	0.9	204
SSD/MDO	13.6	4.1	647	1.8	0.9	204
SSD/RO	14.5	11.6	682	1.8	2.4	215
MSD/MGO	10.6	1.1	710	1.5	0.9	223
MSD/MDO	10.6	4.5	710	1.5	0.9	223
MSD/RO	11.2	12.7	745	1.5	2.4	234
HSD/MGO	9.6	1.1	710	0.6	0.9	223
HSD/MDO	9.6	4.5	710	0.6	0.9	223
HSD/RO	10.2	12.7	745	0.6	2.4	234
GT/MGO	2.9	1.6	1,014	0.5	0.5	319
GT/MDO	2.9	6.4	1,014	0.5	0.5	319
GT/RO	3.1	18.1	1,067	0.5	1.5	336
ST/MGO	1.6	1.6	1,014	0.3	0.9	319
ST/MDO	1.6	6.4	1,014	0.3	0.9	319
ST/RO	1.7	18.1	1,067	0.3	2.4	336

Table 4.10: Marine Emission Factors and specific fuel consumption (SFC) of different types of Auxiliary Engines (all three activities) derived from Entec (2002)

	NO_X	SO_2	CO_2	HC	PM	SFC
	g/kWh					
MSD/MGO	13.9	1.1	690	0.4	0.3	217
MSD/MDO	13.9	4.3	690	0.4	0.3	217
MSD/RO	14.7	12.3	722	0.4	0.8	227
HSD/MGO	10.9	1.1	690	0.4	0.3	217
HSD/MDO	10.9	4.3	690	0.4	0.3	217
HSD/RO	11.6	12.3	722	0.4	0.8	227

USEPA (2009) reevaluated the values obtained from the 2002 Entec analysis and advised that some adjustment factors could be used for NO_X emission factors, which may be necessary to account for Tier 1, Tier 2, and Tier 3 International Maritime Organization (IMO) standards. This reevaluation was based on the national inventory of ships stopping in the United States (US) ports in 2005. USEPA (2009) published the values and specified the adjustment required for NO_X emission factors as outlined in to meet Tier 1, 2 and 3 Standards (*Table 4.11* and *Table 4.12*). The emission factors for high speed diesel are missing from *Table 4.11*, which makes it difficult to analyse most auxiliary engines that run at speeds greater than 1400 RPM. In such cases, reverting to *Table 4.9* becomes necessary in order to complete the inventory.

For allocation of emission factors, accurate maximum continuous ratings of ships in Durban Port were extracted from the Lloyd's Register of Ship's website, the IHS Fairplay (IHS, 2013). The emission factors were then chosen based on study by Entec (2002) and from USEPA (2009) recommendations for emission inventories. The report by USEPA (2009) pointed out the most recent and best practices of port inventory preparation to encourage uniformity in inventory preparation. The report provides information for port authorities and government agencies to understand the inventories that are prepared by others for various purposes. It also highlights the most up-to-date load factors and emission factors for both propulsion and auxiliary engines from ships and the adjustment factors required for the calculation of NO_X (*Table 4.11, Table 4.12* and *Table 4.13*).

Table 4.11: Revised Marine Emission Factors and specific fuel consumption (SFC) of different types of Main Engines "in port" and "manoeuvring" derived from USEPA (2009)

Engine Type	Fuel Type	Sulphur percentage	NO_X	SO_X	CO_2	HC	PM_{10}	SFC
			Emission Factors (g/kWh)					
SSD	**RO**	2.7%	18.10	10.29	620.62	0.60	1.42	195
	MDO	1.0%	17.00	3.62	588.79	0.60	0.45	185
	MGO	0.5%	17.00	1.81	588.79	0.60	0.31	185
	MGO	0.1%	17.00	0.36	588.79	0.60	0.19	185
MSD	**RO**	2.7%	14.00	11.24	677.91	0.50	1.43	213
	MDO	1.0%	13.20	3.97	646.08	0.50	0.47	203
	MGO	0.5%	13.20	1.98	646.08	0.50	0.31	203
	MGO	0.1%	13.20	0.40	646.08	0.50	0.19	203
GT	**RO**	2.7%	6.10	16.10	970.71	0.10	1.47	305
	MDO	1.0%	5.70	5.67	922.97	0.10	0.58	290
	MGO	0.5%	5.70	2.83	922.97	0.10	0.35	290
	MGO	0.1%	5.70	0.57	922.97	0.10	0.17	290
ST	**RO**	2.7%	2.10	16.10	970.71	0.10	1.47	305
	MDO	1.0%	2.00	5.67	922.97	0.10	0.58	290
	MGO	0.5%	2.00	2.83	922.97	0.10	0.35	290
	MGO	0.1%	2.00	0.57	922.97	0.10	0.17	290

Table 4.12: ECA and Global Control NO_X adjustment factors from USEPA (2009)

Analysis Year	Global		ECA	
	Main	Auxiliary	Main	Auxiliary
2005	0.9024	0.9060	0.9024	0.9060
2010	0.8750	0.8767	0.8750	0.8767
2015	0.8020	0.8059	0.8020	0.8059
2020	0.7565	0.7478	0.5958	0.5842
2025	0.7319	0.7173	0.4278	0.4108
2030	0.7149	0.6955	0.3184	0.2989

Table 4.13: Revised Marine Emission Factors and specific fuel consumption (SFC) of different types of Auxiliary Engines in all modes of operation derived from USEPA (2009)

Fuel Type	Sulphur percentage	NO_X	SO_X	CO_2	HC	PM_{10}	SFC
		Emission Factors (g/kWh)					
RO	2.7%	14.7	11.92	722.54	0.40	1.44	227
MDO	1.0%	13.9	4.24	690.71	0.40	0.49	217
MGO	0.5%	13.9	2.12	690.71	0.40	0.32	217
MGO	0.1%	13.9	0.42	690.71	0.40	0.18	217

As the most recent values available, the above emission factors were used to calculate the total emissions in the study of Durban Port. However, certain assumptions had to be made to obtain realistic estimate for a South African Port since South Africa is not an ECA. Therefore the OGVs visiting the South African coastline are not obliged to change over from RO to marine diesel oil when entering this zone, although some may do so out of environmental responsibility concerns. Therefore, following the environmentally conservative approach, the below assumptions were made for the non-emission control area:

- All OGVs use RO for the main engines when visiting South African Ports.
- All OGVs use MDO for auxiliary engines during their visit in South African ports.
- All OGVs have boilers which stay operational throughout their stay in the port and that all boilers use MDO.

USEPA (2009) suggested an adjustment to all emission factors to compensate for the change from one Tier requirement to another, as specified by IMO. Since the study was conducted in 2012/2013, all emission factors adopted for NO_X calculations in *Table 4.11* were adjusted by *0.8750* and *0.8767* for main engines and auxiliary engines respectively (refer to *Table 4.12* for the required adjustment values). Emission factors for other pollutants (i.e. SO_X, CO_2, HC and PM_{10}) were extracted directly from the USEPA report (2009) and applied according to the type of engine and the type of fuel used (*Tables 4.14* to *Table 4.16*).

Table 4.14: Emission factors for Main Engines used for pollution estimates in Durban Port

Engine & Fuel Type	NO_X	SO_X	CO_2	HC	PM_{10}
	Emission Factors (g/kWh)				
SSD/RO	15.8375	10,29	620.62	0.60	1.42
MSD/RO	12.25	11.24	677.91	0.50	1.43
HSD/RO	8.925	12.7	745	0.60	2.4

Table 4.15: Emission factors for Auxiliary Engines used for pollution estimates in Durban Port

Engine & Fuel Type	NO_X	SO_X	CO_2	HC	PM_{10}
	Emission Factors (g/kWh)				
MSD/RO	12.1625	4.24	690.71	0.40	0.49

Table 4.16: Emission factors for Boilers used for pollution estimates in Durban Port

Engine & Fuel Type	NO_X	SO_X	CO_2	HC	PM_{10}
	Emission Factors (g/kWh)				
ST/MDO	1.75	5.67	922.97	0.10	0.58

Boiler Steam Turbine

All ships that use RO must have a boiler onboard to heat up the RO to reduce its viscosity and make it useable for diesel engines. These boilers are normally not used during cruising modes in open waters because main engine exhaust heat is sufficient to heat up the RO and water for domestic use. However in port, the fuel-fired boilers are required for cold start i.e.

when main engines were shut down and RO requires preheating prior to starting the main engines. Emissions result from this activity and these boilers often remain operational throughout the entire stay of the ship alongside in port. The fuel-fired boilers are also used during manoeuvring when the main engine exhaust flow temperature has fallen. Taken from USEPA (2009), the formula below was adopted to calculate the emissions from the fuel-fired boiler for ships in Durban Port.

$$Boiler\ emission\ (g) = BoilerEnergy\ (kW) \times ST\ EF\ (g/kWh) \times Time\ in\ mode\ (hrs)$$

Where: *ST EF = Steam Turbine Emission Factor*

The steam turbine propulsion emission factors (refer to *Table 4.11*) were used to calculate boiler emission in different modes and were multiplied by adjustment factors in *Table 4.12* to give the NOx emissions for the current year (*Table 4.16*). Data on boilers are limited on the IHS website and therefore the assumption was made that all OGVs have at least one boiler onboard, which uses RO. USEPA (2009) provided default figures of boiler energy output for certain types of vessels during certain activities or modes of operation (*Table 4.17*).

Table 4.17: Auxiliary Boiler Energy Defaults in kW (USEPA, 2009)

SHIP TYPE	MANOEUVRING	HOTELLING
Container	506	506
Dry Bulk	109	109
Tanker	346	346
General Cargo	106	106
Car Carrier	371	371
Reefer	464	464
Passenger	1,000	1,000
Other	464	464

4.2.2 Harbour crafts

USEPA (2009) defines harbour crafts as commercial and recreational vessels that spend majority of time within or near a port. Almost all harbour crafts use Category 1 or 2 engines (refer to *Table 4.2* for engine categories). The best practice in calculating emissions from harbour crafts is to obtain the count of vessels and determine the parameters of each vessel types operating in the area of study and then merge this with load factors and emission factors (USEPA, 2009). USEPA (2009) described certain types of harbour craft for inclusion into the marine mobile port inventory (*Table 4.18*).

Table 4.18: Types of harbour crafts (USEPA, 2009)

VESSEL TYPE	DESCRIPTION
Assist tugboats	Help OGVs manoeuvre in the harbour during arrival and departure and shifts from berth. Also provide "tugboat escort" for tankers. Vessels with a DWT of 20,000 tonnes or less use one tugboat, greater than 20,000 tonnes use two tugboats.
Towboats/pushboats/tugboats/Ferries and excursion vessels	Self-propelled vessels that tow or push barges within and outside of the port. Ferries transport people and property. Excursion boats provide harbour cruises and whale watching.
Crew boats	Carry personnel and supplies to and from off-shore and in-harbour locations.
Work boats	Include utility, inspection, survey, spill/response, research, mining, training, and construction.
Dredges and dredging support vessels	Perform or assist in performing dredging activities in the harbour.
Recreational vessels	Privately owned boats, including powerboats and sailboats.

USEPA (2009) outlines the type of information required for harbour craft inventory. This information, if available is normally obtained from the owners and operators of each craft and is as follows:

- Hours of operation
- Percentage of time in each mode
- Vessel characteristics
- Main engine parameters (number, type, age, fuel type and MCR in kilowatts)
- Auxiliary engine parameters (number, type, age, fuel type and MCR in kilowatts)
- Any modifications such as scrubbers or exhaust after treatment.

The best practice in detailed inventory is to obtain the average values for operating hours, number of main and auxiliary engines, engine power and engine age for each vessel (USEPA, 2009).

Only harbour crafts that belong to TNPA were considered for emission estimation in this study. This is because they were the only crafts with data available to conduct the study. All other harbour crafts are privately owned and it was difficult to obtain any data from individual owners. As a significant oversight, it is also not known how many of these privately owned harbor crafts were in the Port during the study period. TNPA provided the technical data and the activity profile of harbour crafts under their jurisdiction. This data included 19 harbour crafts belonging to the Durban Port Control (*Table 4.19*).

Table 4.19: TNPA Harbour crafts in Durban Port

	Official Number	NAME OF VESSEL	Gross Tonnage	Year Built	Type of Vessel	Speed (kts)	Type of ME	Speed of ME (RPM)	ME – Maximum Continuous Rating (kW)	AE – Maximum Continuous Rating (kW)
1	*351605*	NONOTI	295	1982	Tug	10	MAK 6M332	800	2,200	
2	*351606*	UMZUMBE	295	1982	Tug	10	MAK 6M332	800	2,200	
3	*351196*	UMVOTI	295	1982	Tug	10	MAK 6M332	800	2,200	135
4	*351197*	UMSUNDUZI	295.5	1982	Tug	10	MAK 6M332	800	2,200	135
5	*351199*	UMHLALI	315.41	1984	Tug	10	MAK 6M332	900	900	135
6	*351192*	INYALAZI	315.41	1984	Tug	10	MAK 6M332	900	900	135
7	*20202*	MKHUZE	377.78	2001	Tug	12.99	Ruston 6RK270 Mk2	1,000	3,800	135
8	*20203*	UTHUKELA	377.78	2001	Tug	12.99	Ruston 6RK270 Mk2	1,000	3,800	155
9	*21015*	PHOLELA	460.6	2008	Tug	13.32	MAN 7L27/38	1,000	4,700	155
10	*21017*	LOTHENI	460.6	2008	Tug	13.3	MAN 7L27/38	1,000	4,700	155
11	*29904*	ROYAL TERN	69.7	1999	Workboat	11	Cummins KTA 19M		1,044	155
12	*20929*	JOJOSI	128.1	2008	Pilot boat	15	Cummins KTA 19M		1,044	155
13	*20928*	LUFAFA	128.1	2008	Pilot boat	15	Cummins KTA 19M		1,044	155
14	*30302*	ISIPONONO	107.28	2002	Corporate boat		CAT		1,104	124
15	*351163*	INDLOVU	1,093	1976	Floating Crane		Deutz		4,500	155
16	*DTD193E*	STARLING	<25	1975	Launch		CAT 3306		135	
17	*DTD137E*	MOORHEN	<25	1975	Launch		CAT 3306		135	
18	*20638/DTD1171E*	UMCISHU	15.267	2006	Launch		CAT C12			
19	*20637/DTD1172E*	NQOYI	15.267	2006	Launch		CAT C12			

The marine services department of TNPA Durban maintains records of harbour crafts activities that include engine hours, fuel usage and maintenance schedules. This data is recorded on a monthly basis and the annual totals are then calculated for statistical control. The technical data for these crafts were also obtained from the marine services department and were used to calculate the emission estimates.

Load Factors

Although it is the best practice to collect load factors for each vessel operating within a specific port, it is not always possible in most applications. Therefore, USEPA (2009) ruled that in cases where collecting information is not practical, it is reasonable to use the default load factors for harbour crafts as an alternative (*Table 4.20*).

Table 4.20: Harbour craft load factors (USEPA, 2009)

Vessel Type	**Load Factor**
Assist Tugboat	31%
Dredge Tenders	69%
Recreational	21%
Recreational, Auxiliary	32%
Crew Boat	45%
Excursion	42%
Ferry	42%
Government	51%
Ocean Tug	68%
Tugboat	31%
Work Boat	43%
Other Categories	43%
Other Auxiliaries	43%

The load factors used in the study of Durban Port are based on the types of harbour crafts described by USEPA (2009). In the study of Durban Port, three types of harbour crafts were identified to be operated by TNPA and they are tugboats, workboats and excursions. Therefore, only three load factors were allocated for harbour crafts emission estimates (refer to digital dataset provided as CD1).

Emission Factors

Like other non-road engines, the marine engines are allocated the emission Tier structure. All engines built before 2009 fall under Tier 0, Tier 1 and Tier 2. These engines are pre-control engines with Tier 0 as the baseline. Tier 1 includes the initial changes required by the year 2000, which dictates standards for NO_X only. Tier 2 is the second round of standards for NO_X, HC and PM commencing between 2004 and 2007, depending on engine displacement. Two more Tiers were developed and they were termed Tier 3 and Tier 4 for new Category 1 and 2 diesel propulsion engines of more than 50 and 800 horse-power respectively for harbour crafts. Tier 3 commenced in 2009 and applies to all vessels built since the beginning of 2009. Tier 4 standards had been scheduled to commence in 2014 and are based on catalytic exhaust after-treatment technology (USEPA, 2009). However, both Tier 3 and 4 have no bearing on the study of Durban Port because all harbour crafts in question were built prior to 2009 (refer to *Table 4.19*) and the study is based on activities that took place before 2014.

In most cases, the engine power is not known and other characteristics must be considered. In such cases the emission factors recommended by Entec and USEPA (2009) for the Port of Puget Sound can be used (*Table 4.21*). These emission factors are adaptable for any other port where information is lacking, which was the case with Durban Port.

Five of the nineteen harbour crafts use Category 3 propulsion engines (refer to *Table 4.2* for engine categories). These crafts were therefore allocated the highest emission factor for NO_X and PM_{10}, which falls under Category 2 engines (*Table 4.21*). The auxiliary engines for all harbour crafts have less than 1,000 kW power output and therefore fall under Category 1 and thus were all allocated the emission factors (*Table 4.21*).

Table 4.21: Harbour craft emission factors (USEPA, 2009) used for pollution estimates in Durban Port

Minimum Power (kW)	NO_x (g/kWh)	PM_{10} (g/kWh)	SO_2 (g/kWh)	CO_2 (g/kWh)	CH_4 (g/kWh)
Tier 0 Engines					
37	11	0.9	1.3	690	0.09
75	10	0.4	1.3	690	0.09
130	10	0.4	1.3	690	0.09
225	10	0.3	1.3	690	0.09
450	10	0.3	1.3	690	0.09
560	10	0.3	1.3	690	0.09
1000	13	0.3	1.3	690	0.09
Cat 2	13.2	0.72	1.3	690	0.09
Tier 1 Engines					
37	9.8	0.9	1.3	690	0.09
75	9.8	0.4	1.3	690	0.09
130	9.8	0.4	1.3	690	0.09
225	9.8	0.3	1.3	690	0.09
450	9.8	0.3	1.3	690	0.09
560	9.8	0.3	1.3	690	0.09
1000	9.8	0.3	1.3	690	0.09
Cat 2	9.8	0.72	1.3	690	0.09
Tier 2 Engines					
37	6.8	0.4	1.3	690	0.09
75	6.8	0.3	1.3	690	0.09
130	6.8	0.3	1.3	690	0.09
225	6.8	0.3	1.3	690	0.09
450	6.8	0.3	1.3	690	0.09
560	6.8	0.3	1.3	690	0.09
1000	6.8	0.3	1.3	690	0.09
Cat 2	9.8	0.72	1.3	690	0.09

Emission Calculations

The same formula for calculating emissions from OGVs was used for harbour craft emissions. It includes maximum engine power output, the load factor, emission factor and the time spent on a particular activity. However, when used in harbour craft emission inventory, the time spent on a particular activity *(T)* changes to monthly number of hours spent by the vessel in operation. This then gives the total monthly emissions from each engine for a particular type of pollutant when summed up in the formula below.

$$E = P \times LF \times EF \times T$$

4.2.3 Dispersion Modeling

The Atmospheric Dispersion Modelling System (ADMS) is a short-range dispersion model that simulates buoyant releases in the atmosphere by individual sources or in combination (CERC, 2010). This model provides results for distances up to 100 kilometers from the source (CERC, 2010). ADMS was used in this study to calculate the hourly, daily and annual ambient concentrations and spatial distribution of ambient pollutants from ships in Durban Port. The resultant concentration levels allowed for a comparison with NAAQS to determine if any ambient thresholds were exceeded by emissions from ships in the Port. The results were also compared with similar studies from the Danish Ports of Copenhagen, Køge and Elsinore.

Modeling Process

According to Justin Adams (pers. comm., 2013), different berths are assigned to specific ship types or for handling specific types of cargo in Durban Port. However, some of these berths are used as multi-purpose piers where different ships spend certain percentage of their time. The average time spent by each vessel type on specific berth was calculated from the data provided by VTS and this average was based on the entire study period and rounded off to the nearest fifth of a percentage (*Table 4.22*).

Table 4.22: Average percentage time spent by ships across six berths in Durban Port over the study period

	Container terminal (CT)	General cargo terminal (GCT)	Maydon Wharf (MW)	Island View (IV)	Bulk cargo terminal (BCT)	Car carrier terminal (CCT)
CONTAINER	80%	20%	-	-	-	-
BULK CARRIER	20%	30%	30%	-	20%	
TANKER	-	-	-	100%	-	-
GENERAL CARGO	30%	40%	30%	-	-	-
VEHICLE CARRIER	-	-	-	-	-	100%
OTHER	20%	45%	35%	-	-	-

Following an example from the study of three Denmark Ports by Saxe and Larson (2004), certain berths were identified as sources of emissions from the vessels in Port. However, instead of using point sources like Saxe and Larson, the berths in Durban Port were digitized as line sources. The ADMS is capable of modeling line sources of emission by considering the length of each line source (*Figure 4.1*). Therefore the length of each berth was measured and the following assumptions were made to model the emissions:

- Ships alongside a pier act as a line source of emissions across that pier. Seven line sources were identified for different berths (*Figure 4.1*)
- Ships emit pollutants along the same line source in all modes of operation i.e. during manoeuvring, berthing and in loading/unloading modes. This means that the line source represents the average location of emissions in all modes of operation.

The month with the highest number of ships' visit was identified to determine the worst case scenario of ships emissions. The number of ships (467) in May 2012 was divided by the number of days in a month (31 days) and gave an average of 15 OGVs entering or leaving Durban Port each day. The average number of hours each type of vessel spent in the Port (*Table 4.23*) was calculated using the turnaround time for each ship in that category and dividing by the number of ships.

Figure 4.1: The ADMS Model Domain and line sources in Durban Port

Table 4.23: Average time spent by each vessel type in Durban Port

VESSEL TYPE	AVERAGE TIME IN PORT
CONTAINER	55
BULK CARRIER	40
TANKER	72
GENERAL CARGO	57
VEHICLE CARRIER	26
OTHER	95

Container ships are used to illustrate how the conversion was applied in Durban Port. The total number of container ships (132 ships) in Durban Port in May 2012 was multiplied by average hours (55 hours) spent by each container vessel in port per month, which gave the total of 7,260 hours spent by container ships in May 2012. This value was then divided according to the percentage time spent in each berth i.e. 80% (5,808 hours) in container terminal and 20% (1,452 hours) in general cargo terminal. Finally, the daily average emission values in tonnes per day for May 2012 (*Table 4.24*) were converted to grams per second and divided by length of each berth and percentage time spent in each berth, to give emissions in grams per meter per second at each berth (*Table 4.25*). These values were then inputted to the dispersion model. Model output comprised ambient concentrations in µg/m^3. The height of flue gas flux used for the dispersion model was 30 meters for all OGVs and 20 meters for harbour crafts and the temperature of flue gas was 350°C. This was in line with the study by Saxe and Larson (2004) for Denmark Ports in consideration to types and sizes of vessels in Durban Port.

Table 4.24: Total emissions from all OGVs in tonnes per year from 1st of April 2012 to 31st of March 2013 and average emissions in tonnes per month and tonnes per day. The worst month scenario average emissions appear at the bottom of the table for the month of May 2012

All OGVs	NOx	SO_X	CO_2	HC	PM_{10}
TOTAL (tonnes per year)	876.30	734.95	112,163.28	32.67	80.60
TOTAL MONTHLY AVERAGE (APR 2012 – MAR 2013)					
Monthly Average (tonnes per month)	73.025	61.25	9,346.94	2.72	6.71
Daily Average (tonnes per day)	2.40	2.01	307.22	0.09	0.22
WORST MONTH SCENARIO AVERAGES (MAY 2012)					
Total emissions in May 2012 (tonnes per month)	90.85	74.15	11,234	3.37	8.15
Daily Average in May 2012 (tonnes per day)	3.028	2.472	374.47	0.112	0.272

The emissions in tonnes per day were converted to grams per second (*Table 4.25*). These values were inputted to ADMS for the calculations of ambient concentration in micrograms per cubic meter (μg/m^3) at the height of 1.5 m (average breathing height).

Table 4.25: Average emissions in grams per meter per second (g/m/s) from seven berths in Durban Port

	Berth							
	CT	**GCT**	**MW**	**IV**	**BCT**	**CCT**		**Harbour crafts jetty**
Total length (m)	2,754.79	912.06	2,016.11	2,145.92	995.63	1,024.14		
	Emissions in grams per meter per second (g/m/s)							
NO$_X$	4.3317E-03	9.6298E-03	2.7082E-03	3.2696E-03	6.9601E-04	1.1339E-03		1.5513E-02
SO$_2$	3.5363E-03	7.8616E-03	2.2109E-03	2.6692E-03	5.6821E-04	9.2569E-04		2.0951E-03
PM$_{10}$	3.8911E-04	8.6503E-04	2.4327E-04	2.9370E-04	6.2521E-05	1.0186E-04		1.1205E-03

4.3 CHALLENGES AND LIMITATIONS

There are challenges associated with conducting a detailed marine source pollution inventory. Similarly, there were challenges encountered during the study of Durban Port due to port specific data gaps.

- Not all required information was available during this study. USEPA (2009) emphasizes that although the Lloyd's dataset contains some information on auxiliary engines, many ship's records are missing this information. This fact was evident when the Lloyd's database was accessed during the study of Durban Port. Almost half of the ships searched in the IHS Fair-play website did not have information on auxiliary engines. The alternative was to use estimated values which are more suitable for mid-tier approach.
- The lack of access to information on harbour crafts that belong to private owners also posed a challenge. In response, only crafts that belong to the Port authority were included in this study, which make up a small proportion of harbour crafts within the Port. Nevertheless, the harbour crafts from the Port Authorities sail more frequently than any other crafts in order to keep the Port operational. These include tugboats and pilot boats, which sail all the time during arrival and departure of OGVs.
- Uncertainties exist regarding the emission factors and load factors of main engines during hotelling and manoeuvring. This is because some main engine operations commence from the cold start with higher emissions resulting from a cold engine than a warm engine operating under the same load, especially the HC and PM emissions (USEPA, 2009). It is difficult to establish whether the main engines were running during the hotelling mode from each ship. Some ships keep their main engines

running during bunkering or short port visits. This could have huge impact on emissions from main engines. The assumption was made that main engines were always shut-down during hotelling. This is not the most environmentally conservative approach but more realistic than the alternative.

- It is difficult to establish whether the boilers for each ship were running during hotelling. Therefore, applying the environmental conservative approach, it was assumed that boilers in all ships remained operational for the entire duration in Port. This assumption could have huge impact on emissions from the boilers.
- During manoeuvring, the engine loads change rapidly, which causes changes in emissions over time. The detailed inventory requires that accurate load factors be obtained for each vessel calling into port. This could require interviewing the technical staff from ships in port and even accessing some of their onboard technical documents (Entec, 2002). This is not always possible especially with limited access to port facilities, limited authority and limited resources to perform such activities.
- There is always a time delay before the main engines are shut down after docking and before the ship gets underway after starting main engines. These time delays have their own emission effects and may range from 10 minutes to half an hour and more. Although such delays may be traceable from the ship's logbook, it became necessary to estimate the time delay because obtaining logbooks from all ships is impractical. Therefore 20 minutes of emission was added to the main engines for every arrival and departure from the Port.
- Lastly, the time spent by the vessel in each mode is not recorded by the VTS station. The manoeuvring times are only estimated by the harbour pilot for each type of vessel which could lead to underestimating or overestimating the emissions.

4.4 SUMMARY

There were challenges associated with using secondary data analysis approach. The data from Lloyd's Register of ships is not without limitations as is evident with technical data on auxiliary engines. For instance, sixty two Bulk Carriers entered Durban Port in April 2014, two of those had no data in the Lloyd's Register and twenty one vessels lacked data on auxiliary engines. The challenge of lack of technical data from Lloyd's Register was resolved by interpolating from the available data to obtain average values for calculation of emissions from ships that had no data (refer to digital dataset provided as CD1).

The methodology used in the calculation of emissions for Durban Port inventory is current in the mobile source port-related emission inventories (USEPA, 2009). It has been used in larger ports such as the Port of Los Angeles (Starcrest, 2010). This methodology involves a detailed account of the movement of ships in and out of the port, emission factors for the type of engine fitted, the load factors per ship type and the time spent on each activity within the study area. This is a detailed and a more accurate approach, which provides a thorough calculation of emissions from marine mobile sources (USEPA, 2009).

The inventory focused only on marine source emissions and included all OGVs that reported in Durban Port between the 1st of April 2012 and 31st of March 2013 and only the harbour crafts controlled by TNPA. Although the methodology used in this study was detailed in nature, not all the required information was available to attain a fully detailed inventory. For instance not all marine pollution sources were included due to lack of access to data from privately owned harbour crafts in the Port. Therefore these pollution estimates are as accurate as availability of data permits. This means that for OGVs and harbour crafts under TNPA, the estimates are the closest possible to reality.

5. FINDINGS AND RESULTS

5.1 INTRODUCTION

This chapter provides the resultant emissions from the OGVs and the TNPA harbour crafts in Durban Port between the 1st of April 2012 and the 31st of March 2013. The quantitative results are represented as tables showing monthly and annual emissions by vessel type and engine type for each pollutant. The graphs are included as appendices. Emissions from OGVs and harbour crafts are represented separately and then added together to show the total emissions from all marine mobile sources. The results from the dispersion modelling are represented as figures showing concentration of pollutants extending outwards from the Port. The dispersion results took into account the effects of meteorology, including average wind speed and direction, precipitation, temperature and cloud cover during the period of observation. Only three pollutants, namely NO_X, SO_2 and PM_{10} were modeled and were compared with the South African national ambient air quality standards.

5.2 OCEAN GOING VESSEL (OGV) EMISSIONS

5.2.1 Distribution of Ships

The data from VTS station showed that there were 4,238 OGVs active in Durban Port between 1st of April 2012 and 31st of March 2013 (*Table 5.1*). These were represented as a monthly percentage distribution according to ship type (*Appendix A*).

Container ships accounted for 26.7% of the total OGVs and had the highest percentage of all visiting ships over the study period. This is expected as Durban Port has the busiest container terminal in Africa (World Shipping Council, 2012). Bulk carriers made up the second highest number of OGVs at 18.1% followed by tankers and general cargo ships, which were almost equivalent at 15.2% and 15.1% respectively. Vehicle carriers made up the smallest percentage of known types at 8.1%. The ‘other ships’ category, which consisted of a variety of ships including fishing vessels, stern trawlers, dredgers, supply ships, yachts, survey ship, tugs, roll-on roll-off (Ro-Ro), navy ships and passenger vessels, accounted for 12% of the total. The ‘unknown’ ships category, consisting of ships that could not be identified, accounted less than 5% of the total (*Table 5.1*).

Table 5.1: Total number of OGVs and the monthly percentage distribution of vessels per type in Durban Port from 1st of April 2012 to 31st of March 2013

	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	ROW TOTAL	Percentage of GRAND TOTAL
Container ships	98	132	92	95	109	92	92	84	81	84	81	93	**1,133**	**26.7%**
Bulk Carriers	62	64	81	73	75	61	61	63	57	50	65	53	**765**	**18.1%**
Tankers	53	72	51	59	56	50	59	55	52	45	45	48	**645**	**15.2%**
General Cargo	46	86	62	55	54	62	47	50	60	40	34	45	**641**	**15.1%**
Vehicle Carriers	28	33	32	30	28	29	31	24	27	25	25	33	**345**	**8.1%**
Others	39	54	42	44	32	35	35	47	54	32	46	48	**508**	**12.0%**
Unknown	12	26	30	20	22	22	13	12	8	13	5	18	**201**	**4.7%**
COLUMN TOTAL	**338**	**467**	**390**	**376**	**376**	**351**	**338**	**335**	**339**	**289**	**301**	**338**	**4,238**	**100%**
Percentage of GRAND TOTAL	**8.0%**	**11.0%**	**9.2%**	**8.9%**	**8.9%**	**8.3%**	**8.0%**	**7.9%**	**8.0%**	**6.8%**	**7.1%**	**8.0%**	**100%**	

The monthly graphical representation of the total number of ships visiting Durban Port shows May 2012 as the month with the highest number of ships visits (*Figure A2*). This month was used to model the worst case scenario where above average emissions are expected. The lowest number of ships visits occurred in January 2013 with less than 300 ships recorded. The monthly average number of OGV visits in Durban Port was calculated at 324 ships. January and February show the lowest shipping activity at the Port with May, June, July and August being the busiest season. The reasonable explanation for this trend is that shipping business is slower during the festive season as most staff take time off for Christmas and New Year holidays. After February business recovers, peaking mid-year followed by a steady decline until December (*Figure A3*). Only May 2012 had a double digit percentage visit (*Figure A4*).

Container ships have the highest total gross tonnage (39,246,521 tonnes) as they accounted for the greatest number of ships (*Table 5.2*). The Bulk carriers have the second highest gross tonnage of 21,377,851 tonnes and they are closely followed by the vehicle carriers at 17,651,572 tonnes. It is worth noting that the vehicle-carriers have the third highest gross tonnage, far exceeding the tankers (12,382,423 tonnes) and the general cargo vessels (7,421,258 tonnes), although their numbers were almost half (345 ships) the number of both the tankers (645 ships) and the general cargo ships (641 ships). This is because the average gross tonnage of one vehicle carrier is 55,071 tonnes and they are the largest vessels in the Port in terms of average tonnage (refer to *Table 4.1*).

Table 5.2: Total gross tonnage (tonnes) per ship type in Durban Port between 1st of April 2012 and 31st of March 2013

	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	ROW TOTAL	Percentage of GRAND TOTAL
Container ships	3,038,265	4,357,422	3,196,338	3,006,865	3,764,111	3,102,562	3,346,920	2,761,839	3,114,961	3,073,448	3,148,253	3,335,537	39,246,521	**38.5%**
Bulk Carriers	1,667,348	1,731,112	2,414,238	1,978,208	2,068,535	1,677,015	1,751,993	1,606,026	1,831,838	1,303,659	1,849,595	1,498,284	21,377,851	**21.0%**
Tankers	1,009,176	1,445,884	1,037,379	1,098,101	928,330	1,051,534	1,122,383	1,069,517	959,855	723,197	964,149	972,918	12,382,423	**12.1%**
General Cargo	529,391	1,062,916	590,535	686,197	671,653	810,310	535,050	574,521	524,983	465,600	416,552	553,550	7,421,258	**7.3%**
Vehicle Carriers	1,352,398	1,786,262	1,597,968	1,498,718	1,431,428	1,428,109	1,594,908	1,217,649	1,413,387	1,366,946	1,308,490	1,655,309	17,651,572	**17.3%**
Others	43,721	233,348	145,230	143,504	144,432	76,652	144,876	518,822	486,920	637,679	724,035	575,940	3,875,159	**3.8%**
Unknown	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
COLUMN TOTAL	7,640,299	10,616,944	8,981,688	8,411,593	9,008,489	8,146,182	8,496,130	7,748,374	8,331,944	7,570,529	8,411,074	8,591,538	101,954,784	**100%**
Percentage of GRAND TOTAL	**7.5%**	**10.4%**	**8.8%**	**8.3%**	**8.8%**	**8.0%**	**8.3%**	**7.6%**	**8.2%**	**7.4%**	**8.2%**	**8.4%**	**100%**	

May 2012 had the highest tonnage recorded because of more ships visiting the Port with January 2013 being the lowest (*Figure B2*). Only May 2012 achieved a double figure percentage gross tonnage distribution (*Figure B3*).

5.2.2 OGVs Emission Estimates by Pollutant

NO_X EMISSIONS

The total estimated NO_X emissions from all OGVs were 876.30 tonnes over the study period of twelve months emissions (*Table 5.3*). May 2012 experienced the highest emissions at 90.85 tonnes, which accounted for 10.4% of the total annual NO_X emissions (*Appendix C*). This is attributed to May 2012 being the month with the highest number of ships visits over the study period. February 2013 had the lowest emissions of NO_X despite having the second lowest number of visits after January 2013. This discrepancies is as the result of varying emissions by ship type.

Table 5.3: NO_X port emissions in tpm and tpy, and the distribution of emissions in tonnes per ship type and in percentage.

Type of OGV	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	ROW TOTAL (tpy)	Percentage of GRAND TOTAL
Container ship	29.71	35.39	27.29	29.64	36.11	37.23	30.68	31.80	34.10	30.02	27.18	32.74	**381.90**	**43.6%**
Bulk Carrier	4.75	6.01	7.08	6.11	6.64	5.29	6.61	7.14	5.03	5.01	6.12	5.51	**71.30**	**8.1%**
Tanker	11.78	11.50	11.29	11.98	10.64	11.47	10.76	10.59	11.59	9.87	7.97	9.60	**129.03**	**14.7%**
General Cargo	8.00	26.81	17.06	16.67	14.81	17.92	13.41	13.77	16.22	10.53	9.42	12.05	**176.67**	**20.2%**
Vehicle Carrier	3.64	4.19	3.72	3.74	4.00	3.86	3.69	2.89	3.13	2.71	3.00	4.77	**43.35**	**4.9%**
Other	9.36	6.95	5.71	9.66	6.57	4.36	3.79	4.82	10.36	3.12	5.52	3.83	**74.05**	**8.5%**
COLUMN TOTAL (tpm)	**67.25**	**90.85**	**72.16**	**77.79**	**78.77**	**80.14**	**68.93**	**71.01**	**80.42**	**61.27**	**59.21**	**68.50**	**876.30**	**100.0%**
Percentage of GRAND TOTAL	**7.7%**	**10.4%**	**8.2%**	**8.9%**	**9.0%**	**9.1%**	**7.9%**	**8.1%**	**9.2%**	**7.0%**	**6.8%**	**7.8%**	**100%**	

Container ships are by far the highest emitters of NO_X due to the high number of ships visits in the port (*Figure C3*). General cargo ships are the second highest emitters of NO_X despite being fewer than bulk carriers in numbers. This is because the general cargo ships use their own cranes for loading and unloading in Port. Loading and unloading mode has the highest load factor for auxiliary engines across all modes. The vehicle carriers are the least emitters of NO_X contributing less than 5% of the total due to fewer ships visits (*Figure C4*).

SO_X EMISSIONS

The total annual SO_X emissions were calculated at 734.86 tonnes with May 2012 recording the highest emissions at 74.15 tonnes and February 2013 the lowest at 50.08 tonnes (*Table 5.4* and *Appendix D*). May 2012 achieved a double digit figure of 10.1% of the total SO_X emissions (*Figure D2*). Similar to NO_X emissions, the SO_X emissions are highly depended on the amount of ships present in the port at any given time as was the case with the month of May 2012.

Table 5.4: SO_X port emissions in tpm and tpy, and the distribution of emissions in tonnes per ship type and in percentage.

Type of OGV	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	ROW TOTAL (tpy)	Percentage of GRAND TOTAL
Container ship	24.79	30.26	23.02	25.11	29.63	30.88	24.84	26.47	27.02	24.80	21.88	28.77	**317.47**	**43.2%**
Bulk Carrier	3.14	4.96	5.35	4.68	5.33	4.22	5.55	5.99	3.91	4.11	4.88	4.54	**56.66**	**7.7%**
Tanker	10.75	10.97	10.01	11.44	9.84	10.31	10.02	9.49	10.22	8.77	7.26	8.33	**117.42**	**16.0%**
General Cargo	4.92	14.39	9.33	8.45	8.09	10.08	7.28	7.58	8.85	5.69	4.90	6.25	**95.80**	**13.0%**
Vehicle Carrier	2.77	3.25	2.95	3.00	3.19	3.07	2.78	2.26	2.44	2.11	2.27	3.74	**33.85**	**4.6%**
Other	10.77	10.31	10.37	15.92	10.15	7.03	5.84	7.62	14.95	5.04	8.89	6.76	**113.66**	**15.5%**
COLUMN TOTAL (tpm)	57.14	74.15	61.03	68.61	66.23	65.59	56.30	59.42	67.39	50.52	50.08	58.40	**734.86**	**100.0%**
Percentage of GRAND TOTAL	**7.8%**	**10.1%**	**8.3%**	**9.3%**	**9.0%**	**8.9%**	**7.7%**	**8.1%**	**9.2%**	**6.9%**	**6.8%**	**7.9%**	**100%**	

Container ships produced the highest SO_X emissions well above 300 tonnes over a twelve month period (*Figure D3*). The vehicle carriers were the lowest emitters of SO_X pollutant over the study period followed by bulk carriers with both at less than 50 tonnes per year. The tankers are the second highest emitters of SO_X (117.42 tonnes per year), which doubled the emissions from bulk carriers (56.66 tonnes per year) although the number of bulk carriers were more than that of the tankers (*Figure D3*). This discrepancy is attributed to the boiler power ratings. The tankers have bigger boiler power in terms of kilowatts (346 kW) than the bulk carriers at 109 kW (refer to *Table 4.17*). When these factors are applied in emission calculations they have much greater impact on total emissions from the boilers (refer to digital dataset provided as CD1). By percentage, the container ships produced 43.2% of SO_X emissions, which is more than double the tanker emissions, the second highest emitter at 16% (*Figure D4*).

PM_{10} EMISSIONS

The OGVs emitted the total of 80.59 tonnes of PM_{10} between the 1st of April 2014 and 31st March 2014 (*Table 5.5* and *Appendix E*). Over eight tonnes of the total PM_{10} were emitted in May 2012 and this was the highest month of emissions throughout the study period, which made up more than 10% of the total emissions (*Figure E2*). This trend is attributed to the May 2012 being the month with most ships visit. However, the highest number of ships is not the only determining factor of higher emissions. The results show that emissions also depended on the amount of time spent by ships in the Port (i.e. *the turnaround time*). For instance, if comparison is made between June 2012 and December 2012, the results reveal that higher PM_{10} emissions were mostly dependent on the total time spent by all ships than by the number of ships. There were fewer ships in December 2012 (339 OGVs) than in June 2012 (390 OGVs), however the total time spent by OGVs in December 2012 was 5,746 hours compared to 5,134 hours in June 2012 (refer to digital dataset provided as CD1) and hence more emissions resulted in December than in June 2012 (*Figure E1* and *E2*).

Table 5.5: PM_{10} port emissions in tpm and tpy, and the distribution of emissions in tonnes per ship type and in percentage.

Type of OGV	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	ROW TOTAL (tpy)	Percentage of GRAND TOTAL
Container ship	2.69	3.29	2.49	2.72	3.22	3.34	2.70	2.86	2.93	2.69	2.38	3.10	**34.41**	**42.7%**
Bulk Carrier	0.45	0.57	0.64	0.56	0.63	0.50	0.64	0.69	0.47	0.48	0.57	0.53	**6.72**	**8.3%**
Tanker	1.17	1.20	1.10	1.24	1.07	1.12	1.09	1.04	1.12	0.96	0.80	0.92	**12.83**	**15.9%**
General Cargo	0.57	1.65	1.06	0.97	0.93	1.15	0.83	0.87	1.02	0.65	0.57	0.72	**10.98**	**13.6%**
Vehicle Carrier	0.31	0.36	0.32	0.33	0.35	0.34	0.31	0.25	0.27	0.23	0.25	0.41	**3.72**	**4.6%**
Other	1.14	1.09	1.08	1.66	1.06	0.74	0.61	0.80	1.57	0.53	0.94	0.71	**11.92**	**14.8%**
COLUMN TOTAL (tpm)	6.32	8.15	6.69	7.48	7.26	7.18	6.19	6.51	7.38	5.54	5.50	6.39	**80.59**	**100.0%**
Percentage of GRAND TOTAL	**7.8%**	**10.1%**	**8.3%**	**9.3%**	**9.0%**	**8.9%**	**7.7%**	**8.1%**	**9.2%**	**6.9%**	**6.8%**	**7.9%**	**100%**	

The container ships produced the highest PM_{10} emissions at more than 40% and vehicle carriers produced the lowest at less than 5% of the total PM_{10} emissions (*Figure E3* and *E4*). This trend is attributed to the total number of ships per vessel type.

HC EMISSIONS

Hydrocarbons emissions are low in terms tonnage compared to the other pollutants. OGVs produced a total of 32.67 tonnes over one year period with May 2012 accounting for the highest emissions at 3.37 tonnes per year and 10.3% of the total (*Table 5.6* and *Appendix F*). July and August 2012 experienced the same percentage HC emissions of 9% each (*Figure F2*) and had the same amount of ships (376 OGVs each) visiting the port (refer to *Table 5.1*). This trend confirms that emissions are heavily dependent on the number of vessels in the port. However, this is not the only determining factor of higher emissions because July and December 2012 is not in line with this trend. There were fewer ships in December 2012 at 339 ships compared to 376 ships in July 2012 (refer to *Table 5.1*), however more emissions resulted in December than in July 2012 (*Figure F1* and *F2*). This is because the fewer ships spent more time (17,078 hours) in the Port than the 376 ships in July 2012, which only spent 15,597 hours in total (refer to digital dataset provided as CD1).

Table 5.6: Total HC port emissions in tpm and tpy, and distribution of emissions in tonnes per ship type and in percentage

Type of OGV	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	ROW TOTAL (tpy)	Percentage of GRAND TOTAL
Container ship	1.10	1.32	0.99	1.10	1.34	1.38	1.13	1.18	1.25	1.11	1.00	1.23	**14.14**	**43.3%**
Bulk Carrier	0.18	0.23	0.27	0.23	0.25	0.20	0.25	0.27	0.19	0.19	0.23	0.21	**2.70**	**8.3%**
Tanker	0.45	0.44	0.43	0.46	0.41	0.43	0.41	0.40	0.44	0.37	0.30	0.36	**4.90**	**15.0%**
General Cargo	0.29	0.93	0.59	0.58	0.52	0.63	0.47	0.48	0.57	0.37	0.33	0.42	**6.15**	**18.8%**
Vehicle Carrier	0.13	0.15	0.14	0.14	0.15	0.14	0.13	0.11	0.12	0.10	0.11	0.18	**1.59**	**4.9%**
Other	0.37	0.30	0.26	0.42	0.28	0.19	0.16	0.21	0.44	0.14	0.24	0.17	**3.19**	**9.8%**
COLUMN TOTAL (tpm)	2.52	3.37	2.66	2.93	2.94	2.98	2.56	2.65	3.00	2.28	2.22	2.56	**32.67**	**100.0%**
Percentage of GRAND TOTAL	**7.7%**	**10.3%**	**8.1%**	**9.0%**	**9.0%**	**9.1%**	**7.8%**	**8.1%**	**9.2%**	**7.0%**	**6.8%**	**7.8%**	**100%**	

The container ships are the leading emitters of HC in the Port at 14.14 tonnes per year due to large number of vessels over one year. General cargo ships are the second biggest emitters of HC at 6.15 tonnes per year (18.8%) and surpassed the tankers at 4.9 tonnes per year and bulk carriers at 2.7 tonnes per year accounting 15% and 8.3% respectively (*Figure F3* and *Figure F4*). This is despite general cargo vessels having fewer ships than both the tankers and bulk carriers (refer to *Table 5.1*). It therefore follows that emissions may also depend on the type of vessel.

CO_2 EMISSIONS

The monthly CO_2 emissions are calculated in thousands of tonnes due to high emission factors of CO_2 pollutant per engine type (refer to digital dataset provided as CD1). May 2012 showed the highest CO_2 emissions because of high number of ships and January and February 2013 showed the lowest emissions due to low ship activity rate (*Table 5.7* and *Appendix G*). Only May 2012 reached the double percentage digit of the total emissions at 10% (*Figure G2*). There were more ships in June (390 OGVs) than in August 2012 (376), however there were fewer CO_2 emissions in June 2012 than in August 2012. This is because ships spent fewer hours in the port in June 2012 (23,384 hours) than in August 2012 (31,328 hours). This is an indication that both the number of ships in port and the amount of time spent by ships in port have bearing on emissions produced.

Table 5.7: CO_2 port emissions in tpm and tpy, and the distribution of emissions in tonnes per ship type and in percentage.

Type of OGV	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	ROW TOTAL (tpy)	Percentage of GRAND TOTAL
Container ship	3,896	4,733	3,623	3,955	4,666	4,906	3,906	4,192	4,273	3,912	3,443	4,553	**50,057**	**44.6%**
Bulk Carrier	410	625	627	561	655	528	722	796	462	533	603	585	**7,107**	**6.3%**
Tanker	1,647	1,645	1,524	1,750	1,511	1,583	1,520	1,431	1,548	1,341	1,087	1,253	**17,840**	**15.9%**
General Cargo	673	2,094	1,374	1,241	1,155	1,466	1,057	1,091	1,265	822	700	892	**13,830**	**12.3%**
Vehicle Carrier	426	500	450	463	496	474	424	347	374	320	347	578	**5,198**	**4.6%**
Other	1,726	1,639	1,665	2,568	1,634	1,123	927	1,201	2,379	790	1,405	1,063	**18,120**	**16.2%**
COLUMN TOTAL (tpm)	8,778	11,234	9,262	10,538	10,116	10,078	8,556	9,058	10,301	7,719	7,585	8,923	**112,151**	**100.0%**
Percentage of GRAND TOTAL	**7.8%**	**10.0%**	**8.3%**	**9.4%**	**9.0%**	**9.0%**	**7.6%**	**8.1%**	**9.2%**	**6.9%**	**6.8%**	**8.0%**	**100%**	

Container had more ships in port and spent more hours than other ships and produced 50,057 tonnes of CO_2 emissions in one year (*Figure 5.26*). This is more than double the amount of CO_2 emissions produced by the second biggest emitters, which is the other vessels category at 18,120 tonnes per year (*Figure G3*). Emissions from the rest of the other five vessel types were governed by two more factors. The time spent by each ship type in the port and the maximum continuous rating (MCR) of engines per ship type, particularly the boiler MCR mostly influenced emissions from these five categories of ships.

The ship type named ‘other type category’, had the second highest emissions of CO_2 because they spent more time in Port than the other four types of ships, namely bulk carriers, tankers, general cargo, and vehicle carriers. The hours spent by each category were bulk carriers 40,520 hrs, tankers 40,624 hrs, general cargo 46,601 hrs, vehicle carriers 10,088 hrs and other vessels spent 51,433 hrs in the Port over the study period (refer to digital dataset provided as CD1).

The tankers produced more CO_2 emissions than the general cargo vessels although the latter spent more time in Port. This deviation can be attributed to the MCR from the boilers since the MCR for tankers (346 kW) is higher than that of general cargo vessels (106 kW) (refer to *Table 4.17* for boiler MCR values). It therefore follows the tankers will have higher CO_2 emissions accounting 15.9% of the total, than the general cargo vessels, which accounted 12.3% of the total emissions (*Figure G4*).

5.2.3 Emissions per Vessel Type from Different Engine Types

This section provides a comparison between emissions of various pollutants from the three types of engines found onboard the OGVs. The three types of engines include the main propulsion engines, the auxiliary engines and the boilers. Although there were more container ships in the Port at any given time, the emissions from their main engines were lower than the emissions from the other vessels’ main propulsion engines over the study period. This is particularly so when compared to bulk carriers and general cargo ships. The container ships’ main propulsion engines emitted fewer NO_X, SO_X, PM_{10}, HC and CO_2 than the bulk carriers and only surpassed the general cargo with NO_X and HC emissions. This is because of the difference in the manoeuvring speeds and maximum speeds of container ships and bulk carriers, which influences the load factors. The formula from USEPA (2009) below, was used to calculate the load factors for main engines and resulted in smaller load factors for container ships and higher load factors for bulk carriers and general cargo vessels (refer to digital dataset provided as CD1).

$$Load\ Factor = \left(\frac{Actual\ Speed}{Maximum\ Speed}\right)^3$$

The total emissions from the main engines are represented in *Table 5.8*.

Table 5.8: Total estimated port emissions (tpy) per vessel type from Main Propulsion Engines

Type of OGV	**Number of ships**	**Total hours spent in Port**	**NO_X**	**SO_X**	**CO_2**	**HC**	**PM_{10}**
			tpy				
Container ship	1,133	69,212	24.50	15.95	961.98	0.92	2.20
Bulk Carrier	765	40,520	30.93	20.60	1,238.03	1.18	2.88
Tanker	645	40,625	17.57	12.60	759.76	0.68	1.69
General Cargo	641	46,601	21.99	17.27	1,040.09	0.87	2.27
Vehicle Carrier	345	10,089	4.70	3.05	183.68	0.18	0.42
Other	508	51,434	4.01	3.74	224.67	0.17	0.49
TOTAL	**4,037**	**258,480**	**103.70**	**73.21**	**4,408.21**	**4.00**	**9.96**

The auxiliary engines emissions show a different trend to the main engines emissions (*Table 5.8* and *5.9*). The container ships' auxiliary engines had the highest emissions of all types of pollutants. This was followed by general cargo ships and tankers. The vehicle carriers' auxiliary engines emitted the least in all pollutants because of their low numbers and also because of less time spent in the port.

Table 5.9: Total estimated port emissions (tpy) per vessel type from Auxiliary Engines

Type of OGV	**Number of ships**	**Total hours spent in Port**	**NO_X**	**SO_X**	**CO_2**	**HC**	**PM_{10}**
			tpy				
Container ship	1,133	69,212	295.93	102.93	1,6767.99	9.71	11.90
Bulk Carrier	765	40,520	32.82	11.39	1,853.67	1.08	1.32
Tanker	645	40,625	88.63	30.90	5,037.96	2.92	3.57
General Cargo	641	46,601	146.12	50.88	8,288.38	4.80	5.88
Vehicle Carrier	345	10,089	32.64	11.38	1,854.18	1.07	1.32
Other	508	51,434	40.42	14.08	2,294.23	1.33	1.63
TOTAL	**4,037**	**258,480**	**636.56**	**221.56**	**36,096.42**	**20.91**	**25.61**

The boilers show a similar trend as the auxiliary engines where the container ships had the highest emissions of every pollutant investigated. However, the boilers from other vessel types are the second biggest emitters after the container ships because they spent the second highest number of hours in the Port over the study period (*Table 5.10*).

Table 5.10: Total estimated port emissions (tpy) per vessel type from Boilers

Type of OGV	Number of ships	Total hours spent in Port	NO_X	SO_X	CO_2	HC	PM_{10}
			tpy				
Container ship	1,133	69,212	61.46	198.59	32,326.84	3.50	20.31
Bulk Carrier	765	40,520	7.64	24.76	4,027.07	0.44	2.53
Tanker	645	40,625	22.81	73.93	12,042.40	1.30	7.56
General Cargo	641	46,601	8.54	27.65	4,501.14	0.49	2.83
Vehicle Carrier	345	10,089	5.99	19.41	3,160.02	0.34	1.99
Other	508	51,434	29.60	95.84	15,601.19	1.69	9.80
TOTAL	**4,037**	**258,480**	**136.04**	**440.18**	**71,658.65**	**7.76**	**45.03**

5.2.4 Total Emissions by Engine Type

The auxiliary engines are the major polluters of NO_X and HC and they exceed both the main engines and the boilers in those pollutants (*Table 5.11*). The boilers exceed both the main engines and the auxiliary engines with SO_X, CO_2 and PM_{10} emissions. The main engines emit less because they remain shut-down when the ship is alongside and they only operate during the manoeuvring mode. On the other hand, the auxiliary engines and the boilers are in continuous operation in all three modes. The boilers exceed the auxiliary engines with SO_X, CO_2 and PM_{10} emissions because they have higher emission factors than the auxiliary engines in all three of these pollutants. On the contrary, auxiliary engines exceed the boilers in NO_X and HC because they have higher emission factors than the boilers in both pollutants (refer to *Tables 4.15* and *4.16* for auxiliary engine and boiler emission factors respectively).

Table 5.11: Total estimated port emissions (tpy) per engine type from OGVs

Type of Engine	NO_X	SO_X	CO_2	HC	PM_{10}
	tpy				
Main Engines	103.7	73.21	4,408.21	4.00	9.96
Auxiliary Engines	636.56	221.56	36,096.42	20.91	25.61
Boilers	136.04	440.18	71,658.65	7.76	45.03
TOTAL	**876.30**	**734.95**	**112,163.28**	**32.67**	**80.60**

The emissions from various engines are represented as a percentage emission of pollutants for easy reference (*Table 5.12*).

Table 5.12: Percentage distribution of pollutants per engine type from OGVs

Type of Engine	NO_X	SO_X	CO_2	HC	PM_{10}
Main Engines	11.8%	10.0%	3.9%	12.2%	12.4%
Auxiliary Engines	72.6%	30.1%	32.2%	64.0%	31.8%
Boilers	15.5%	59.9%	63.9%	23.8%	55.9%
TOTAL	100%	100%	100%	100%	100%

The auxiliary engines predominate the NO_X and HC emissions and the boilers predominate the SO_X, CO_2 and PM_{10} emissions (*Figure 5.1*). The main propulsion engines have the lowest emissions of all engines in the port due to lesser hours of operation.

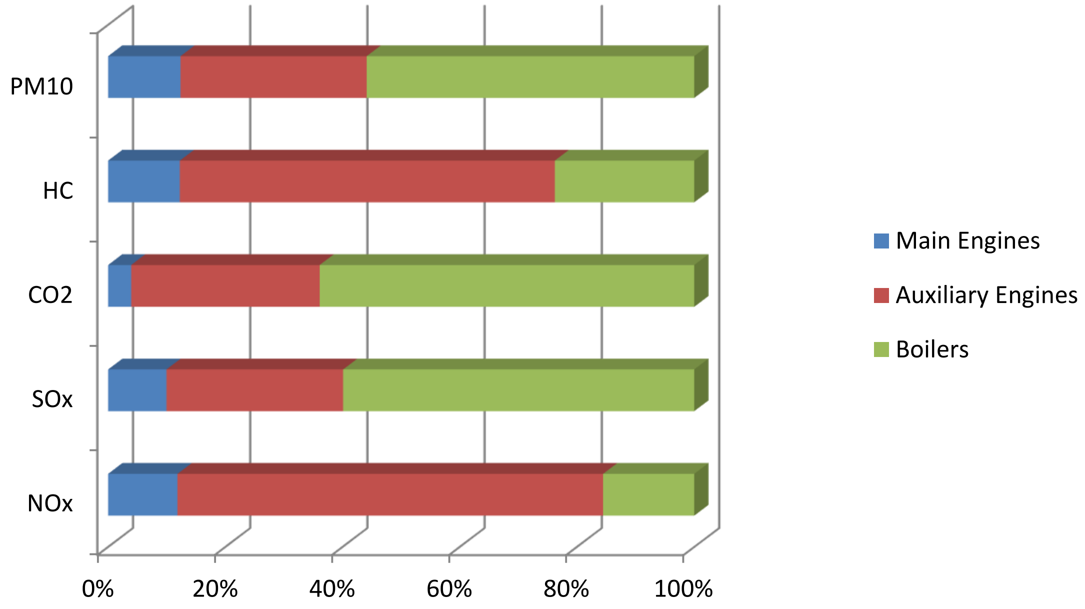


Figure 5.1: Percentage distribution of pollutants per engine type from OGVs

5.2.5 Total Emissions by Ship Type

The container ships emitted the highest levels of all pollutants under consideration while vehicle carriers emitted the lowest due to their fewer numbers and shorter times spent in the port (*Table 5.13*). The container ships contributed more than 40% of all pollutants over the study period. The general cargo vessels are the second highest emitters of NO_X at 20.2% followed by tankers at 14.7%. The tankers follow the container ships with their SO_X and PM_{10} emissions at 16% and 15.9% of total SO_x and total PM_{10} emissions respectively. The other vessels category was the second highest emitters of CO_2 at 16.2%. The general cargo ships are the second largest emitters of HC at 18.8% of total HC emissions.

Table 5.13: Total estimated port emissions (tpy) per vessel type from OGVs

Type of OGV	Number of ships	Total hours spent in Port	NO$_X$	SO$_X$	CO$_2$	HC	PM$_{10}$
			tpy (%)				
Container ships	1,133	69,212	381.90 (43.5%)	317.47 (43.2%)	50,056.81 (44.6%)	14.14 (43.3%)	34.41 (42.7%)
Bulk Carriers	765	40,520	71.31 (8.2%)	56.75 (7.7%)	7,118.76 (6.3%)	2.70 (8.3%)	6.73 (8.4%)
Tankers	645	40,625	129.03 (14.7%)	117.42 (16.0%)	17,840.12 (15.9%)	4.90 (15.0%)	12.83 (15.9%)
General Cargo	641	46,601	176.67 (20.2%)	95.80 (13.0%)	13,829.62 (12.3%)	6.15 (18.8%)	10.98 (13.6%)
Vehicle Carriers	345	10,089	43.35 (5.0%)	33.85 (4.6%)	5,197.87 (4.6%)	1.59 (4.9%)	3.72 (4.6%)
Others	508	51,434	74.05 (8.5%)	113.66 (15.5%)	18,120.10 (16.2%)	3.19 (9.8%)	11.92 (14.8%)
TOTAL	**4,037**	**258,480**	**876.30 (100%)**	**734.95 (100%)**	**112,163.28 (100%)**	**32.67 (100%)**	**80.60 (100%)**

It is apparent that the container ships dominate the emissions of all pollutants accounting for more than 40% of OGVs emissions in port (*Figure 5.2*). This is because of their large numbers and the longest time spent in Port. They are followed by tankers in SO$_X$ and PM$_{10}$ emissions because of high boiler MCR and their large numbers compared to the other five types of ships. The general cargo vessels became the second highest emitters of NO$_X$ and HC after container ships whilst the other ships category were the second highest emitters of CO$_2$, both due to longer hours spent in the Port than most ships other than container ships.

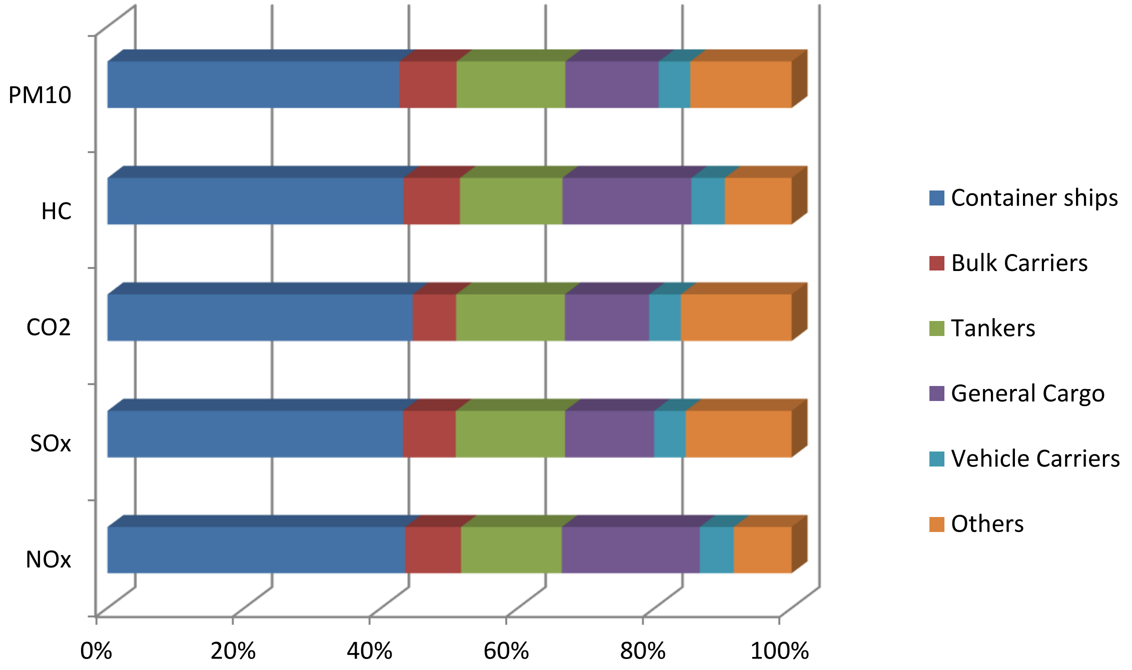


Figure 5.2: Percentage distribution of pollutants per vessel type from OGVs

5.3 HARBOUR CRAFTS EMISSIONS

5.3.1 Distribution of Crafts

Thirteen of the nineteen harbour crafts were active during the study period from 1st April 2012 to 31st March 2013 as shown by the engine hours, also known as operational hours (*Table 5.14*). A total of 19,505 operational hours were spent by all harbour crafts. The month with the highest operational hours was November 2012 with the total of 1,894 hours (9.7% of total hours) spent by all vessels combined. The lowest number of operational hours occurred in March 2013, which registered a total of 1,420 hours (7.3%) of operation for all harbour crafts (*Appendix H*). The operational time of all harbour crafts averaged 1,625 hours per month.

Table 5.14: Monthly distribution of operational hours and the percentage of time spent by each harbour crafts over the study period

NAME OF VESSEL	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	ROW TOTAL	Percentage of GRAND TOTAL
	Engine hours													
NONOTI	106	71	97	95	22	89	109	103	76	88	73	67	**996**	**5.1%**
UMZUMBE	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0.0%**
UMVOTI	97	113	151	127	63	78	131	58	87	30	0	0	**935**	**4.8%**
UMSUNDUZI	0	0	0	0	0	244	290	334	308	266	303	286	**2,031**	**10.4%**
UMHLALI	67	107	114	96	175	128	82	127	84	90	150	142	**1,362**	**7.0%**
INYALAZI	283	291	298	335	326	178	0	0	0	51	77	82	**1,921**	**9.8%**
MKHUZE	308		0	157	128	165	168	100	93	82	0	0	**1,201**	**6.2%**
UTHUKELA	17	245	332	292	278	313	333	317	292	259	298	278	**3,254**	**16.7%**
PHOLELA	293	311	313	260	225	413	256	340	292	249	255	285	**3,492**	**17.9%**
LOTHENI	316	306	347	313	343	134	270	297	304	277	291	280	**3,478**	**17.8%**
ROYAL TERN	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0.0%**
JOJOSI	0	0	0	0	0	0	29	71	0	20	27	0	**147**	**0.8%**
LUFAFA	0	0	0	0	0	0	120	98	105	83	51	0	**457**	**2.3%**
ISIPONONO	0	0	0	0	0	0	8	0	6	0	0	0	**14**	**0.1%**
INDLOVU	24	41	0	0	0	0	26	49	26	29	22	0	**217**	**1.1%**
STARLING	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0.0%**
MOORHEN	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0.0%**
UMCISHU	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0.0%**
NQOYI	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0.0%**
COLUMN TOTAL	**1,511**	**1,485**	**1,652**	**1,675**	**1,560**	**1,742**	**1,822**	**1,894**	**1,673**	**1,524**	**1,547**	**1,420**	**19,505**	**100.0%**
Percentage of GRAND TOTAL	**7.7%**	**7.6%**	**8.5%**	**8.6%**	**8.0%**	**8.9%**	**9.3%**	**9.7%**	**8.6%**	**7.8%**	**7.9%**	**7.3%**	**100.0%**	

The tugboats PHOLELA, LOTHENI and UTHUKELA topped all other vessels in terms of operational hours each covering over 3,000 hours or 16% of the total operational time. The other tugboats in operation were UMSUNDUZI, INYALAZI, UMHLALI, UMKHUZE, NONOTI and UMVOTI. All nine tugboats covered the total of 18,670 hours of operation over the study period. This means that the tugboats accounted for more than 95% of the total time spent by harbour crafts in operation. UMZUMBE is the only tugboat that did not sail during the study period. Other harbor crafts that sailed during the study period were the pilot boats LUFAFA and JOJOSI, the floating crane INDLOVU, and the corporate boat ISIPONONO. All other harbour crafts remained alongside for the entire period of study (*Figure H3* and *H4*).

The tugboats are the most active harbour crafts in Durban Port accounting for more than 95% of the total operational hours of harbour crafts controlled by TNPA. This is because the tugboats sail regularly to safely guide the OGVs as they enter or leave the Port. Coming alongside is virtually impossible for the OGVs without the assistance of tugboats. The second most active type of harbour craft is the pilot boat that conveys the marine pilots from shore to ship and *vice versa* to bring the OGVs alongside. According to Aubrey Baloyi in Durban (pers. comm., 2013), the marine pilot will at times use a helicopter for the same purpose but this is depended on the sea state and the availability of the helicopter as the pilot boats are more economical in good weather. Peter Phillips, the Marine Technical Manager of TNPA in Durban Port (pers. comm., 2013), highlighted that the floating crane INDLOVU, which was the third active type of harbour craft, is responsible for offloading cargo from a ship in one berth and transferring it to another berth. This is important when an ocean going vessel carrying multiple cargoes is unable to make a cold shift or hot shift from one pier to another in order to discharge cargo. The use of a floating crane helps improve the port services and hence accounted for 1.1% of the total operational time by harbour crafts. The corporate boat ISIPONONO, the fourth most active type of harbour craft, is fundamentally responsible for harbour tours that are provided by TNPA to its associates and VIP guests and thus accounted for 0.1% of total operational time by harbour crafts (*Table 5.15*).

Table 5.15: Total operational hours per harbour crafts type from 1st of April 2012 to 31st of March 2013

Vessel Type	Total engine hours	Percentage of time
Tugboats	18,670	95.7%
Workboats	0	0.0%
Pilot boats	604	3.1%
Corporate boat	14	0.1%
Floating Crane	217	1.1%
Launch	0	0.0%
TOTAL	**19,505**	**100.0%**

5.3.2 Harbour Crafts Emissions Estimates by Pollutants

NO_X EMISSIONS

The total NO_X emissions from the harbour crafts were 196.75 tonnes over the period of one year (*Table 5.16).* This makes a monthly average NO_X emissions of 16.4 tonnes and includes emissions from both the main propulsion and the auxiliary engines. There is an increasing trend of activities from August 2012 to November 2012 and then a decreasing trend from November 2012 until March 2013 (*Figure I1*). The highest NO_X emissions took place in November 2012 and accounted for 19.79 tonnes (10.1% of the total) and the lowest emissions occurred in March 2013 at 14.5 tonnes, which makes 7.4% of total emissions from harbour crafts (*Figure I2*).

Table 5.16: Total NO_X emissions (tonnes) by harbour crafts from ME and AE and the monthly percentage distribution of total NO_X emissions

	ME (tonnes)	AE (tonnes)	**ROW TOTAL (tpm)**	**Percentage of GRAND TOTAL**
Apr-12	14.92	0.46	**15.38**	**7.8%**
May-12	14.40	0.47	**14.87**	**7.6%**
Jun-12	15.70	0.51	**16.21**	**8.2%**
Jul-12	15.67	0.51	**16.18**	**8.2%**
Aug-12	14.32	0.48	**14.80**	**7.5%**
Sep-12	16.66	0.53	**17.19**	**8.7%**
Oct-12	18.21	0.59	**18.80**	**9.6%**
Nov-12	19.17	0.62	**19.79**	**10.1%**
Dec-12	17.27	0.54	**17.80**	**9.0%**
Jan-13	15.31	0.49	**15.80**	**8.0%**
Feb-13	14.96	0.49	**15.45**	**7.9%**
Mar-13	14.06	0.44	**14.50**	**7.4%**
COLUMN TOTAL (tpy)	**191**	**6**	**196.75**	**100.0%**
Percentage of GRAND TOTAL	**96.9%**	**3.1%**	**100.0%**	

SO_X EMISSIONS FROM HARBOUR CRAFTS

The harbour crafts produced a total of 2.24 tonnes of SO_X emissions over one year period with November 2012 achieving the highest emissions of 2.67 tonnes due to high activity levels and March 2013 the lowest at 1.97 tonnes (*Table 5.17* and *Figure J1*). The increasing trend of emissions from August 2012 to November 2012 and then decreasing from November 2012 until March 2013 (*Figure J1*) looks similar to the activity rate in hours (refer to *Figure H1*). There is therefore a close relationship between number of hours of operation and emissions and this is true for all pollutants under consideration. November 2012 is the only month that achieved a double percentage digit of 10% (*Figure J2*).

Table 5.17: Total SO_X emissions (tonnes) by harbour crafts from ME and AE and the monthly percentage distribution of total SO_X emissions

	ME (tonnes)	AE (tonnes)	**ROW TOTAL (tpm)**	**Percentage of GRAND TOTAL**
Apr-12	2.02	0.09	**2.11**	**7.9%**
May-12	1.95	0.09	**2.04**	**7.6%**
Jun-12	2.13	0.10	**2.23**	**8.3%**
Jul-12	2.13	0.10	**2.22**	**8.3%**
Aug-12	1.95	0.09	**2.05**	**7.6%**
Sep-12	2.24	0.10	**2.35**	**8.7%**
Oct-12	2.42	0.11	**2.54**	**9.5%**
Nov-12	2.56	0.12	**2.67**	**10.0%**
Dec-12	2.30	0.10	**2.40**	**9.0%**
Jan-13	2.05	0.09	**2.14**	**8.0%**
Feb-13	2.01	0.09	**2.10**	**7.8%**
Mar-13	1.89	0.08	**1.97**	**7.4%**
COLUMN TOTAL (tpy)	**25.65**	**1.17**	**26.82**	**100.0%**
Percentage of GRAND TOTAL	**95,6%**	**4,4%**	**100,0%**	

PM_{10} EMISSIONS FROM HARBOUR CRAFTS

All months produced just above one tonnes of PM_{10} emissions from the harbour crafts with the monthly average of 1.17 tonnes (*Table 5.18* and *Figure K1*). Only the months from September to December 2012 exceeded the monthly average value with November being the highest at 1.4284 tonnes making 10.1% of total emissions (*Figure K2*).

Table 5.18: Total PM_{10} emissions (tonnes) by harbour crafts from ME and AE and the monthly percentage distribution of total PM_{10} emissions

	ME (tonnes)	AE (tonnes)	**ROW TOTAL (tpm)**	**Percentage of GRAND TOTAL**
Apr-12	1.0769	0.0203	**1.0972**	**7.8%**
May-12	1.0358	0.0206	**1.0564**	**7.5%**
Jun-12	1.1302	0.0226	**1.1528**	**8.2%**
Jul-12	1.1270	0.0226	**1.1496**	**8.2%**
Aug-12	1.0239	0.0212	**1.0450**	**7.4%**
Sep-12	1.2067	0.0235	**1.2301**	**8.7%**
Oct-12	1.3331	0.0259	**1.3591**	**9.6%**
Nov-12	1.4010	0.0273	**1.4284**	**10.1%**
Dec-12	1.2638	0.0237	**1.2876**	**9.1%**
Jan-13	1.1166	0.0217	**1.1383**	**8.1%**
Feb-13	1.0862	0.0218	**1.1080**	**7.9%**
Mar-13	1.0206	0.0194	**1.0400**	**7.4%**
COLUMN TOTAL (tpy)	**13.8220**	**0.2706**	**14.0926**	**100.0%**
Percentage of GRAND TOTAL	**98.1%**	**1.9%**	**100.0%**	

HC EMISSIONS FROM HARBOUR CRAFTS

The HC emissions have the smallest tonnage of all pollutants studied because of their small emission factor of 0.09 g/kWh (refer to *Table 4.21*). As a result, the total HC emissions from the harbour crafts were 1.8570 tonnes over one year period (Table 5.19). The monthly average was calculated at 0.1548 tonnes with that figure only exceeded from September till December 2012 (*Appendix L*).

Table 5.19: Total HC emissions (tonnes) by harbour crafts from ME and AE and the monthly percentage distribution of total HC emissions

	ME (tonnes)	AE (tonnes)	**ROW TOTAL (tpm)**	**Percentage of GRAND TOTAL**
Apr-12	0.1397	0.0061	**0.1458**	**7.9%**
May-12	0.1353	0.0062	**0.1415**	**7.6%**
Jun-12	0.1473	0.0068	**0.1541**	**8.3%**
Jul-12	0.1472	0.0068	**0.1540**	**8.3%**
Aug-12	0.1353	0.0063	**0.1417**	**7.6%**
Sep-12	0.1553	0.0070	**0.1624**	**8.7%**
Oct-12	0.1678	0.0078	**0.1756**	**9.5%**
Nov-12	0.1770	0.0082	**0.1852**	**10.0%**
Dec-12	0.1592	0.0071	**0.1663**	**9.0%**
Jan-13	0.1416	0.0065	**0.1481**	**8.0%**
Feb-13	0.1391	0.0065	**0.1456**	**7.8%**
Mar-13	0.1309	0.0058	**0.1367**	**7.4%**
COLUMN TOTAL (tpy)	**1.7758**	**0.0812**	**1.8570**	**100.0%**
Percentage of GRAND TOTAL	**95.6%**	**4.4%**	**100.0%**	

CO_2 EMISSIONS FROM HARBOUR CRAFTS

The CO_2 emissions have the highest tonnage of all pollutants under consideration as they carry the highest emission factor of 690 g/kWh (refer to *Table 4.21*). The total CO_2 emissions from harbor crafts over one year period were 14,237.13 tonnes with November being the highest at 1,419.8 tonnes (*Table 5.20* and *Figure M1*). Similar to other pollutants, only November reached a double digit percentage at 10% of the total emissions (*Figure M2*).

Table 5.20: Total CO_2 emissions (tonnes) by harbour crafts from ME and AE and the monthly percentage distribution of total CO_2 emissions

	ME (tonnes)	AE (tonnes)	**ROW TOTAL (tpm)**	**Percentage of GRAND TOTAL**
Apr-12	1,071.36	46.72	**1,118.08**	**7.9%**
May-12	1,037.38	47.27	**1,084.65**	**7.6%**
Jun-12	1,129.39	51.95	**1,181.34**	**8.3%**
Jul-12	1,128.45	52.07	**1,180.52**	**8.3%**
Aug-12	1,037.48	48.67	**1,086.15**	**7.6%**
Sep-12	1,190.76	53.98	**1,244.74**	**8.7%**
Oct-12	1,286.79	59.66	**1,346.45**	**9.5%**
Nov-12	1,356.93	62.87	**1,419.80**	**10.0%**
Dec-12	1,220.60	54.62	**1,275.21**	**9.0%**
Jan-13	1,085.93	49.85	**1,135.77**	**8.0%**
Feb-13	1,066.43	50.16	**1,116.59**	**7.8%**
Mar-13	1,003.21	44.61	**1,047.82**	**7.4%**
COLUMN TOTAL (tpy)	**13,614.71**	**622.41**	**14,237.13**	**100.0%**
Percentage of GRAND TOTAL	**95.6%**	**4.4%**	**100.0%**	

5.3.3 Emissions by Pollutant per Engine Type

The data provided by TNPA indicate that harbour crafts utilize the two types of engines, namely the main propulsion engine and auxiliary engine, equally in the port. This means that the number of hours of operation for both engines is the same (refer to digital dataset provided as CD1). However, the total annual port emissions in tonnes and the percentage distribution of pollutants between the main engines and auxiliary engines is not the same. The main engines are by far the biggest polluters, accounting for more than 95% of all pollutants from harbour crafts (*Table 5.21* and *Figure 5.3*). The huge discrepancies between the two engines are attributed to the fact that the main propulsion engines have higher emission factors than auxiliary engine. Therefore, for the same number of hours of operation the main engines will emit more pollutants than auxiliary engines.

Table 5.21: Total estimated port emissions (tpy and percentage) per engine type from harbour crafts

Type of Engine	**NO_X**	**SO_X**	**CO_2**	**HC**	**PM_{10}**
Main Engines (tpy) %	190.62 96.9%	25.65 95.6%	13,614.71 95.6%	1.78 95.6%	13.82 98.1%
Auxiliary Engines (tpy) %	6.13 3.1%	1.17 4.4%	622.41 4.4%	0.08 4.4%	0.27 1.9%
TOTAL (tpy) **%**	**196.75** **100%**	**26.82** **100%**	**14,237.13** **100%**	**1.86** **100%**	**14.09** **100%**

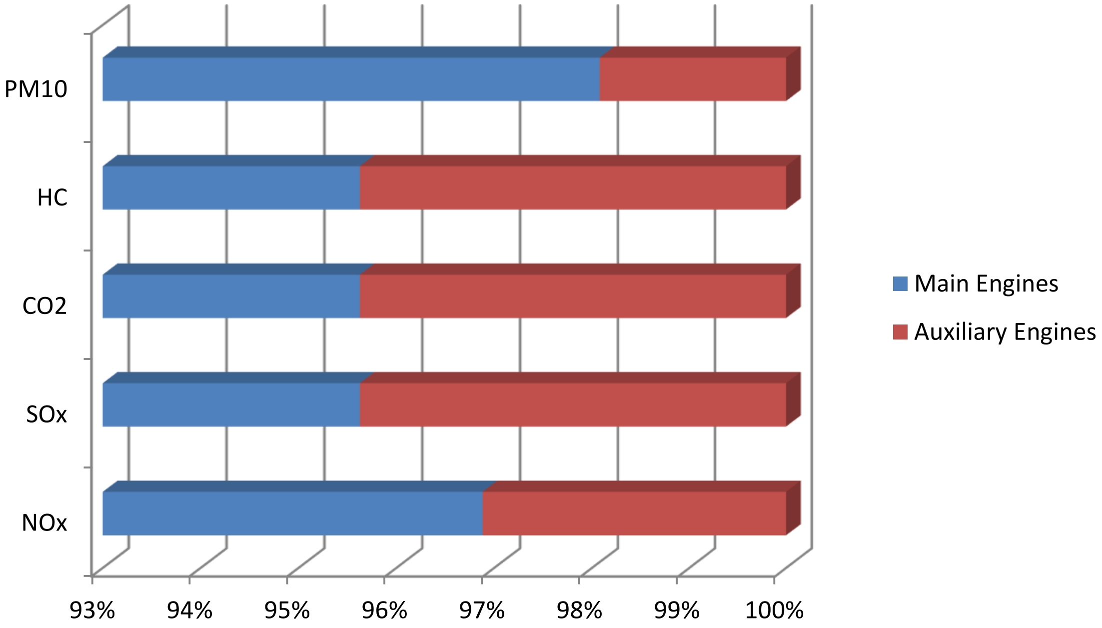


Figure 5.3: Percentage distribution of pollutants from harbour crafts per engine type

5.3.4 Emissions by Pollutant per Type of Craft

The tugboats were the most active harbour crafts and sailed everyday covering the total of 18,670 engine hours of operation over one year period (refer to *Table 5.15*). This resulted in tugboats being the highest emitters of pollutants in all harbour crafts exceeding 96% emissions of all pollutants (*Table 5.22* and *Figure 5.4*). The second biggest emitter after the tugboats was the floating crane at approximately 2.1% and then pilot boats at approximately 1.6% of total emissions of all pollutants. The corporate boat contributed approximately 0.04% emissions of all pollutants.

The number of operational hours spent by the two pilot boats (604 hours) was almost three times that of the floating crane (217 hours), however the emissions from the floating crane exceeded the emissions from the pilot boats combined (*Table 5.22*). This is likely due to the size of engine fitted onboard the floating crane where the floating crane's main engine capacity is 4,500 kW compared to the pilot boats' 1,044 kW engine power output (refer to *Table 4.19*).

Table 5.22: Total estimated port emissions (tpy) per vessel type from harbour crafts

Craft Type	NO$_X$	SO$_X$	CO$_2$	HC	PM$_{10}$
Tugboats (tpy)	189.41	25.83	13,707.57	1.79	13.56
%	96.26%	96.28%	96.28%	96.28%	96.25%
Pilot boats (tpy)	3.07	0.42	224.86	0.03	0.22
%	1.56%	1.58%	1.58%	1.58%	1.54%
Corporate boat (tpy)	0.07	0.01	4.98	0.0006	0.005
%	0.04%	0.04%	0.04%	0.04%	0.03%
Floating Crane (tpy)	4.21	0.56	299.71	0.04	0.31
%	2.14%	2.10%	2.10%	2.10%	2.18%
TOTAL (tpy)	**196.75**	**26.82**	**14,237.13**	**1.86**	**14.09**
%	**100%**	**100%**	**100%**	**100%**	**100%**

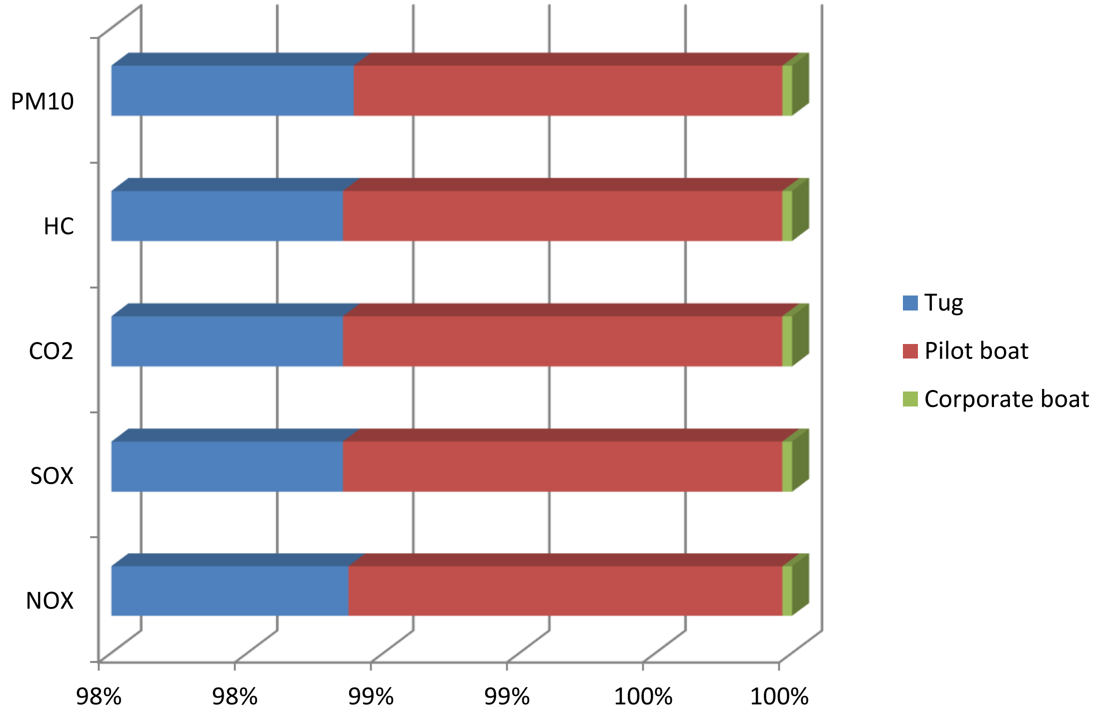


Figure 5.4: Percentage distribution of pollutants per vessel type from harbour crafts

5.4 INTEGRATION OF UNKNOWN OCEAN GOING VESSELS

There were 201 unknown OGVs and emissions from these vessels were not calculated. The emissions from OGVs were calculated from the total of 4,037 vessels. The unknown vessels accounted only five percent of OGVs and therefore a fair assumption was made that their emissions will make up five percent of the total. The total emissions from the known vessels can therefore be increased by five percent to compensate for the unknown vessels (*Table 5.23*).

Table 5.23: Total emissions from all OGVs in tonnes per year from 1st of April 2012 to 31st of March 2013

	NO_X	**SO_X**	**CO_2**	**HC**	**PM_{10}**
Number of known OGVs	4,037				
Emissions from known OGVs (tpy)	876.30	734.86	112,163.28	32.67	80.60
Number of unknown OGVs	201				
Emissions from unknown OGVs(tpy) ***(5% of known OGVs)***	43.82	36.74	5,608.16	1.634	4.03
Total Number of OGVs	4,238				
TOTAL Emissions from all OGVs (tpy)	**920.12**	**771.60**	**117,771.44**	**34.30**	**84.63**

5.5 TOTAL EMISSIONS

The emissions from all OGVs (*Table 5.24*) and harbour crafts (*Table 5.25*) were broken down into monthly averages and daily averages by dividing the total emissions with the number of months and days over the study period. The total emissions from all ships in the port were then calculated by adding the total emissions from all OGVs and total emissions from all harbour crafts studied (*Table 5.26*).

Table 5.24: Total emissions from OGVs from 1st of April 2012 to 31st of March 2013

All OGVs	NOx	SO_X	CO_2	HC	PM_{10}
TOTAL (tonnes per year)	**920.12**	**771.70**	**117,771.44**	**34.30**	**84.63**
Monthly Average (tonnes per month)	**76.68**	**64.31**	**9,814.29**	**2.86**	**7.05**
Daily Average (tonnes per day)	**2.52**	**2.11**	**322.66**	**0.094**	**0.232**

Table 5.25: Total emissions from TNPA harbour crafts from 1st of April 2012 to 31st of March 2013

All harbour crafts	NO_X	SO_X	CO_2	HC	PM_{10}
TOTAL (tonnes per year)	196.75	26.82	14,237.13	1.86	14.09
Monthly Average (tonnes per month)	13.56	2.24	1,186.43	0.16	1.17
Daily Average (tonnes per day)	0.45	0.075	39.55	0.0053	0.039

Table 5.26: Total emissions from all vessels in Durban Port from 1st of April 2012 to 31st of March 2013

	NOx	SO_X	CO_2	HC	PM_{10}
TOTAL Emissions from all OGVs (tpy)	**920.12**	**771.60**	**117,771.44**	**34.30**	**84.63**
TOTAL Emissions from all harbour crafts (tpy)	**196.75**	**26.82**	**14,237.13**	**1.86**	**14.09**
TOTAL from all vessels (tpy)	**1,116.87**	**798.42**	**132,008.57**	**36.16**	**98.72**
Monthly Average from all vessels (tpm)	**93.07**	**66.54**	**11,000.71**	**3.01**	**8.23**
Daily Average from all vessels (tpd)	**3.06**	**2.19**	**361.67**	**0.099**	**0.27**

5.6 DISPERSION MODEL RESULTS

The ADMS is able to model three priority pollutants which includes NO_X, SO_2 and PM_{10}. It takes into account the average wind speed and direction to calculate and map the pollutants distribution for hourly, daily and annual results. It must be noted that the annual NO_X, SO_2 and PM_{10} emissions distributions in Figure 5.5, Figure 5.7 and Figure 5.9 are all spread out in a North Easterly and South Westerly direction, which is in line with the annual wind rose pattern depicted in *Figure 2.4*.

5.6.1 Oxides of Nitrogen (NO_X)

The dispersion model indicate that the ships' annual NO_X contribution to the ambient concentration were measurable at four of the seven receptors, namely Durban CBD, uShaka Marine World, Island View Storage (IVS) and Marine Drive Residential (*Figure 5.5*). The other three receptors experienced an annual average concentration below 1 µg/m^3. The hourly NO_X concentrations at various receptors are based on the worst case (P100 or 100th percentile) hourly average concentration during May 2012, which experienced the highest emissions of pollutants (*Table 5.27* and *Figure 5.6*). The maximum annual average NO_X concentration of 8.32 µg/m^3 and the P100 hourly maximum of 55.82 µg/m^3 occurred near the harbour craft jetty (*Figure 5.5* and *Figure 5.6*). The assumption was made that all NO_X emissions from ships were converted to NO_2 for comparison with the NAAQS.

Table 5.27: Annual average and P100 hourly NO_X concentrations at receptors

Receptor	**Height of Measurement (m)**	**Annual Average Concentration (µg/m^3)**	**P100 Hourly Average Concentration (µg/m^3)**
Dirky Uys	1.5	0.45	14.00
Testing Ground	1.5	0.13	12.38
Syd Rick Turner	1.5	0.20	19.84
Glenwood Prep School	1.5	0.24	25.26
Golf Course	1.5	0.53	20.62
Durban CBD	1.5	1.87	24.32
Ushaka Marine World	1.5	2.17	18.01
IVS	1.5	2.20	17.84
Marine Drive Res	1.5	1.20	15.47

The maximum annual average concentration of NO_2 resulting from ship emissions (assuming long term emissions at the level experienced in May 2012) was 8.32 µg/m^3 and thus remained below the NAAQS of 40 µg/m^3. The maximum P100 hourly NO_2 concentration across the study domain was 55.82 µg/m^3, which was also lower than the NAAQS of 200 µg/m^3 (refer to the ADMS model results in *Figure 5.5* and *Figure 5.6* and the summary of results in *Table 5.27*). It must be highlighted that these are significant contributions to the NAAQS and should not be ignored in cumulative assessments.

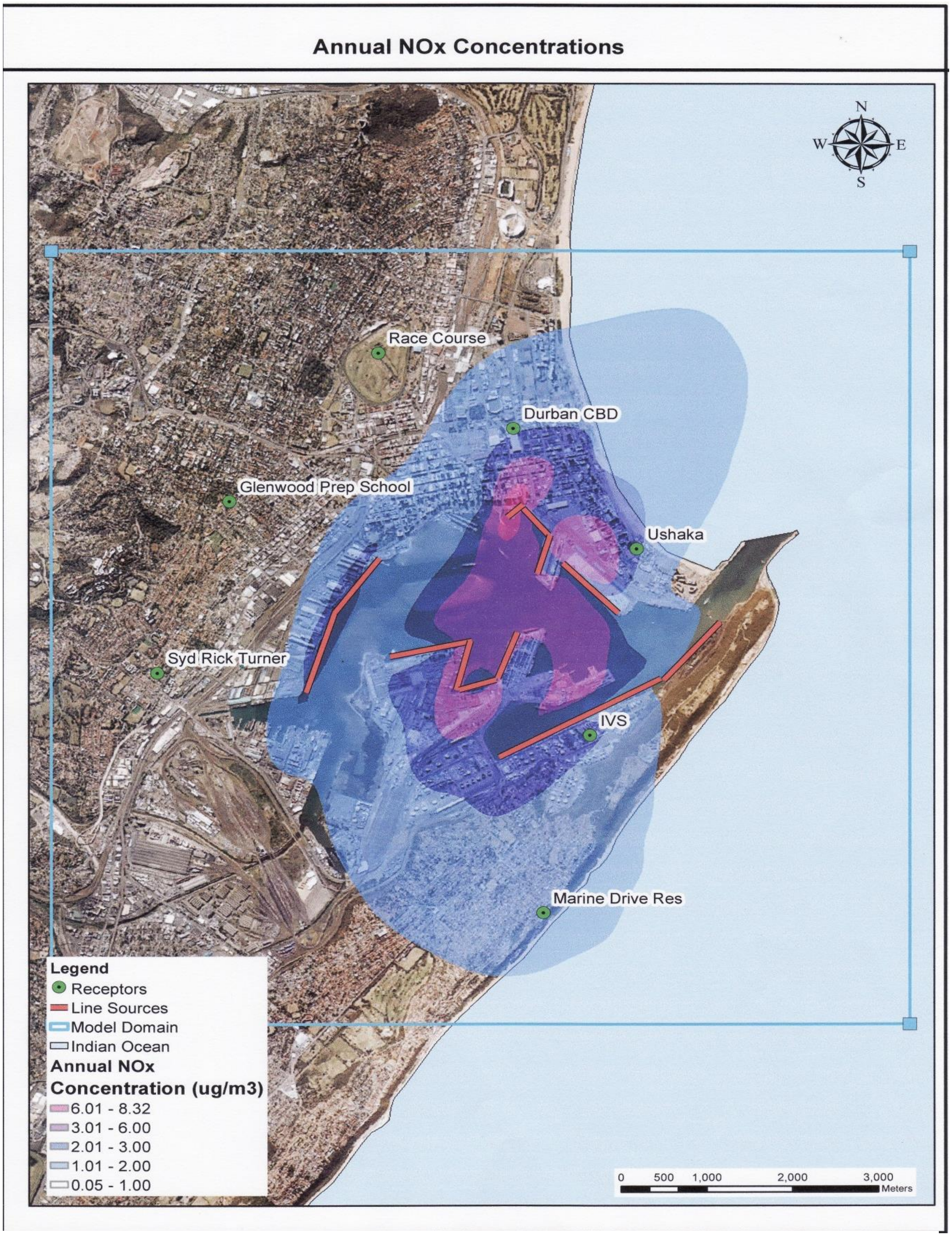


Figure 5.5: Annual average NO_X concentration from ADMS model

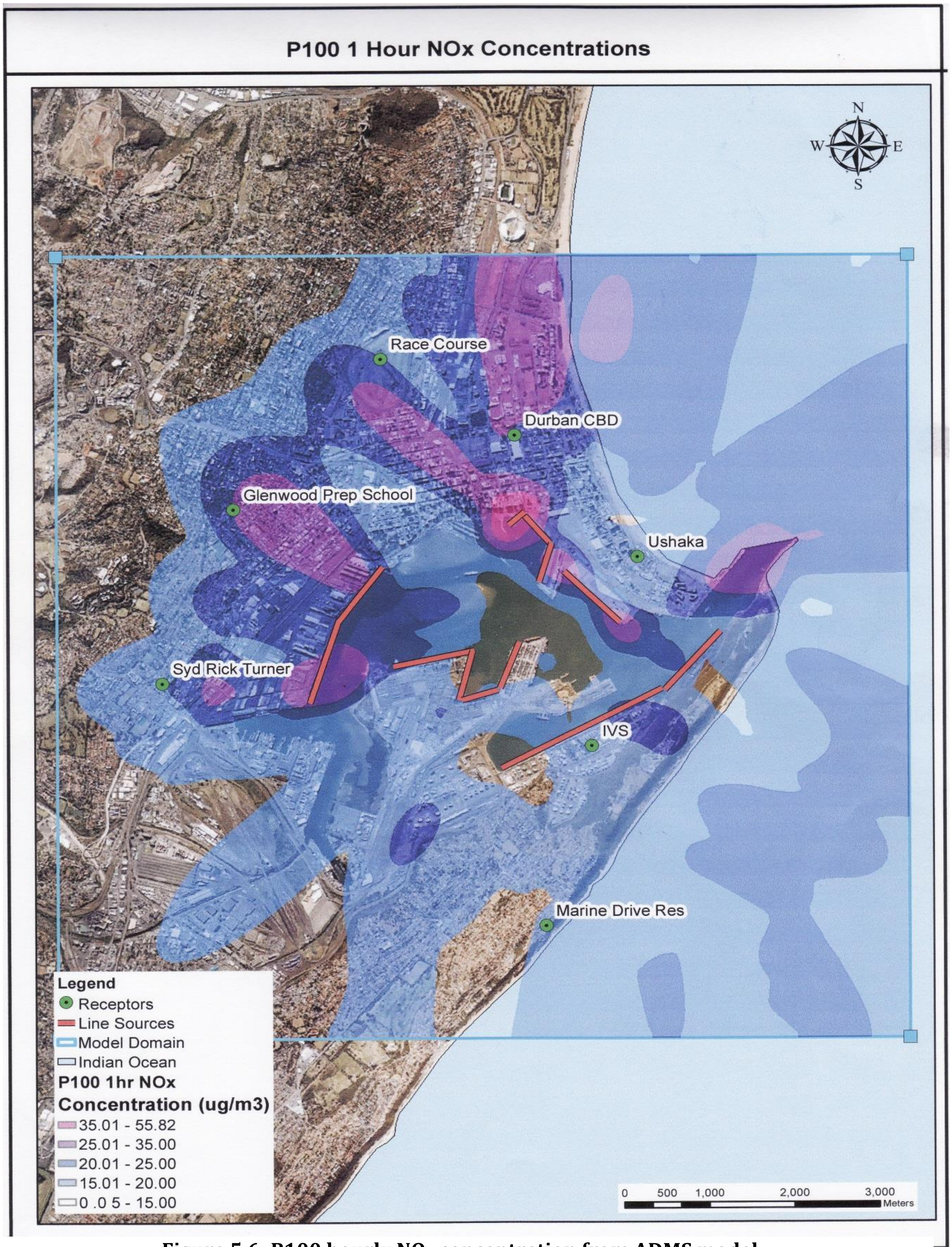


Figure 5.6: P100 hourly NO$_X$ concentration from ADMS model

5.6.2 Sulphur Dioxide (SO_2)

The results from the dispersion model indicate that the highest P100 SO_2 hourly average concentration was experienced at the Glenwood Preparatory School receptor (*Table 5.28*). The ships' SO_2 contribution to the annual average ambient concentrations was measurable at three receptors (*Figure 5.7*). However the P100 hourly concentration was observed at all receptors except the Marine Drive residential receptor (*Figure 5.8*).

Table 5.28: Annual average and P100 hourly SO_2 concentrations at receptors

Receptor	**Height of Measurement (m)**	**Annual Average Concentration (μg/m³)**	**P100 Hourly Average Concentration (μg/m³)**
Dirky Uys	1.5	0.34	11.37
Testing Ground	1.5	0.10	9.54
Syd Rick Turner	1.5	0.15	16.07
Glenwood Prep School	1.5	0.18	20.62
Golf Course	1.5	0.39	12.51
Durban CBD	1.5	1.03	16.50
Ushaka Marine World	1.5	1.75	14.70
IVS	1.5	1.67	14.55
Marine Drive Res	1.5	0.92	10.97

The ADMS results reveal that the maximum annual average concentration of SO_2 resulting from ship emissions (assuming long term emissions at the level experienced in May 2012) was 3.55 $\mu g/m^3$ and remained well below the NAAQS of 50 $\mu g/m^3$. The maximum P100 hourly concentrations of SO_2 that resulted from ships emissions was 26.75 $\mu g/m^3$, which was also well below the hourly NAAQS of 350 $\mu g/m^3$ (refer to the ADMS model results in *Figure 5.7* and *Figure 5.8* and the summary of results in *Table 5.28*). However, these results should not be ignored in cumulative assessments of urban air quality.

Figure 5.7: Annual average SO_2 concentration from ADMS model

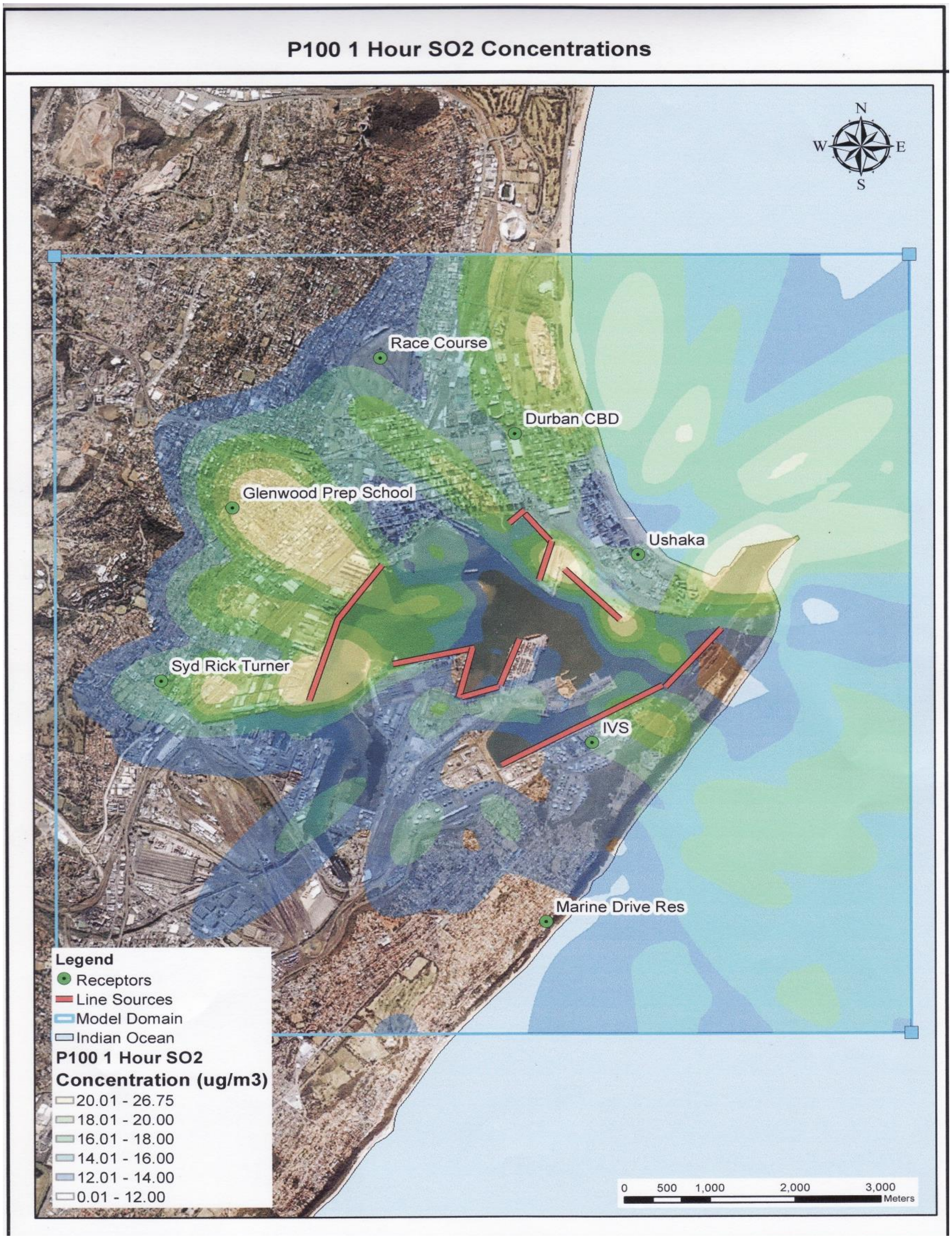


Figure 5.8: P100 hourly SO_2 concentration from ADMS model

5.6.3 Particulate Matter of less than ten micrometers (PM_{10})

The Durban CBD and the Ushaka Marine World experienced the highest average P100 24-hourly PM_{10} concentration (*Table 5.29*). The annual average concentrations of PM_{10} from ships in Port were measurable at four receptors (*Figure 5.9*). The ships' P100 24-hourly PM_{10} contributions to ambient concentrations were measurable across five of the seven receptors (*Figure 5.10*). The P100 24 hour values are relevant to the measured PM_{10} concentration because the air quality standard has an averaging period of 24 hours.

Table 5.29: Annual average and P100 24-hourly PM_{10} concentrations at receptors

Receptor	Height of Measurement (m)	Annual Average Concentration (µg/m³)	P100 24-Hourly Average Concentration (µg/m³)
Dirky Uys	1.5	0.05	0.20
Testing Ground	1.5	0.01	0.21
Syd Rick Turner	1.5	0.02	0.27
Glenwood Prep School	1.5	0.02	0.34
Golf Course	1.5	0.06	0.59
Durban CBD	1.5	0.24	0.96
Ushaka Marine World	1.5	0.20	0.96
IVS	1.5	0.22	0.80
Marine Drive Res	1.5	0.12	0.48

The maximum annual average concentration of PM_{10} resulting from ships (assuming long term emissions at the level experience in May 2012) was 0.83 µg/m³, which is well below the current annual NAAQS of 50 µg/m³ and the maximum P100 24-hourly concentration resulting from ships was 3.08 µg/m³, which is well below the current NAAQS at 120 µg/m³ (refer to the ADMS model results in *Figure 5.9* and *Figure 5.10* and the summary of results in *Table 5.29*). The PM_{10} concentrations from ships emissions do not exceed allowable NAAQS, however their contribution must not be ignored in cumulative assessments of urban ambient air quality.

Figure 5.9: Annual average PM_{10} concentration from ADMS model

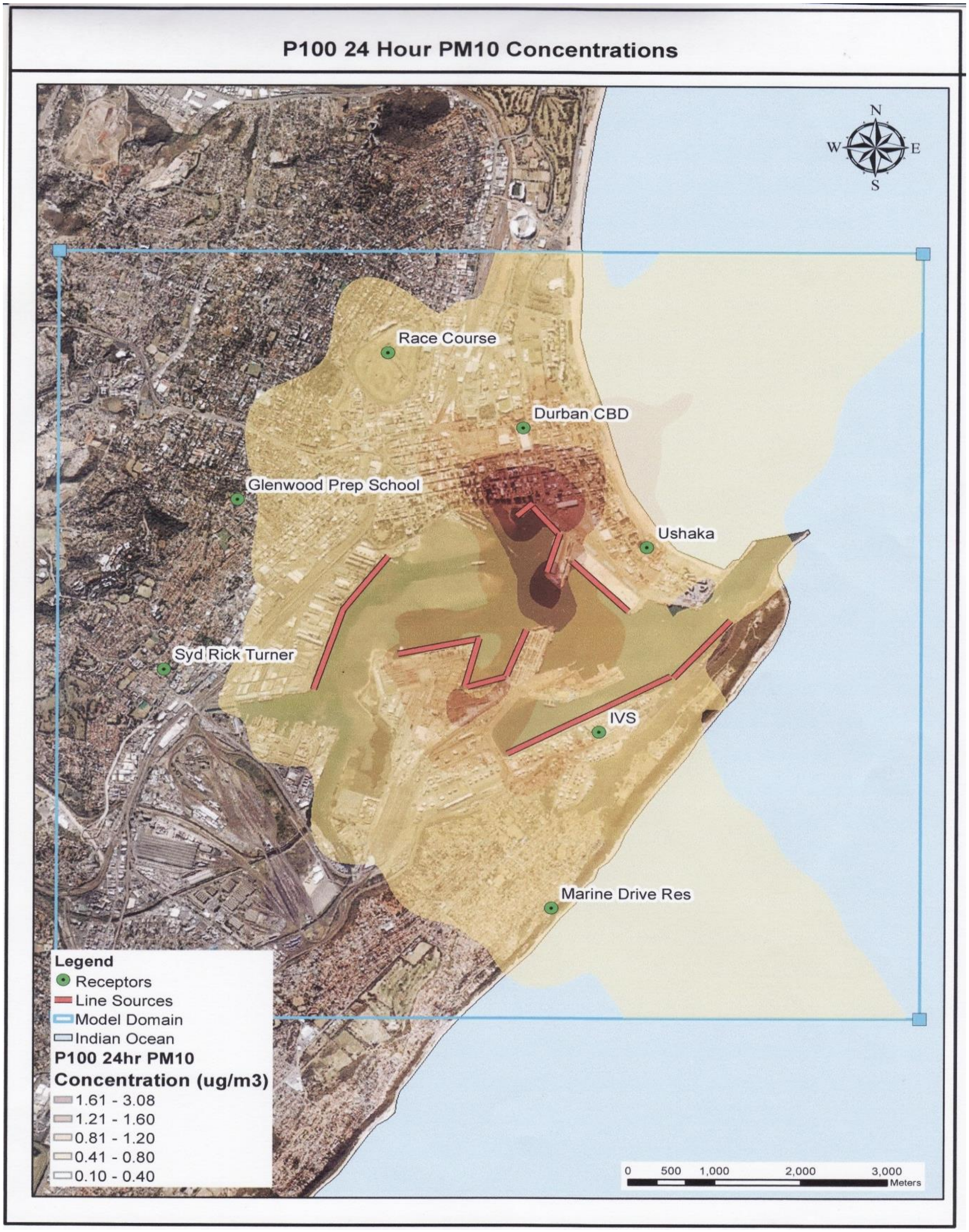


Figure 5.10: P100 24-Hourly PM$_{10}$ concentration from ADMS model

6. FINAL DISCUSSION AND RECOMMENDATIONS

6.1 INTRODUCTION

This study was aimed at determining the contribution of ships exhaust gas emissions to the pollution of air in the Durban Port area. It focused mainly on calculating pollution emitted by ships whilst manoeuvring or docked inside Durban Port over the period from 1st of April 2012 till 31st of March 2013. The study area is approximately 14.8 square nautical miles or 27.4 square kilometers and bounded by the coordinates listed in paragraph 2.1 (refer to *Figure 2.1*). Five pollutants, NO_X, SO_X, PM_{10}, HC and CO_2, formed the focus of this study. The study focused on all OGVs calling into Durban Port and the harbour crafts belonging to TNPA. In this chapter, comparisons were made between emissions from ships in Durban Port and the surrounding industries in SDB including vehicular emissions and between emissions from ships in Durban Port and other ports around the world.

6.2 COMPARISON BETWEEN SHIP EMISSIONS AND INDUSTRIAL SOURCES IN THE SOUTH DURBAN REGION

6.2.1 Sulphur Dioxide

The ships' total annual SO_2 emissions were calculated at 798.42 tonnes per annum. This value is well below the emissions from Engen Refinery, which recorded 2,700 tonnes per annum in 2010. Compared to SO_2 emissions from SAPREF at 11 tonnes per day in 2011, the ships daily emission were five times less at 2.19 tonnes per day. Although Engen's and SAPREF's emissions were based on 2010 and 2011 annual performance report respectively, the current figures are not expected to be vastly different from the compared figures. Mondi's SO_2 emission figures for 2006 ranged between 500 and 1,000 tonnes per annum are compatible to the ships emission of 798.42 tonnes per annum. When compared to vehicular emissions in SDB, the SO_2 emission from ships in Port at 798.42 tonnes per year were higher than the SO_2 emissions from vehicles at 203 tonnes per annum (refer to *Table 6.1* below for industry comparison of SO_2 emissions). These results show that the port emissions of SO_2 should not be ignored in cumulative air quality impact assessments. Ambient SO_2 is a critical concern for those living in South Durban, and up until this point, port emissions have not been considered in ambient assessments.

6.2.2 Nitrogen Oxides

The total annual NO_X emissions from ships in Port were calculated at 1,116.87 tonnes per annum and were lower than Engen's emissions in 2010 at 1,760 tonnes per annum and also less than SAPREF's emissions in 2011 at 1,241 tonnes per annum (refer to *Table 6.1* for industry comparison of NO_X emissions). No comparisons were made with Mondi Paper Mill due to lack of data. Once again, these results show that the port emissions should not be ignored in cumulative air quality impact assessments

6.2.3 Particulate Matter of Less Than 10 micrometers

The PM_{10} emissions from Engen in 2010 were 176 tonnes per annum and the calculated emissions from ships in 2013 were almost half that amount at 98.72 tonnes per annum. However, compared to SAPREF's PM_{10} emissions of 2011 at 73 tonnes per annum, the ships emissions were higher. PM_{10} was the only pollutant where ships emitted higher than anyone of the industries concerned (refer to *Table 6.1* for industry comparison of PM_{10} emissions). These results show that the port emissions should not be ignored in cumulative air quality impact assessments, particularly the assessment of ambient particulates and dust fallout impacts.

6.2.4 Hydrocarbons

If all HC emissions from ships are assumed to be benzene or VOCs, then such emissions from ships can be compared to benzene emissions from Engen and VOCs from SAPREF as provided in their environmental performance reports. Annual HC emissions from ships in 2012 to 2013 were 36.16 tonnes per annum and were well below benzene emissions of 1,519 tonnes per annum from Engen in 2010 and well below the VOCs emissions of 3,158 tonnes per annum from SAPREF in 2011 (refer to *Table 6.1* for industry comparison of HC emissions).

6.2.5 Carbon Dioxide

The CO_2 emissions from Engen in 2010 were estimated at 717,933 tonnes per annum and SAPREF in 2011 were estimated at 866,000 tonnes per. The CO_2 emissions from ships in 2013 were less than one fifth of both industry emissions at 132,000.57 tonnes per annum. Therefore the contribution of ships to the carbon footprint and other pollutants while in the Port may be significant but remains less than other industries in the region. However, since the Government Gazette dated 14 March 2014 declaring greenhouse gases as priority pollutants was released by the Department of Environmental Affairs, the total CO_2 emissions from ships must be compared with the new requirements. The regulations state that all emitters of greenhouse gases in excess of 0.1 Megatonnes annually or measured as $CO_{2\text{-eq}}$ are required to submit a pollution prevention plan (RSA, 2014). The CO_2 emissions of 132,000.57 tonnes per annum (0.132 Megatonnes) from ships in Durban Port exceed the set limit of 0.1 Megatonnes. When the CO_2 emissions from ships in Port are compared with vehicular emissions from Tara road, which is a single street 6.4 kilometers long in SDB, ships emit more CO_2 at 132,000.57 per annum than the vehicles at 4,185 tonnes per annum. Although these results may change if all the streets within the SDB are included, nevertheless the results show that the port emissions should not be ignored in cumulative air quality impact assessments (refer to *Table 6.1* for industry comparison of CO_2 emissions).

Table 6.1: Comparison of ships' emissions to the three adjacent industries and the vehicular emissions in Durban South Basin

	SHIPS IN PORT (2012 – 2013)		**Engen (2010)**		**SAPREF (2011)**		**Mondi (2006)**		**Vehicular Emissions in SDB (2012)**	
POLLUTANT	Ave Annual Emission (*tpy*)	Ave Daily Emission (*tpd*)	Ave Annual Emission (*tpy*)	Ave Daily Emission (*tpd*)	Ave Annual Emission (*tpy*)	Ave Daily Emission (*tpd*)	Ave Annual Emission (*tpy*)	Ave Daily Emission (*tpd*)	Ave Annual Emission (*tpy*)	Ave Daily Emission (*tpd*)
SO_2	798.42	2.19	2,700	9	4,015	11	500-1,000	1.4 – 2.74	203	0.56
NO_X	1,116.87	3.06	1,786	4.8	1,241	3.4	-	-		
PM_{10}	98.72	0.27	176	0.48	73	0.2	-	-		
HC	36.16	0.099	1,519	4.16	3,158	8.65	-	-		
CO_2	132,008.57	361.7	717,933	1,966.9	866,000	2,372.6	-	-	4,185 (Tara Road)	11.5 (Tara Road)

6.3 COMPARISON WITH OTHER FOREIGN PORTS

This section compares the results obtained in the study of Durban Port to the methodologies used and the result from three other ports elsewhere around the globe i.e. in Europe, America and Asia. The results from each port show disparities with the results from Durban Port (*Table 6.2*). These disparities are attributed to various factors from each study ranging from difference in sizes of study areas to the differences in number of ships and methodologies used.

Table 6.2: Comparison of emissions in tonnes per year from OGVs in Durban Port and three other ports around the globe

Port	Year of Study	Number of OGVs (movements)	NO_X	SO_X	CO_2	HC	PM_{10}
			tpy				
Durban Port (South Africa)	2012 - 2013	4,238	876	735	112,163	33	81
JN Port (India)	2006	2,841	369	291			30
Port of Los Angeles (USA)	2005 & 2007	5,430	6,206	5,609	11,340,000,000 (2007 Study)	247	634
Port of Copenhagen (Denmark)	2001	5,729	555	129			14

6.3.1 Comparison between Durban Port and JN Port

The results obtained in JN Port are compatible to the results obtained in Durban Port. This is because both study areas were contained within the port limits covering 23.5 square nautical miles for JN Port and 14.8 square nautical miles for Durban Port.

For JN Port, only the emissions from OGVs were estimated and therefore for a conforming comparison, only OGVs in Durban Port will be compared. The number of ships' activities in Durban Port (4,238) was 1.5 times the number of ships' activities in JN Port (2,841) over one year period. It therefore follows that the amount of emission for all pollutants in Durban Port should be more or less 1.5 times the amount of emission in JN Port, assuming similar ship categories and proportions within these categories. However, instead the emissions in Durban Port were approximately 2.5 times the emissions for JN Port (*Table 6.3*) and the reasonable explanation for this discrepancy is described below.

Table 6.3: Comparison of results between JN Port and Durban Port

Port	Number of OGV activities	NO_X	SO_X	PM_{10}
Durban Port (South Africa)	4,238	920	772	85
JN Port (India)	2,841	369	291	30
RATIO (Durban Port/JN Port)	**1: 1.5**	**1: 2.5**	**1: 2.7**	**1: 2.8**

The discrepancies between the ratio of ships activities and emission values in the two ports can be attributed to the following important differences between the two studies:

- The JN Port study only considered ships emissions during the hotelling mode and did not include emissions from the manoeuvring mode. This means that for JN Port, all emissions resulted from auxiliary engines and none from either the main propulsion engines or the boilers. However with the study of Durban Port, all modes of operation were considered and pollutions from all three engines were included in the study.
- The maximum continuous ratings (MCR) for the auxiliary engines in JN Port were average values for the type of ships under study. These values were adopted from the USEPA guideline document released in 2000. However, the Durban Port study utilized specific MCR values for each ship in Port, which were extracted from IHS Lloyd’s register website. The average values were used only where no data was available and the averages were drawn from the similar types of ships in the Port.
- The load factors for auxiliary engines used in JN Port differ from those used in Durban Port. The load factors were modified by USEPA (2009) after conducting several studies. Except for container ships and bulk carriers, most of the load factors in JN Port were higher than the load factors used for Durban Port study (refer to *Table 3.1 and 4.8*).
- The emission factors used for Durban Port differed from those used in JN Port because certain adjustments had to be made following the changes imposed by MARPOL from *Tier 1* to *Tier 2* in January 2011 for NO_X and sulphur content reductions in fuel in January 2010 for SO_X (refer to *Figures 3.2 and 3.3* for change of Tiers and *Table 4.12* for adjustment factors).
- Lastly, the JN Port study assumed that all auxiliary engines used residual fuel oil which had higher emission factors than the diesel fuel oil assumed for the Durban Port study.

6.3.2 Comparison between Durban Port and the Port of Los Angeles (POLA)

The study of POLA was conducted over an area of 4,025.6 square nautical miles, which is 272 times larger than the Durban Port study area of 14.8 square nautical miles. The POLA study included calculation of ships emissions from transit within the study area, manoeuvring inside the port, hotelling at berth and at anchorage. This data was collected from various sources including the port control, the port tenants such as terminal controllers, and ships agencies. The more expansive data which included the call records of ships were obtained from Marine Exchange of Southern California, which tracks and records the movement of all OGVs entering and departing San Pedro Bay. In addition, the port undertakes a Vessel Boarding Program to gather specific vessel characteristics and operational data from ships visiting the port (Starcrest, 2007). Such data collection services are not available in Durban Port and hence the study area was limited by the availability of data.

It became apparent during literature review that there are few ports globally that have been inventoried for marine mobile pollution sources, particularly using the detailed approach. This left fewer options of port inventory results that could be compared to the Durban Port study. The study of POLA was therefore chosen for its similarity in methodology to the Durban Port study despite the massive area size difference between the two studies. Therefore, to compensate for this discrepancy in area size, a comparison was made using ratios of sizes and emissions between the two ports and the analyses were based on this relationship.

There were 4,238 OGVs manoeuvring within Durban Port over the study period from the 1st of April 2012 until the 31st of March 2013 and the Port of Los Angeles registered 5,430 OGVs movements over the one year study period in 2005 (*Table 6.4*). This means that 1,192 more vessels manoeuvred in POLA than in Durban Port and this included the 777 vessels that conducted hot-shifts within POLA and between POLA and the adjacent POLB in San Pedro Bay (Starcrest, 2007).

The 2005 pollution inventory of POLA included four of the five pollutants of interest for the study of Durban Port, namely NO_X, SO_2, PM_{10} and HC. CO_2 did not form part of the 2005 inventory in POLA, however it was done separately under the expanded greenhouse gas (GHG) inventory for 2007.

Table 6.4: Comparison of emissions from OGVs between POLA and Durban Port

Port	**Year of Study**	**Area size (square miles)**	**Number of OGV activities**	**NO_X**	**SO_X**	**CO_2**	**HC**	**PM_{10}**
						tpy		
Durban Port (South Africa)	2012 - 2013	14.8	4,238	876	735	112,163	33	81
Port of Los Angeles (USA)	2005	4,025.6	5,430	6,206	5,609		247	634
RATIO (POLA/Durban Port)		**1:272**	**1:1.3**	**1:7.1**	**1:7.6**		**1:7.5**	**1:7.8**
Port of Los Angeles (USA)	2007		4,942			11,340,000,000		
RATIO (POLA/Durban Port)			**1:1.2**			**1:101,103**		

When the 2005 and 2007 POLA inventories on OGVs are compared to the 2012-2013 Durban Port inventory, disparities in emissions between the two ports are realized. The results show that the emissions in POLA are approximately seven times greater than the Durban Port emissions for all four priority pollutants and hundred thousand times more than Durban Port in CO_2 emissions (*Table 6.4*). Such disparities are mainly attributed to the following important factors:

- The difference in sizes between the two study areas is significant. The study area of Durban Port is limited to within the port boundaries and covers approximately 14.8 square nautical miles. The area bounding the study site of POLA is in excess of 4,025.6 square nautical miles. This area is more than 272 times larger than the Durban Port study area.
- A ship proceeding at transit speed has higher emission factor for propulsion engines than a ship proceeding at manoeuvring speed and therefore produces more emissions. The vastness of POLA study area allows ships to proceed at transit speeds and even cruising speeds inbound and outbound from the port while ships in Durban Port only manoeuvred within the port at not more than eight knots.
- The POLA study included another activity called hotelling at anchorage. Ships spend hours and sometimes days at the anchorage awaiting berths in the port to load or off-load their cargo. This duration of anchorage can easily surpass the duration alongside in the port with both auxiliary and boiler engines running and sometimes the main propulsion engines at idling mode. Hotelling at anchorage was not included in Durban Port study because the anchorage area falls outside the chosen area of study and operational data on ships at anchorage was not available.

The other difference in results between POLA and Durban Port is the types of engines that pollute the most. The main propulsion engines dominate the emissions in POLA whereas in Durban Port the auxiliary engines and boilers are the most dominant of all pollutants. The reasons for such differences can be explained as follows:

- In Durban Port, the main propulsion engines are mostly shutdown and in a non-emitting mode. On the contrary, at POLA the main propulsion engines spend more time running and emitting pollutants because of the expansion of the study area included in the study of POLA.
- In Durban Port, the main propulsion engines are always operating at manoeuvring speed whereas in POLA they maybe in idling, manoeuvring, transiting or cruising speeds, which can produce more emissions than simple manoeuvring.
- When the main propulsion engines are running, there is less demand for auxiliary engines and boilers because certain power demands for hotelling or domestic use is generated by propulsion engines. Therefore this will reduce the emissions from the auxiliary engine and boilers.
- The POLA has been fitted with Alternative Maritime Power (AMP), which is the air quality program of reducing emissions from vessels docked at the POLA (2015). This system allows for cold ironing where the major polluting engines in the port, namely auxiliary and boiler engines are completely shut off and the ship is using shore power supply for hotelling services. This may well account for the discrepancy in the ratios of areas versus emissions between the two ports. For instance the area ratio between Durban Port and POLA is one in 272 but the pollution ratio is one in seven between the two ports. This meant that the total emissions from auxiliary engines and boilers in POLA may have reduced substantially. The auxiliary engines and boilers in Durban Port accounted for over 90 percent of total emissions and if these were completely eliminated or reduced by a large percentage, then the emissions in Durban Port and in POLA may be compatible. Not every space within the POLA study area is occupied by vessels. Although the POLA area is huge compared to Durban Port area, however most emission occur closer to the port where there is a larger concentration of ships within the study area. Therefore, the larger portion of the massive space encompassing the POLA study area did not account for any pollution because ships normally follow the same track in and out of the port.

A similarity exists regarding the types of vessels that produce most pollutants. Both studies revealed that the container ships produce more pollutions than other vessels within the study areas and they account for more than 40% of emissions of all pollutants in both ports (refer to *Figure 3.6* and *Figure 5.2*). The studies also reveal that the tugboats dominate the pollution from harbour crafts in both ports although in Durban Port they are responsible for over 90% of emissions and in POLA they account for at least 40% of emissions (refer to

Figure 3.8, Figure 3.9 and *Figure 5.4*). The difference can be attributed to the fewer numbers of other types of harbour crafts studied in Durban Port due to lack of data. There were 19 harbour crafts inventoried in Durban Port and five of those did not emit any pollutants during the study period and therefore only 15 harbour crafts, which included 10 tugboats, were responsible for all the emissions. The last similarity is that the main propulsion engines from harbour crafts dominate the emissions from both ports because they have the same operational hours as auxiliary engines but they have higher emission factors than the auxiliary engines.

The harbour crafts in POLA were 13 times more than in Durban Port. However, the ratios of emissions of various pollutants are not uniform but differ from one pollutant to another. For instance the NO_X emissions in POLA are six times more than Durban Port, but the SO_X emissions are less than a third of the Durban Port emissions. The PM_{10} and HC emissions are 3 times and 13 times more than Durban Port emissions respectively (*Table 6.5*).

Table 6.5: Comparison of emissions from harbour crafts between POLA and Durban Port

Port	**Year of Study**	**Number of Harbour crafts inventoried**	**NO_X**	**SO_X**	**CO_2**	**HC**	**PM_{10}**
			Tpy				
Durban Port (South Africa)	2012 - 2013	19	197	27	14,237	2	14
Port of Los Angeles (USA)	2005	255	1,259	7		26	38
RATIO (POLA/Durban Port)		**1:13**	**1:6**	**1:0.3**		**1:13**	**1:3**

The fluctuation in emission ratios between the two ports can be associated with the differences in emission factors used in both studies (*Table 6.6*). The bottom row of *Table 6.6* was mostly used in calculations of emissions because most harbour crafts engines fall under Category 2. In the table, the SO_2 emission factors for POLA (0.15 g/kWh) make up an eighth of SO_2 emission factors for Durban Port study (1.3 g/kWh) and this has resulted into more SO_2 emissions in Durban Port (27 tpy) than in POLA (7 tpy) despite POLA having more harbour crafts than Durban Port over one year period. The HC emission factors for POLA (0.27 g/kWh) are six times greater than those used in Durban Port (0.09 g/kWh) and this created a significant difference in the amount of HC emissions from harbour crafts in each port (refer to *Tables 6.5* and *6.6*).

Table 6.6: Comparison between emission factors for harbour crafts in POLA and in Durban Port

	DURBAN PORT					PORT OF LOS ANGELES				
Minimum Power (kW)	**NO_x (g/kWh)**	**PM_{10} (g/kWh)**	**SO_2 (g/kWh)**	**CO_2 (g/kWh)**	**HC (g/kWh)**	**NO_x (g/kWh)**	**PM_{10} (g/kWh)**	**SO_2 (g/kWh)**	**CO_2 (g/kWh)**	**HC (g/kWh)**
Tier 2 Engines						**Tier 2 Engines**				
37	6.8	0.4	1.3	690	0.09	6.8	0.4	0.15		0.27
75	6.8	0.3	1.3	690	0.09	6.8	0.3	0.15		0.27
130	6.8	0.3	1.3	690	0.09	6.8	0.3	0.15		0.27
225	6.8	0.3	1.3	690	0.09	6.8	0.3	0.15		0.27
450	6.8	0.3	1.3	690	0.09	6.8	0.3	0.15		0.27
560	6.8	0.3	1.3	690	0.09	6.8	0.3	0.15		0.27
1,000	6.8	0.3	1.3	690	0.09	6.8	0.3	0.15		0.27
Cat 2	9.8	0.72	1.3	690	0.09	9.8	0.72	0.15		0.50

6.3.3 Comparison between Durban Port and the Port of Copenhagen

The comparison between the Port of Copenhagen and Durban Port is based on emission calculations and the results from the dispersion model. There were more ships in the Port of Copenhagen than in Durban Port. However, more emissions resulted in Durban Port than in the Port of Copenhagen (*Table 6.7*).

Table 6.7: Comparison of emissions from OGVs between the Port of Copenhagen and Durban Port

Port	**Year of Study**	**Number of OGV activities**	**NO_X**	**SO_X**	**CO_2**	**HC**	**PM**
			Tpy				
Durban Port (South Africa)	2012 - 2013	4,238	876	735	112,163	33	81
Port of Copenhagen (Denmark)	2001	5,729	555	129			14
RATIO (Durban Port/ Port of Copenhagen)		**1:0.7**	**1:2**	**1:6**			**1:6**

The disparities in ratios between the number of vessels and the resultant emissions can be attributed to the following important factors:

- The study of the Port of Copenhagen assumed that cargo ships used MSD engines for propulsion and therefore the same emission factors were used for all cargo ships in the port. While in Durban Port the emission factors varied according to the types of engines ranging from SSD and MSD to HSD. The majority of main propulsion engines in Durban Port were SSD, which had higher emission factors than the MSD.
- The Port of Copenhagen assumed that the heavy fuel oil contained a maximum of 1.5% sulphur content in accordance with MARPOL Convention Annex VI, as the port is within the emission control area in the Baltic Sea. The Durban Port is not in

emission control area and therefore the maximum sulphur content in fuel was assumed to be 3.5%. The higher sulphur content results in higher SO_2 emissions.

- The emission factors of SO_2, NO_X and PM for the main propulsion engines in the Port of Copenhagen study were assumed to be 6 g/kWh, 12 g/kWh and 0.44 g/kWh respectively. These were lower compared to the Durban Port study where main propulsion engines emission factors used for SO_2, NO_X and PM were approximately 10 g/kWh, 16 g/kWh and 0.6 g/kWh respectively. This was because of the difference in sulphur contents of fuel due to emission area controls and the sizes of engines in question (refer to *Table 3.15* and *Table 4.14*).
- The load factors in Copenhagen were assumed to range between 25% and 50% for manoeuvring and hotelling modes and in Durban Port, the majority of vessels including container ships and bulk carriers had load factors below 20% in hotelling mode. All vessels in Durban Port had load factor lower than 25% in the hotelling mode except for the vehicle carriers, which had 26% load factor (refer to *Table 4.8*).
- The Durban Port study included the emissions from the boilers in all modes of operations, which resulted in considerable amounts of emissions. There was no evidence that boiler emissions were included in the study of the Port of Copenhagen.

The results from the dispersion model of the Port of Copenhagen indicated that the NO_X hourly emission limits of 200µg/m^3 were exceeded. The other two pollutants, namely SO_2 and PM were below the set limits of 350µg/m^3 and 50µg/m^3 respectively in Copenhagen. Durban Port achieved hourly figures below set limits for all three pollutants (*Table 6.8*).

The Port of Copenhagen had fewer emissions than Durban Port in terms of tonnage, however the dispersion model results indicate higher concentrations of pollutants in Copenhagen than in Durban Port (*Table 6.8*). This may be because in the Port of Copenhagen modelling, ships were defined as point source emitters whereas in Durban Port they were described as line sources of emission. In a point source scenario, pollutants may be stacked in one point and have limitations in horizontal divergence. However, in the line source scenario pollutant have a wider area to spread. Another important factor that could influence the results is the meteorological differences between the areas studied. Although the meteorological factors for the Port of Copenhagen study were not available, however the meteorological variables inputted in the dispersion model will impact on the concentrations of pollutants.

Table 6.8: Comparison between the dispersion model results of Port of Copenhagen and Durban Port

Port	Year of Study	Number of OGV activities	NO_X		SO_2		TSP (Copenhagen) PM_{10} (Durban)	
			Hourly mean values (µg/m^3)					
			Model value	Limit Value	Model value	Limit Value	Model value	Limit Value
Durban (South Africa)	2012 - 2013	4,238	**55.82**	**200**	**26.75**	**500**	**3.08** **(24-hourly)**	**120** **(24-hourly)**
Copenhagen (Denmark)	2001	5,729	**615**	**200**	**142**	**350**	**1.10** **(hourly)**	**50** **(hourly)**

6.4 STUDY SUMMARY

The study of Durban Port was focused on calculating the emissions from the ships that were entering, leaving or docking in the Port from the 1st of April 2012 until the 31st March 2013. It used the activity-based method to calculate the emissions of NO_X, SO_2, PM_{10}, HC and CO_2 from ships while in the Port. The three types of ships' activities considered were manoeuvring, hotelling and loading/unloading and the focus was on OGVs and harbour crafts under the control of TNPA.

The results indicate that the OGVs, particularly the container ships, were the major emitters of all pollutants studied. The auxiliary engines dominated the emissions of NO_X and HC, while the boilers dominated the SO_2, PM_{10} and CO_2 emissions from the OGVs in the Port. The main propulsion engine emissions from the harbour crafts surpassed the emissions from the auxiliary engines. There was a strong indication that ships accounted for fewer emissions than other industries within the SDB in all pollutants except PM_{10}. Although ships emitted more PM_{10} per annum than SAPREF, it was still lower than Engen's PM_{10} emissions. However, when compared with vehicular emissions, ships showed higher annual emissions of SO_2 within the SDB and also dominated CO_2 emission when one busy road in the SDB was considered. When the ADMS was used to model the concentration of NO_X, SO_2 and PM_{10}, the results indicated that the ambient concentration of pollutants from ships were below the NAAQS. However, the overall results indicate that emissions from ships are significant and should not be ignored in cumulative air quality assessments.

6.5 LIMITATIONS

The results showed that most emissions of SO_X, CO_2 and PM_{10} from OGVs develop from the boilers. This is because of the assumption that all OGVs operate boilers which may not necessarily be true. However, with limited data about the boiler operations it is difficult to accurately estimate emissions resulting from the boilers, which may lead to overestimating the boiler emissions.

Most ships have more than one auxiliary generators and sometimes more than one generator are running at any given time. This is done so that the ship is able to conduct various tasks during the time of high demand in power supply especially during loading and offloading operations. It is therefore difficult to know how many auxiliary engines were running under certain conditions and over what duration they were being operated. For the purpose of this study, only one auxiliary engine was assumed to be operational aboard each vessel at any given time and this may lead to underestimating the emissions from the auxiliary engines.

The lack of data on privately owned harbour crafts other than TNPA crafts is a critical setback and has impact on the marine mobile port inventory. It is not easy to estimate the contribution of these harbour crafts to the pollution in the port and therefore hard to determine the impact of the lack of such data to the marine mobile port inventory.

6.6 RECOMMENDATIONS

The US Ports authorities embarked on vessel boarding program that focuses on gathering specific vessel characteristics and operational data from ships visiting their ports. The data collected during such operations include the vessel's main engine capacity, fuel type and usage, number of auxiliary engines and their capacities as well as the ship's manoeuvring data and port activities (Starcrest, 2007). Such a program has a potential to increase the database on ships visiting a particular port. Durban Port could conduct similar operations where the missing data on ships visiting the port can be collected and stored.

Methods of recording operational data and obtaining technical data on privately owned harbour crafts can be implemented. These may include regular boarding operations on harbour crafts in the port or a compulsory declaration by all harbour crafts on their status and operations, which can be sent at regular intervals to the port authorities. This will enable the port to conduct a more accurate inventory and an improved pollution assessment of marine mobile sources.

The port infrastructure and services can be improved by building the shore electrical power supply facilities to reduce the ships emissions during the docking mode. Approximately 90% of ships pollution in the port comes from auxiliary engines and boilers (refer to *Table 5.12* and *Figure 5.1*). This is because the auxiliary engines and the boilers remain operational during the docking mode. More than 80% of the ship's time in port is spent in docking mode and if this time can be spent without any emissions, then the ships' total emissions in port can be reduced by more than half.

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APPENDICES

Appendix A: Distribution of OGVs per ship type per month.

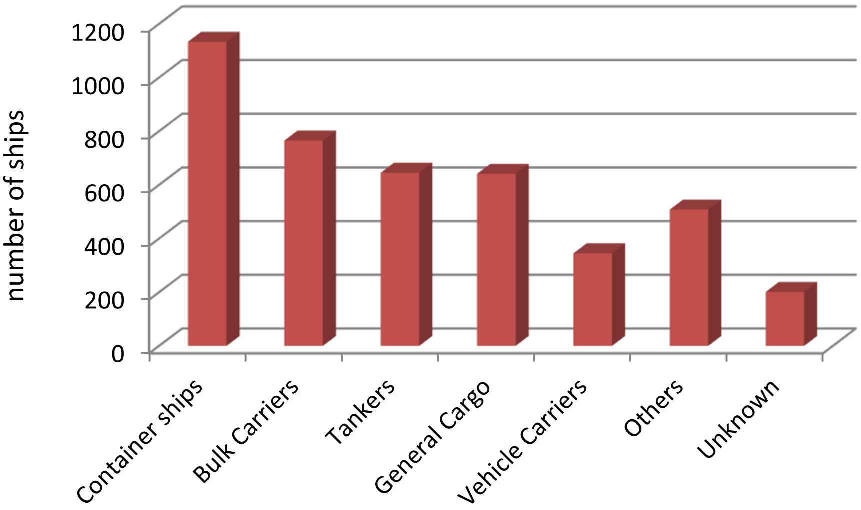

Figure A1: Total number of OGVs in Durban Port from 1st of April 2012 till 31st of March 2013

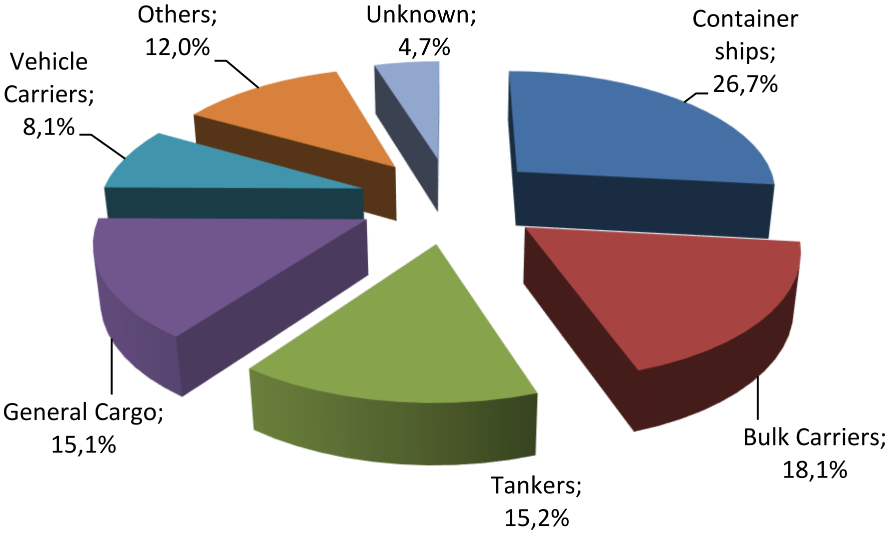

Figure A2: Percentage distribution of OGVs manoeuvring in Durban Port between 1st of April 2012 and 31st of March 2013

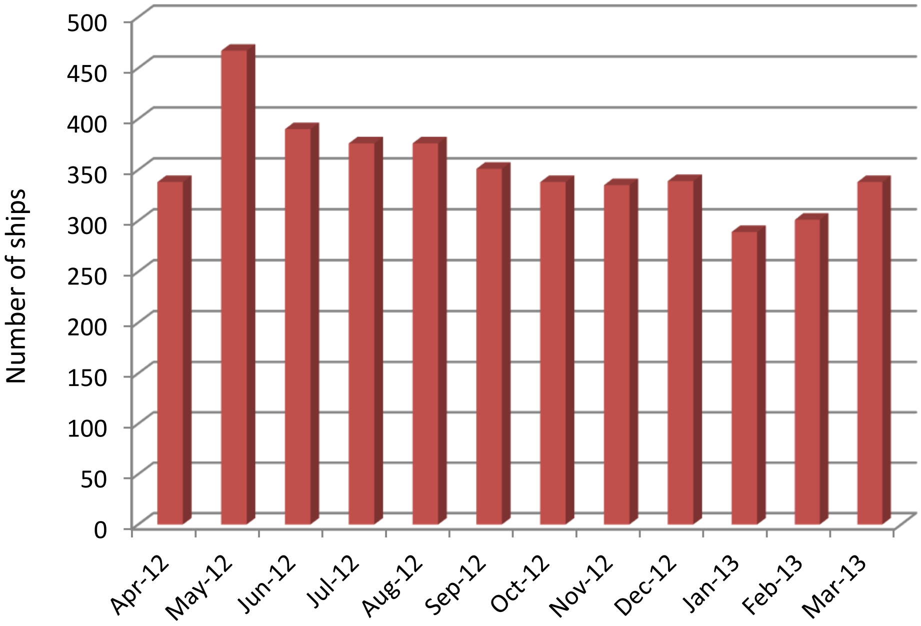

Figure A3: Total number of ships per month calling into Durban Port from 1st of April 2012 to 31st of March 2013

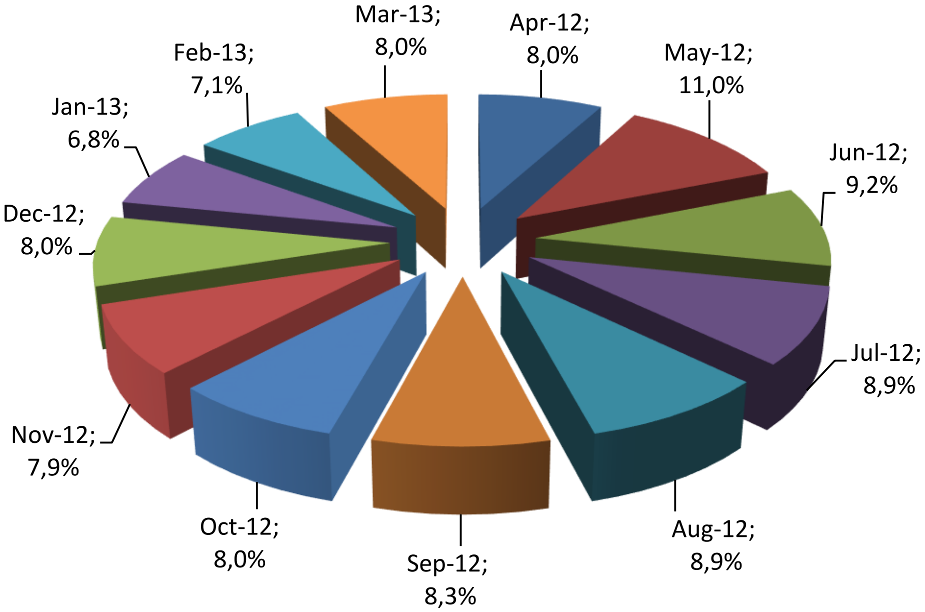

Figure A4: Monthly percentage distribution of ships calling into Durban Port from 1st of April 2012 to 31st of March 2013

Appendix B: Gross Tonnage distribution of OGVs per ship type per month.

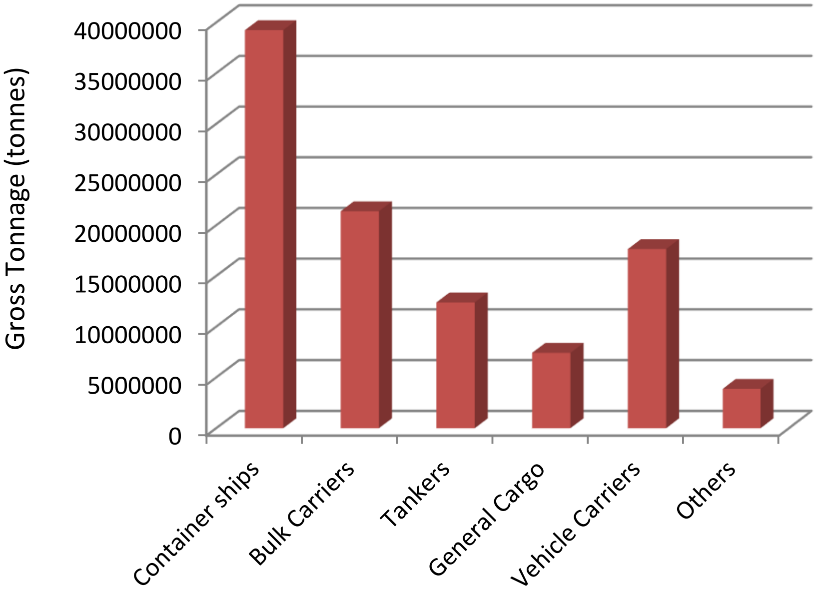

Figure B1: Total gross tonnage (tonnes) per ship type in Durban Port between 1st of April 2012 and 31st of March 2013

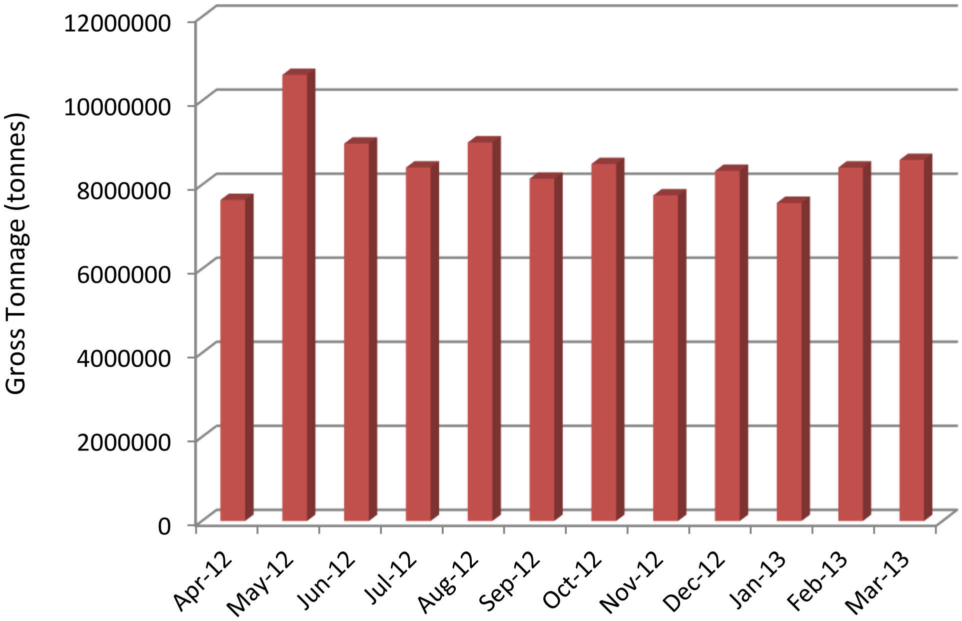

Figure B2: The total gross tonnage of all ships per month in Durban Port from 1st of April 2012 to 31st of March 2013

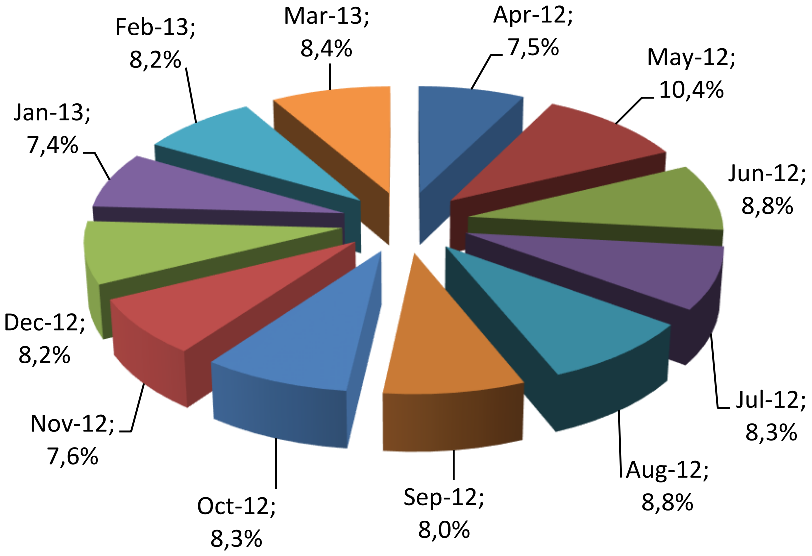

Figure B3: Monthly percentage distribution of the total gross tonnage of all ships in Durban Port from 1st April 2012 to 31st March 2013

Appendix C: NO_X Emissions from OGVs

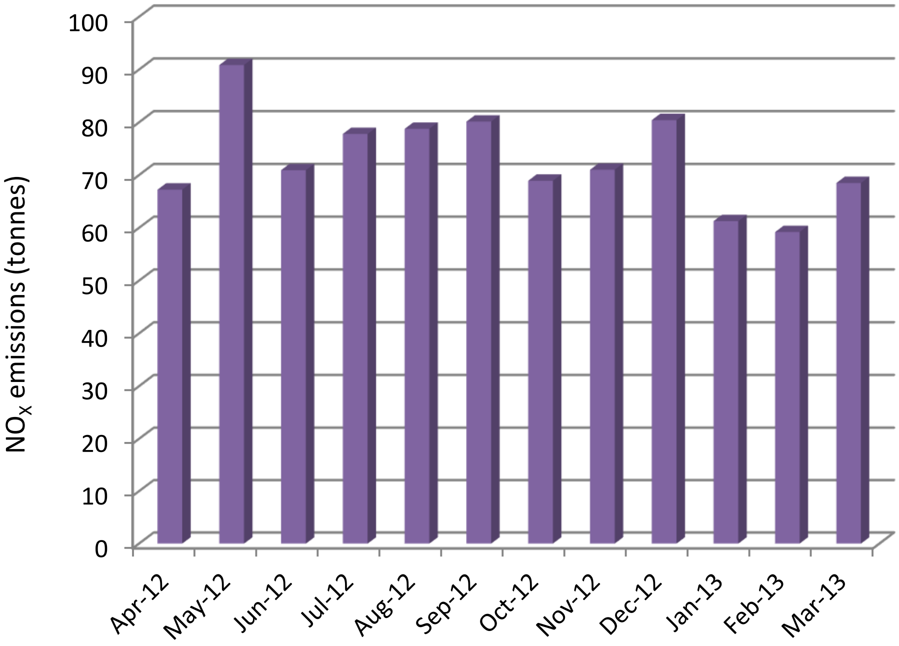

Figure C1: Total NO_X emissions (tpm) from OGVs

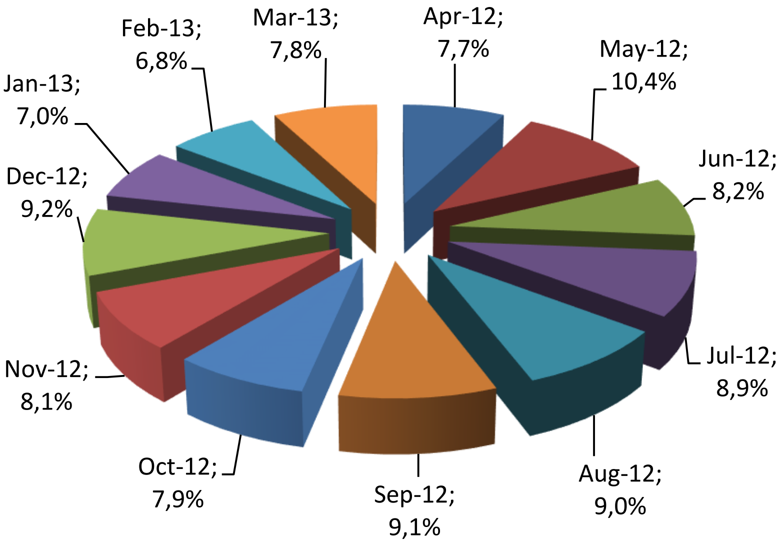

Figure C2: Monthly percentage distribution of NO_X emissions from OGVs

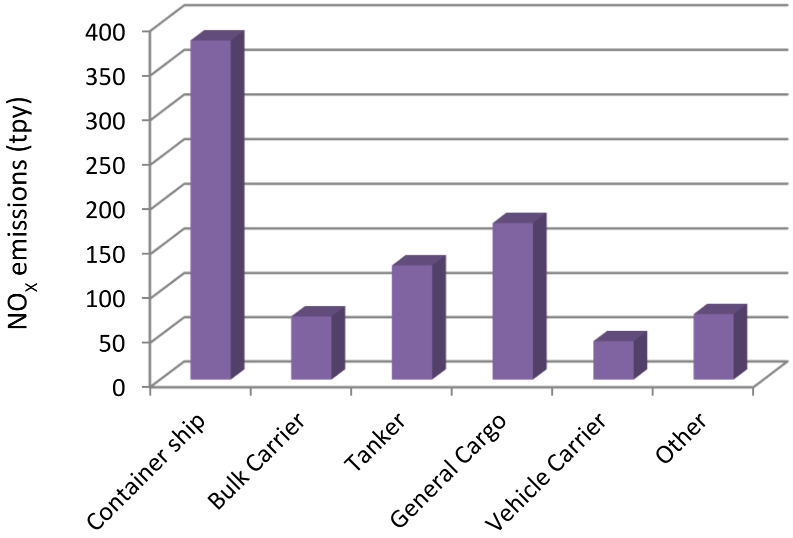

Figure C3: Total NO_X emissions (tpy) from OGVs per ship type

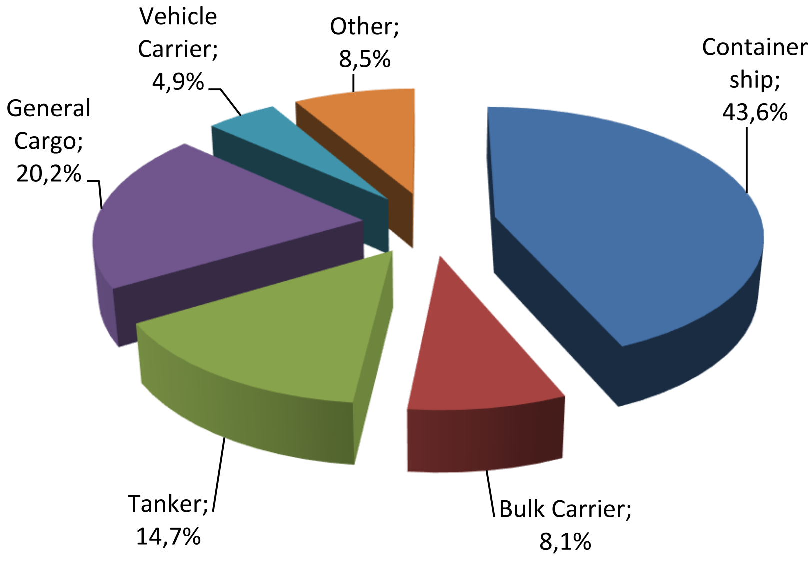

Figure C4: Percentage distribution of the total NO_X emissions per ship type

Appendix D: SO_X Emissions from OGVs

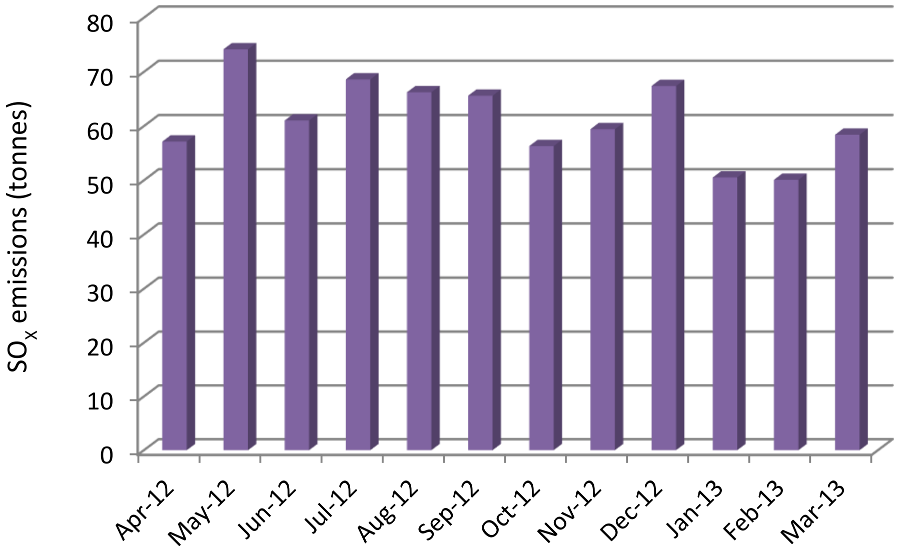

Figure D1: SO_X emissions (tpm) from OGVs

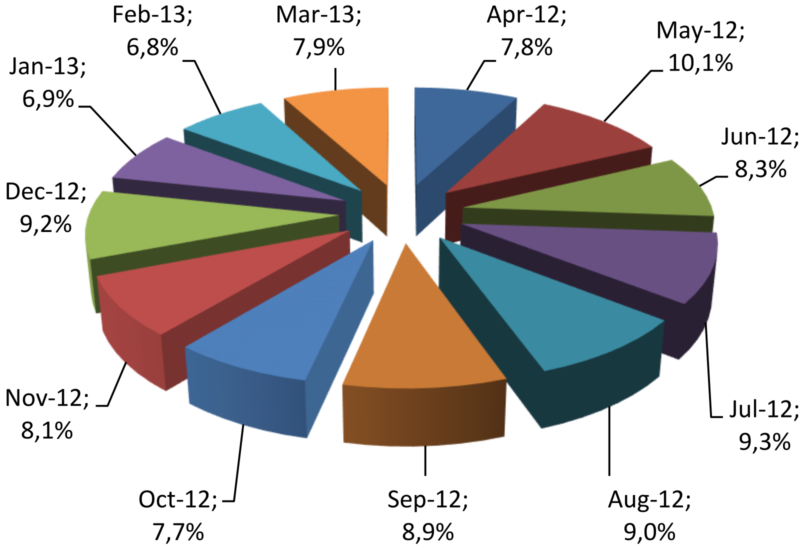

Figure D2: Monthly percentage distribution of SO_X emissions from OGVs

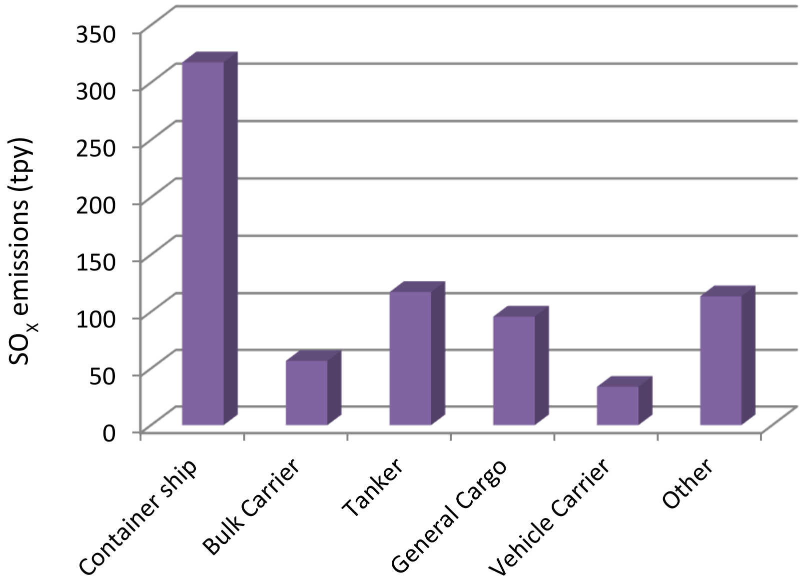

Figure D3: Total SO_X emissions (tpy) from OGVs per ship type

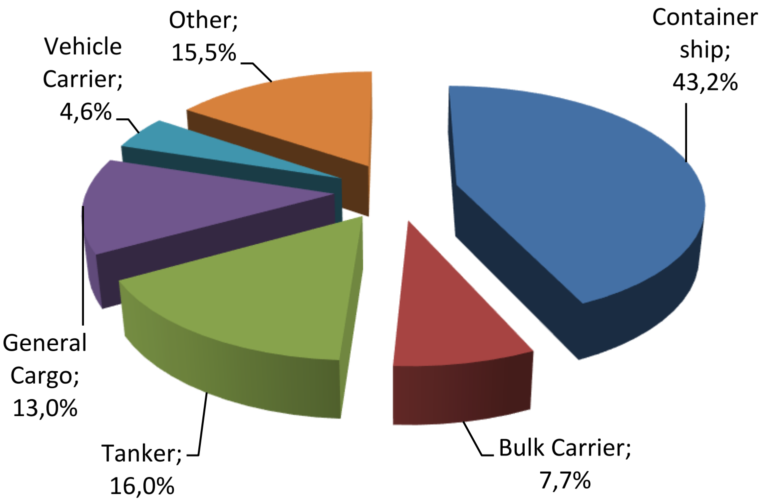

Figure D4: Percentage distribution of the total SO_X emissions per ship type

Appendix E: PM$_{10}$ Emissions from OGVs

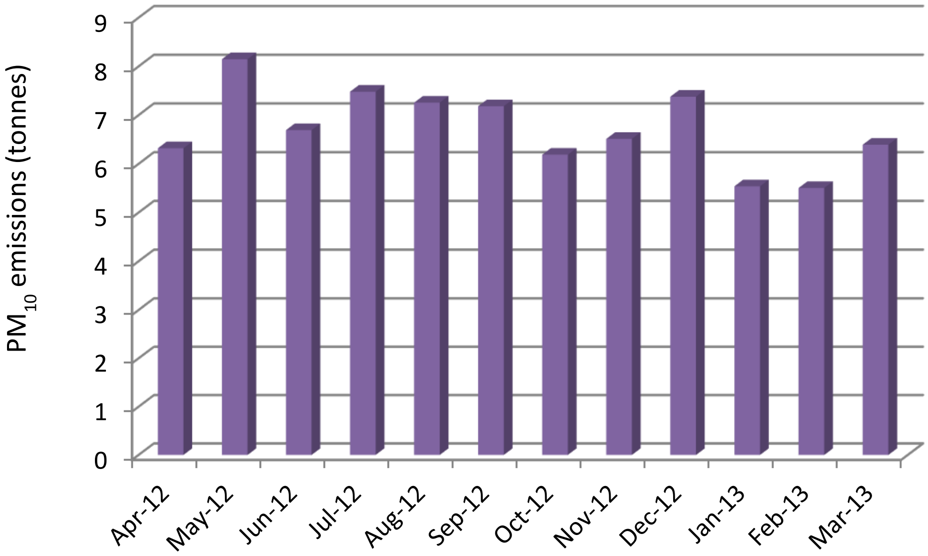

Figure E1: Total PM10 emissions (tpm) from OGVs

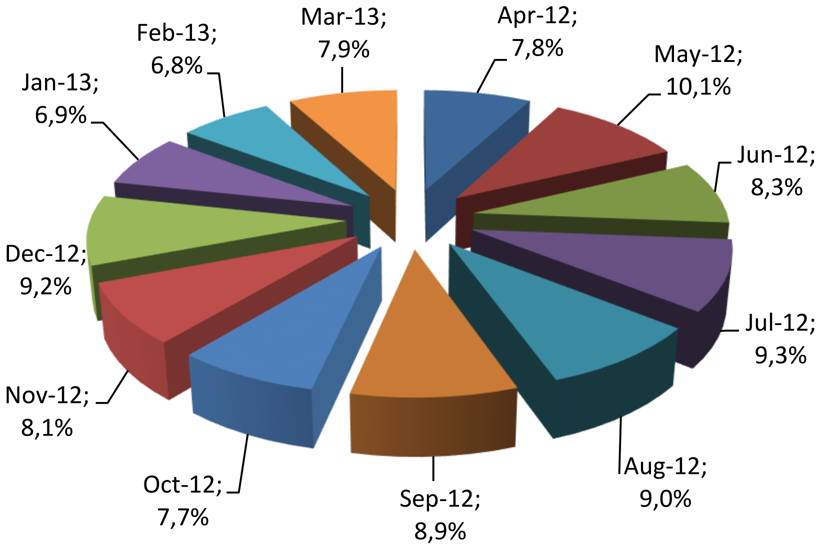

Figure E2: Monthly percentage distribution of PM$_{10}$ emissions from OGVs

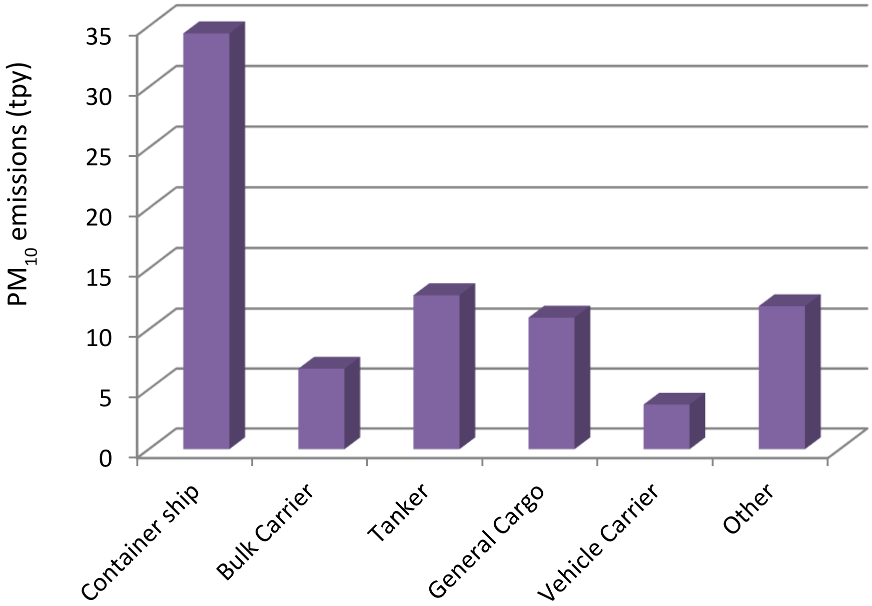

Figure E3: Total PM_{10} emissions (tpy) from OGVs per ship type

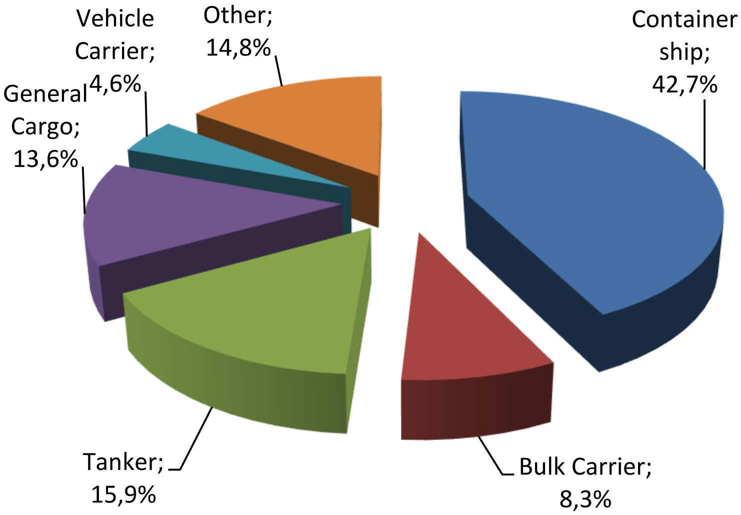

Figure E4: Percentage distribution of the total PM_{10} emissions per ship type

Appendix F: HC Emissions from OGVs

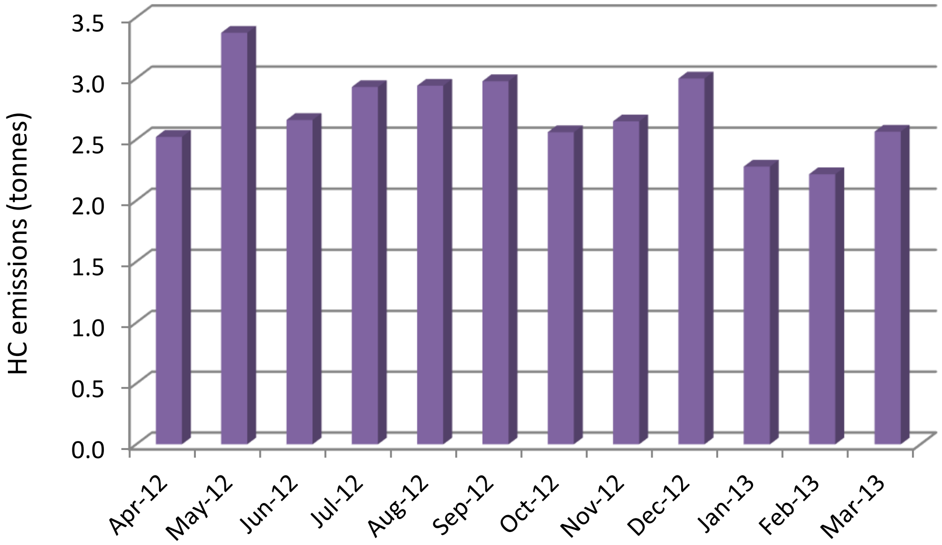

Figure F1: HC emissions (tpm) from OGVs

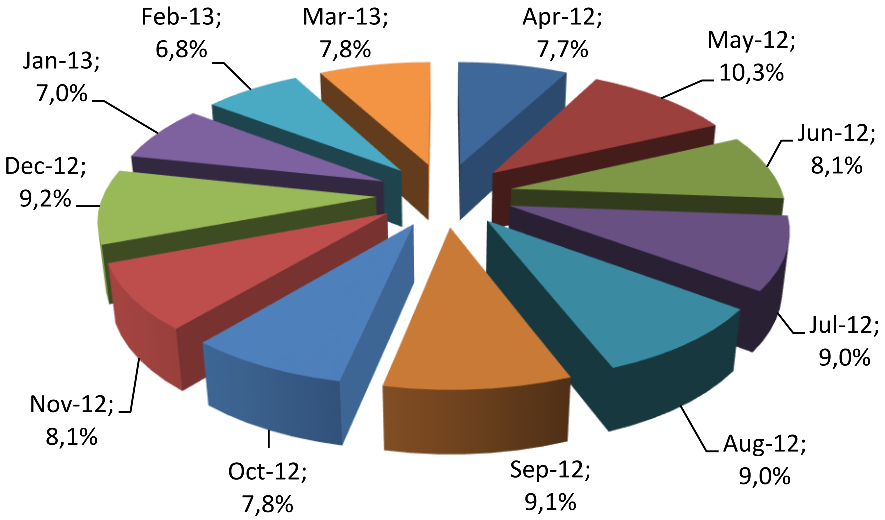

Figure F2: Monthly percentage distribution of HC emissions from OGVs

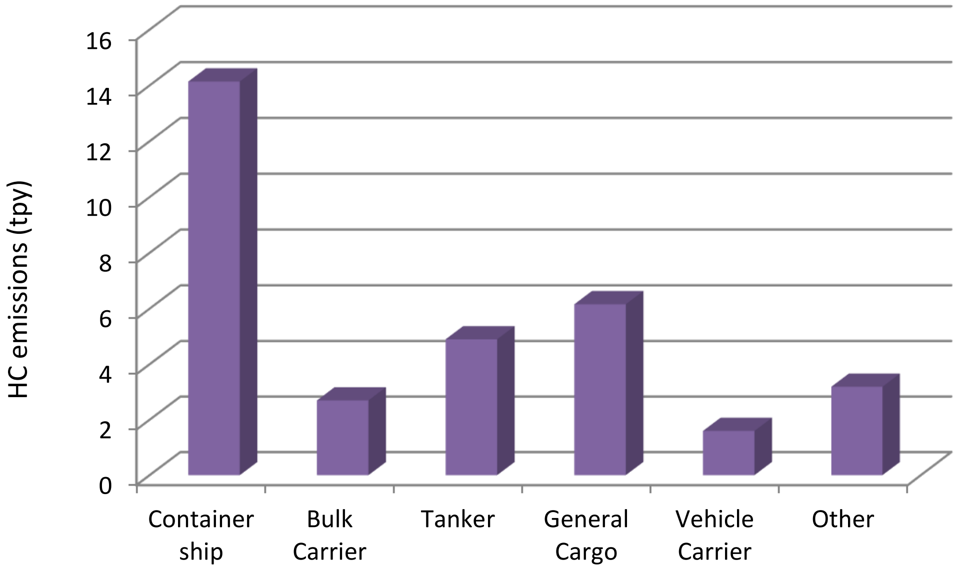

Figure F3: Percentage distribution of the total HC emissions per ship type

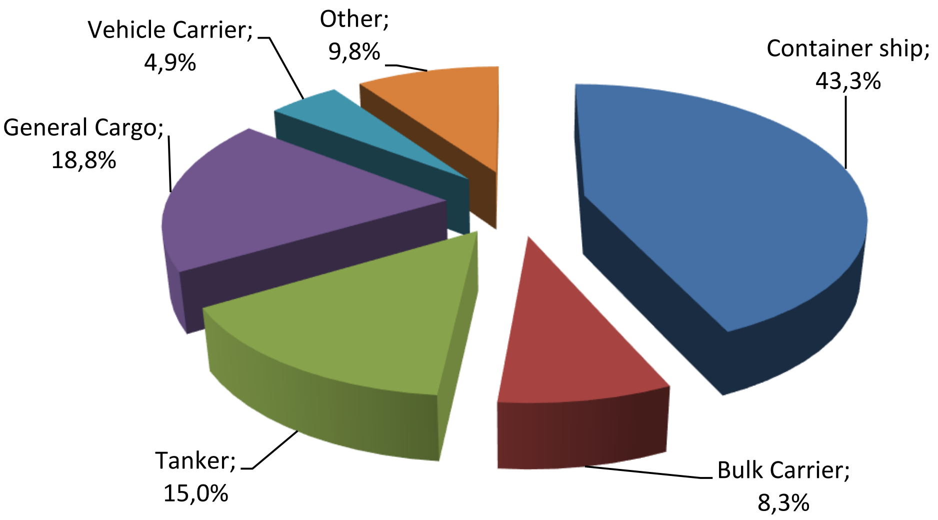

Figure F4: Total HC emissions (tpy) from OGVs per ship type

Appendix G: CO₂ Emissions from OGVs

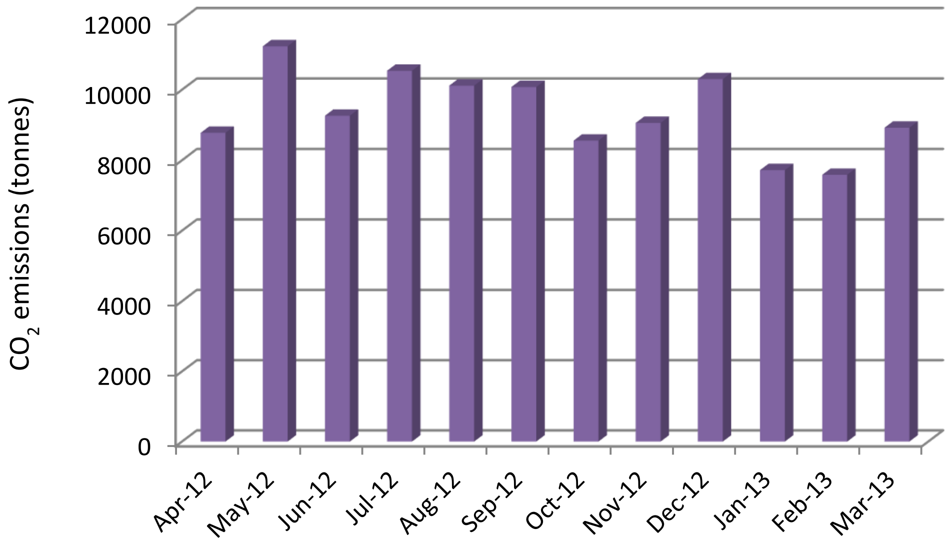

Figure G1: Total CO_2 emissions (tpm) from OGVs

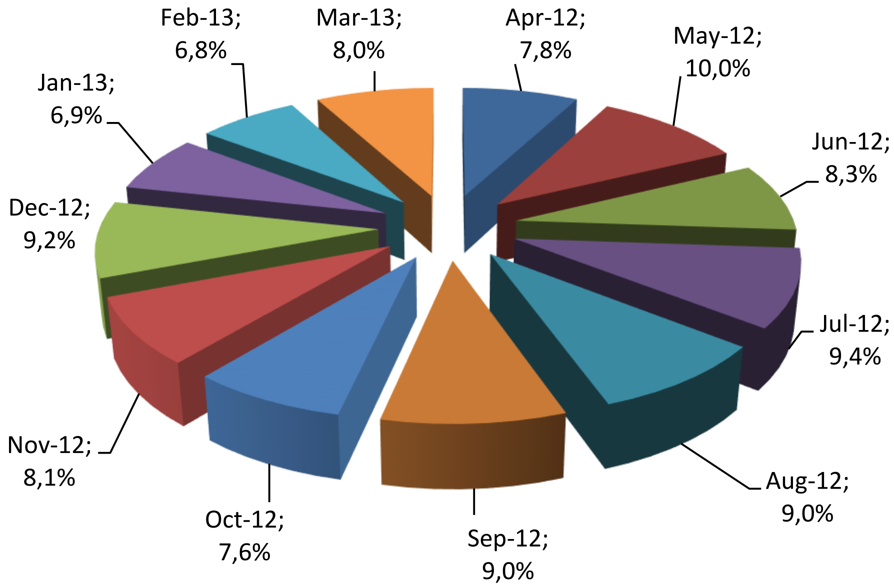

Figure G2: Monthly percentage distribution of CO_2 emissions from OGVs

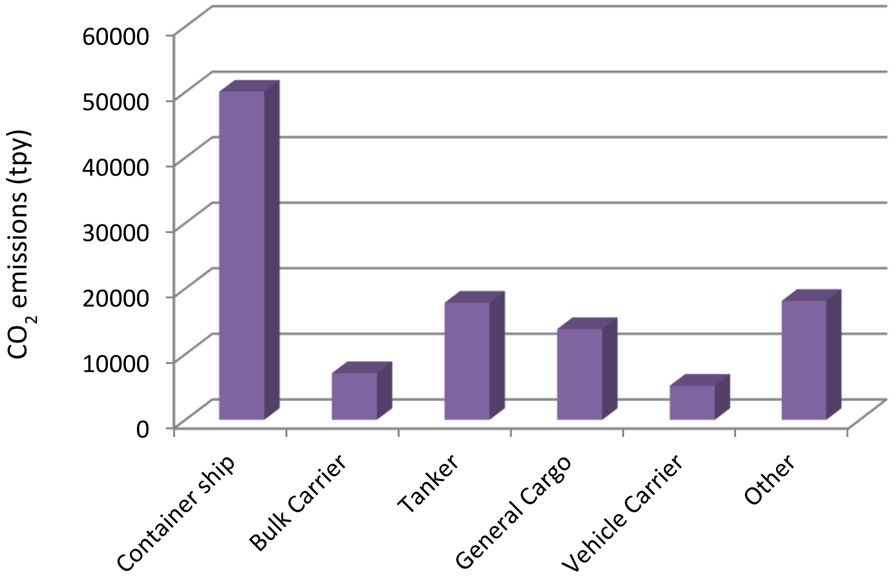

Figure G3: Total CO$_2$ emissions (tpy) from OGVs per ship type

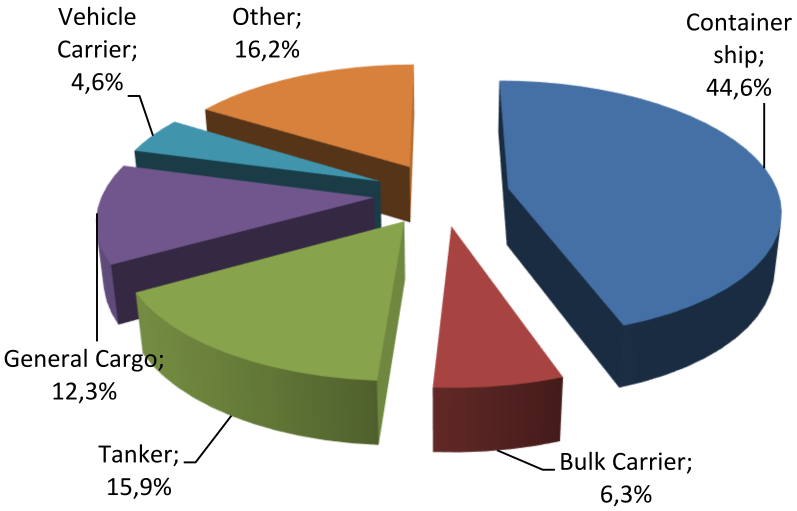

Figure G4: Percentage distribution of the total CO$_2$ emissions per ship type

Appendix H: Distribution of operational hours of TNPA harbour crafts

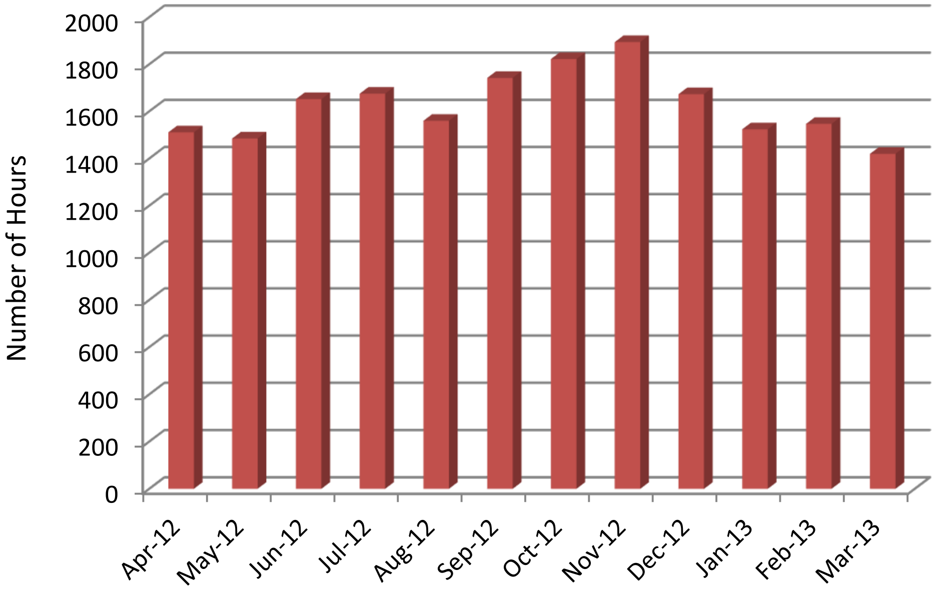

Figure H1: Monthly distribution of operational hours from all harbour crafts

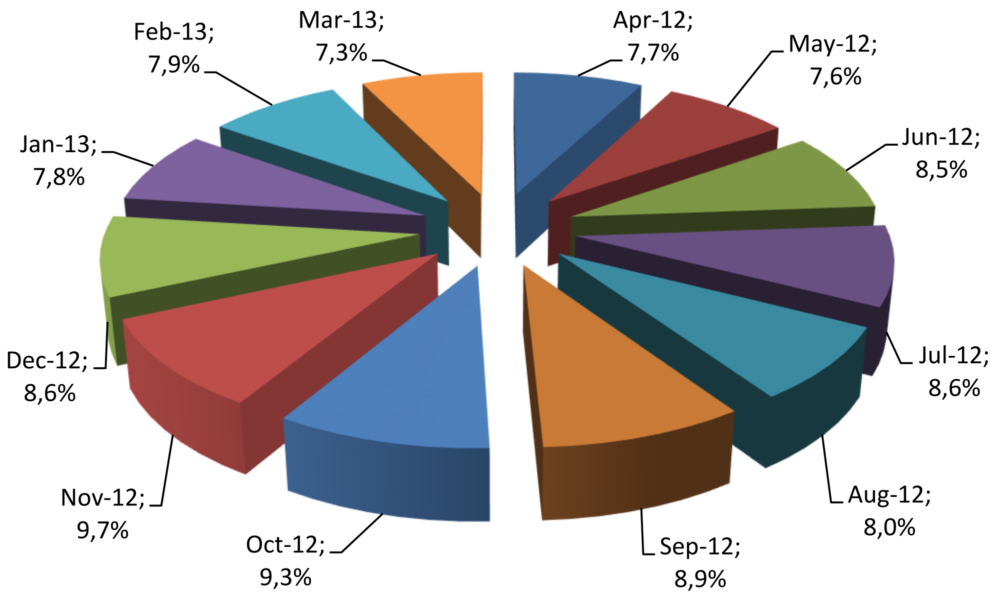

Figure H2: Monthly percentage distribution of operational hours from all harbour crafts

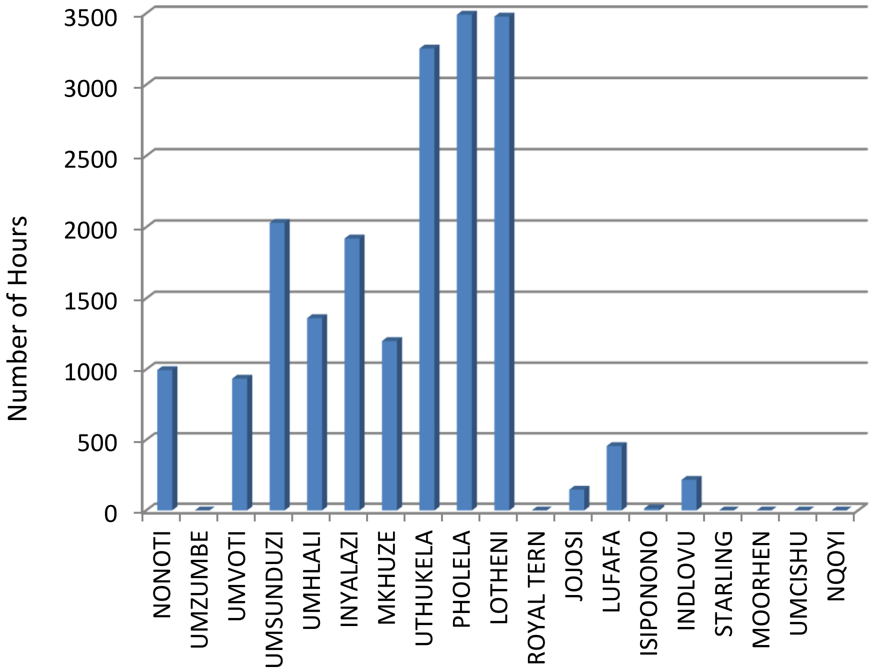

Figure H3: Total operational hours recorded by each harbour craft from 1st of April 2012 to 31st of March 2013

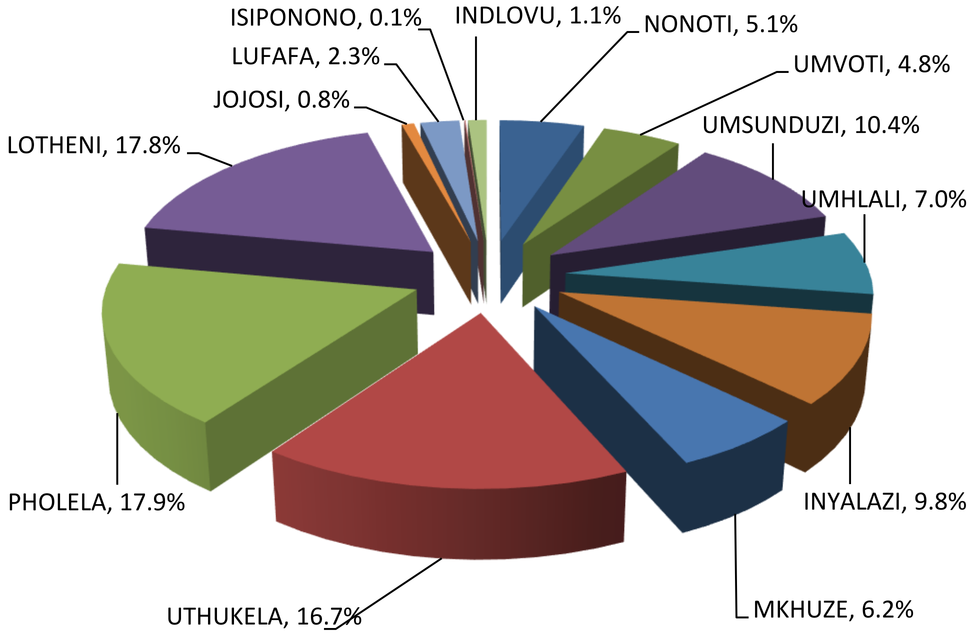

Figure H4: Percentage distribution of operational hours for each harbour craft. Harbour crafts that recorded zero operational hours are not represented in this graph

Appendix I: NO$_X$ Emissions from Harbour Crafts

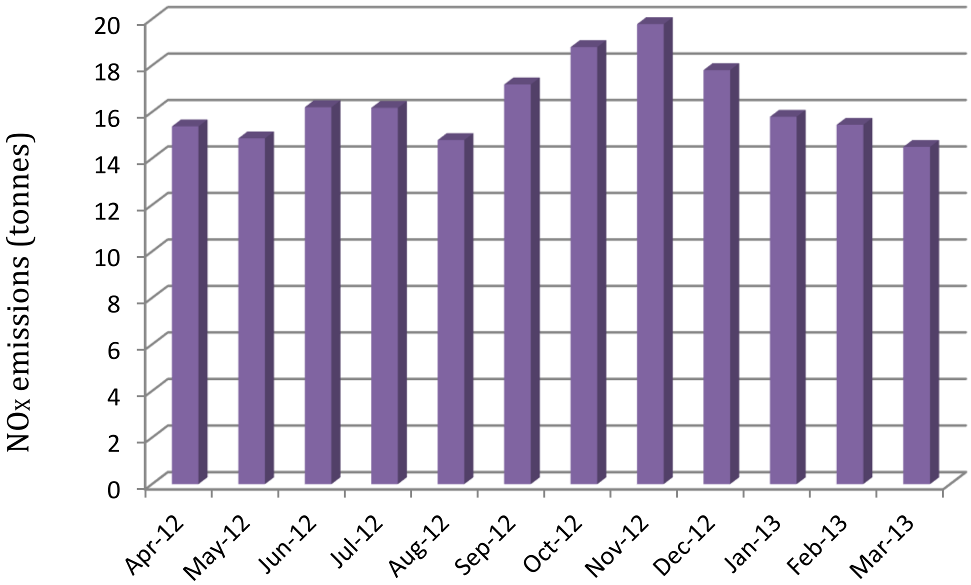

Figure I1: Total NO$_X$ emissions (tpm) by all harbour crafts

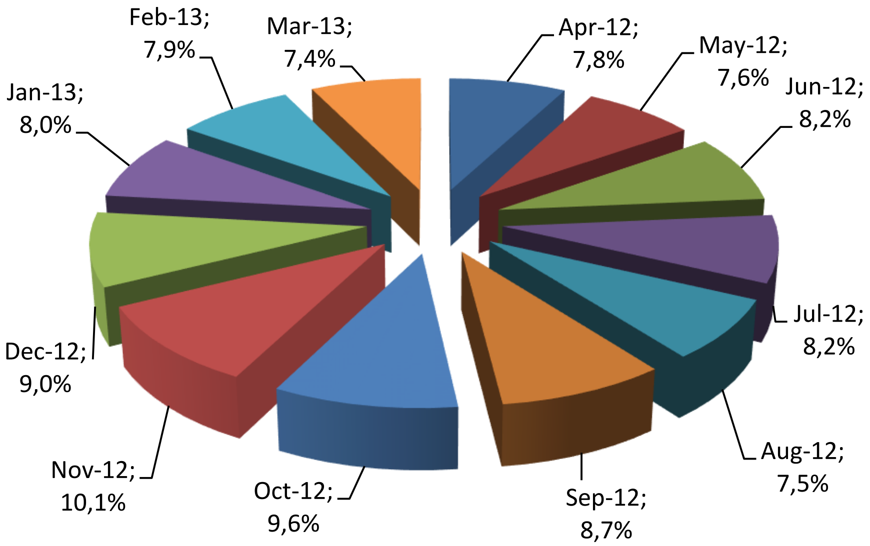

Figure I2: Monthly percentage distribution of NO$_X$ emissions from all harbour crafts

Appendix J: SO$_X$ Emissions from Harbour Crafts

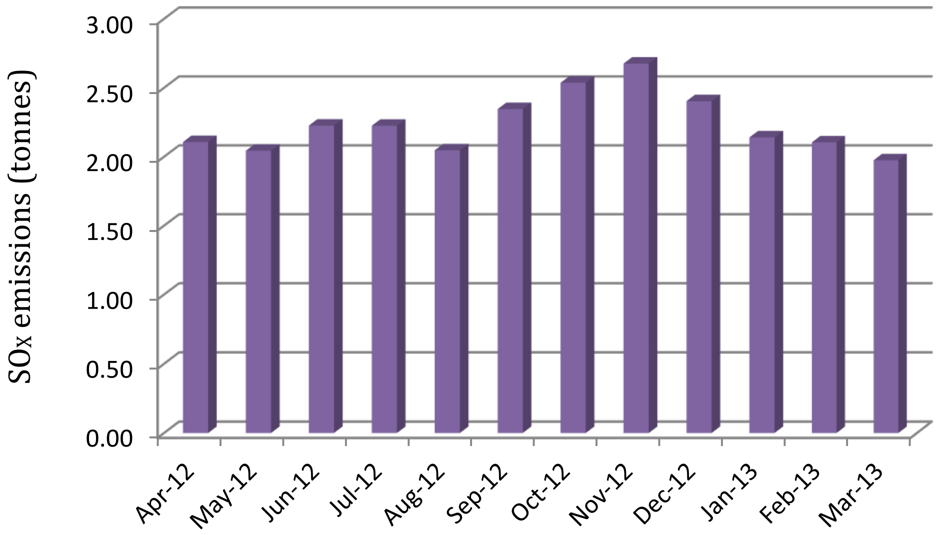

Figure J1: Total SO$_X$ emissions (tpm) by all harbour crafts

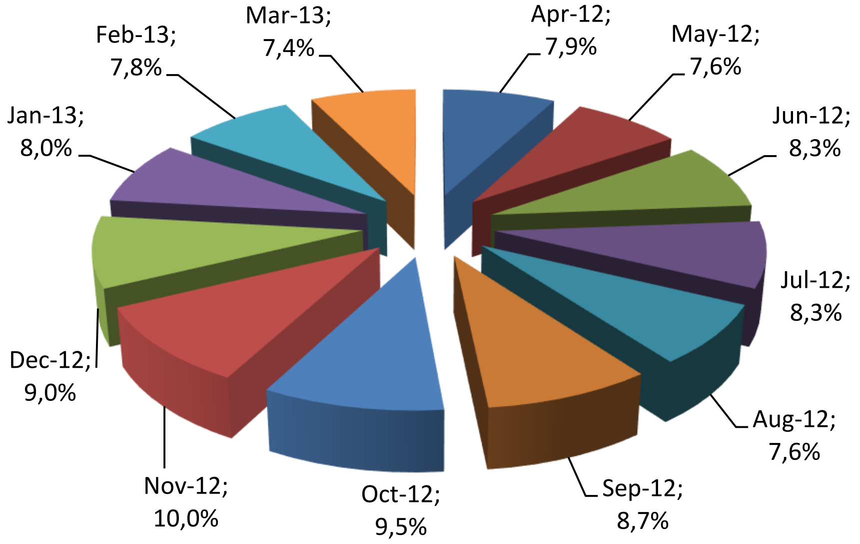

Figure J2: Monthly percentage distribution of SO$_X$ emissions from harbour crafts

Appendix K: PM$_{10}$ Emissions from Harbour Crafts

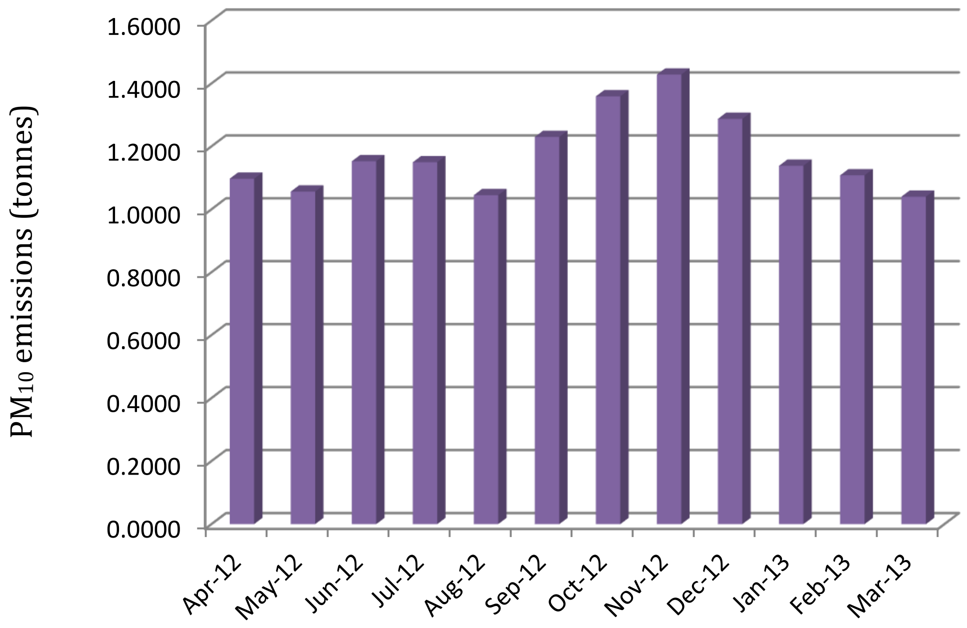

Figure K1: Total PM$_{10}$ emissions (tpm) by all harbour crafts

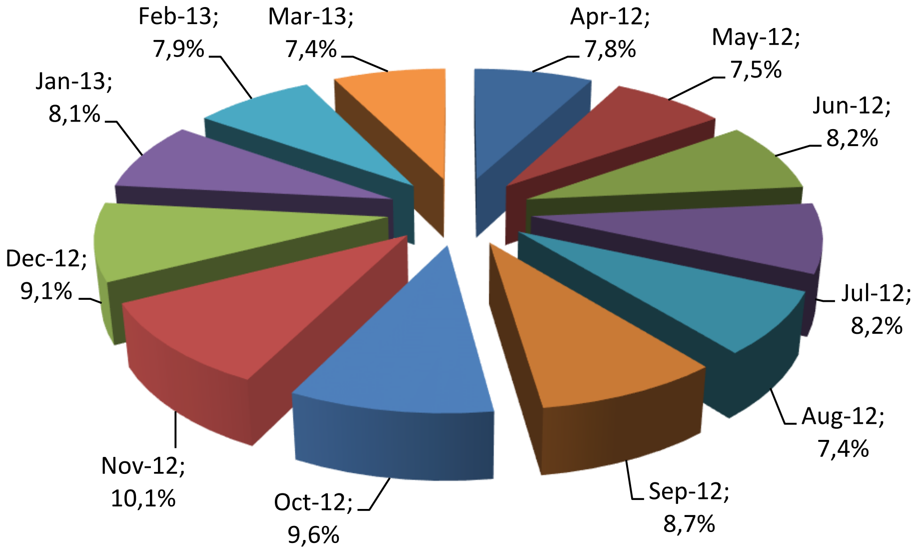

Figure K2: Monthly percentage distribution of PM$_{10}$ emissions from by harbour crafts

Appendix L: HC Emissions from Harbour Crafts

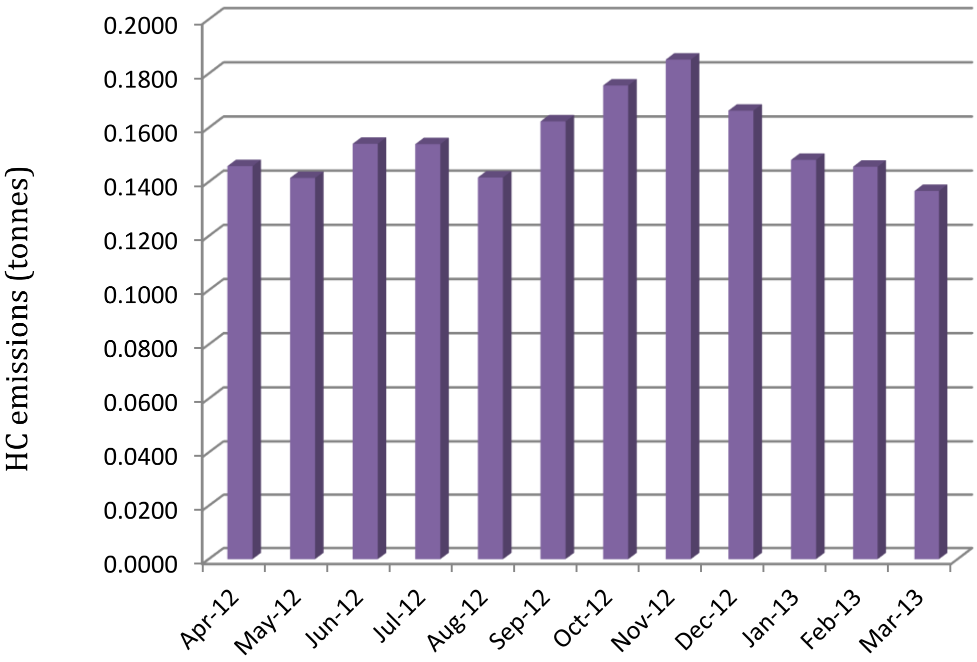

Figure L1: Total HC emissions (tpm) by all harbour crafts

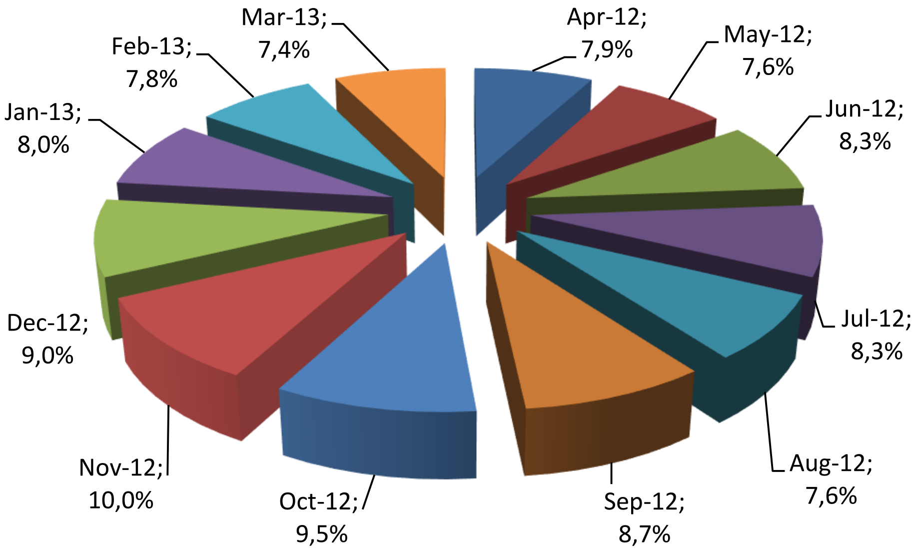

Figure L2: Monthly percentage distribution of HC emissions from harbour crafts

Appendix M: CO₂ Emissions from Harbour Crafts

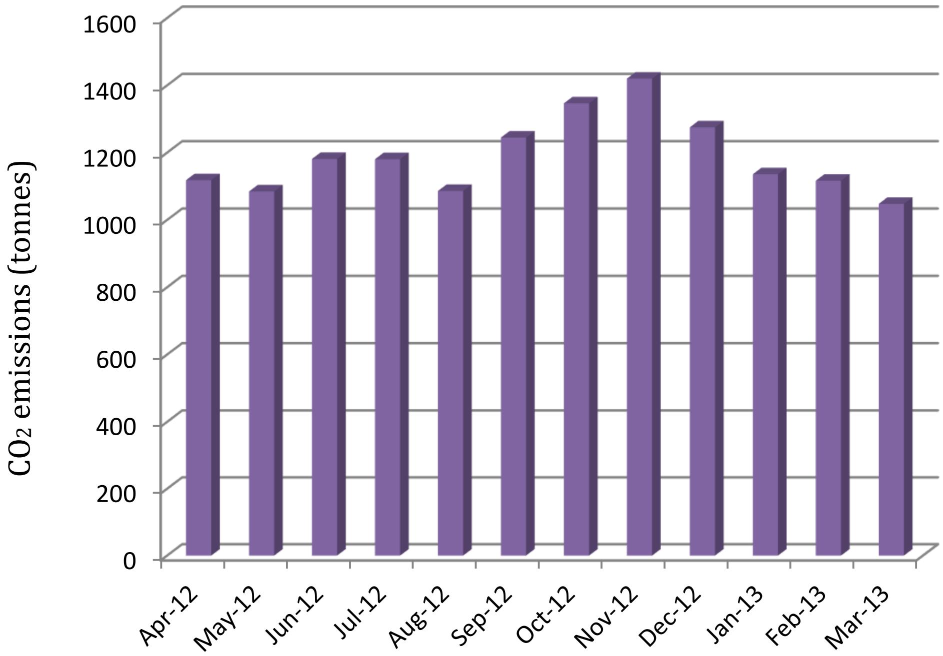

Figure M1: Total CO_2 emissions (tpm) by all harbour crafts

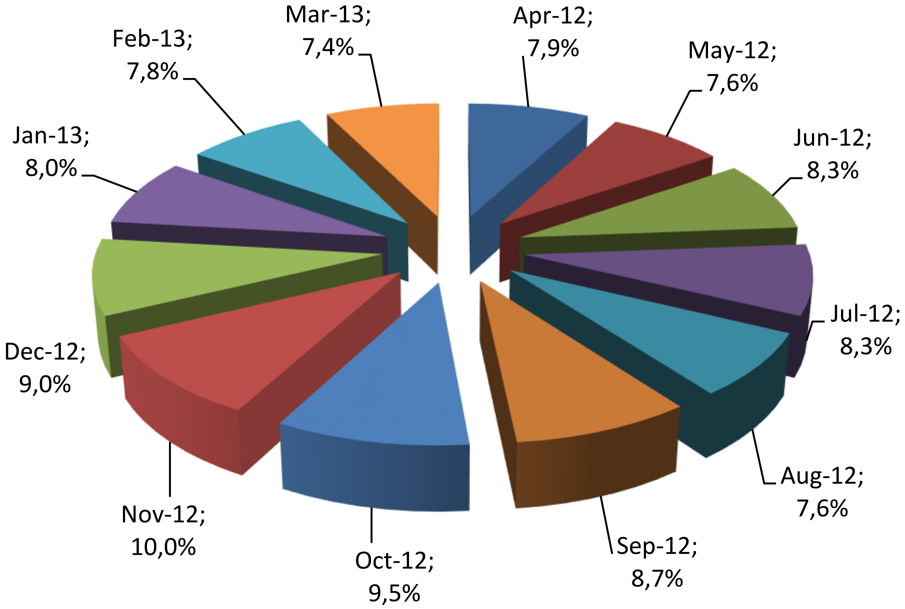

Figure M2: Monthly percentage distribution of CO_2 emissions from harbour crafts