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# How the Suez Canal can contribute to the reduction of air pollution from ships

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# HOW THE SUEZ CANAL CAN CONTRIBUTE TO THE REDUCTION OF AIR POLLUTION FROM SHIPS

**By**

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## DECLARATION

I certify that all the materials in this dissertation that is not my own work have been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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# ABSTRACT

Title of dissertation: **How the Suez Canal can contribute to the reduction of air pollution from ships**

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The continuous increase in air pollution from ships has triggered all stakeholders in the maritime industry to react. This dissertation reviews the procedures implemented by the International Maritime Organization (IMO) to limit emissions, identifies the different sources of air pollution in seaports and canals, offers means to estimate them and finally investigates if and how the Suez canal could be used to reduce these emissions.

The Suez Canal has been selected due to the increase in the total number of vessels transiting over the years that induce a similar threat concerning air emissions for seaports and the importance of the Canal in international trade that could constitute a legitimate place to implement active environmental policies.

In order to stress the increase of air pollution in the Suez Canal, the methodology on air emission inventory derived from the ICF consultant was used and an analysis of best practices in ports to select the most appropriate solution for the Canal is also offered.

The main conclusions are that container vessels are the main source of air pollution amongst the different types of vessel types, an element that is not directly reflected so far in the Suez Canal tariff system.



**KEY WORDS:** Air pollution, environment, Suez Canal, environmental policy, air emission inventory

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## ABBREVIATIONS

| | |
|---|---|
| AIS | Automatic Identification System |
| CEMS | Continuous Emission Monitoring Systems |
| CO | Carbon monoxide |
| DOC | Diesel Oxidation Catalysts |
| EEA | Energy and Environmental Analysis Inc |
| EIAPP | Environmental International Air Pollution Prevention Certificate |
| EPA | U.S. Environmental Protection Agency |
| EU | European Union |
| FGV | Foreign going vessels |
| FOEI | Friends of the Earth International |
| g/kwh | Grams per kilowatt-hour |
| GPS | Global Positioning System |
| GRT | Gross register tonnage |
| HAM | Humid air motors |
| HSF | Sea water scrubbers with high sulphur fuel |
| IAPP | International Air Pollution Prevention Certificate |
| IIASA | International Institute for Applied Systems Analysis |
| IMO | International Maritime Organization |
| IMO | International Maritime Organization |
| IPIECA | International Petroleum Industry Conservation Association |
| kw | kilowatt |
| kwh | kilowatt-hour |
| LNG | Liquefied Natural Gas |
| LSF | low sulphur fuel |
| MEL | Marine Energy Ltd. |
| NERA | National Economical Research Associates |
| $NH_3$ | Ammonia |
| NOx | Nitrogen |

| | |
|---|---|
| NRT | Vessels net register tonnage |
| PM | Particular matters |
| PM | Particulate Matters |
| Ppm | Parts per million |
| RAINS-ASIA | International Assessment of Energy Use Impact on the Environment in Asia |
| RPM | Revolutions per minute |
| RPM | Revolutions per Minutes |
| SCNT | Suez Canal net tonnage |
| SCR | Sea scraper |
| SDR | Special Drawing Right |
| SECA | Sulphur Emission Control Areas |
| $SO_2$ | Sulphur oxide |
| SOx | Sulphur oxides |
| TUP | Tariff of using port |
| VLCC | Very large crude carriers |
| VOCs | Volatile organic compounds |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

In the last decades, ocean-going vessels have increased in number and size. This increasing trend has two contradicting aspects, beside the promotion in maritime services there is also a huge potential of pollution from their activities. Exhaust gases generated from the vessel's diesel engines are one of these pollutants that contribute significantly in deteriorating air quality in coastal areas.

This issue is important as air pollution has become one of the greatest problems affecting the world's population these days, and is considered to be the seventh leading reason of fatalities worldwide. Air pollution kills an estimated 2.7 million human beings prematurely every year. For instance in the USA air pollution kills 50,000-100,000 annually, while in Europe it causes deaths to about 300,000 lives prematurely. The main causes of air-pollution-related losses are asthma, bronchitis, emphysema, lung disease, heart disease, and respiratory allergies. More than half of these fatalities are due to emissions from transportation sources or mobile sources (Jacobson, 2006).

Air pollution has many particular characteristics. Firstly, it can be local or trans-boundary. Secondly, pollutants cause negative environmental impacts either alone or through chemical reactions. For instance, the ozone is not emitted directly from combustion sources but it is due to a reaction between volatile organic compounds (VOCs) and nitrogen oxides (NOx) in the presence of sunlight. While Particular Matters (PM) are emitted directly from combustion sources without any chemical reaction (so-called primary particles) or formed as secondary particles through gases like Sulphur oxides (SOx), Nitrogen oxides (NOx) and Ammonia ($NH_3$). These two substances, ozone and particular matters are of direct concern to health diseases (Commission of the European Communities, 2005).

The composite interaction between pollutants, impacts and pollution receptors is shown in figure (1) that illustrates that diverse pollutants can cause a similar environmental impact. Moreover, huge sectors of economical activities are responsible for the discharge of air pollutants, except the agriculture sector which is the predominant source for Ammonia.

Air pollution also affects the ecosystem. The deposition of the acidifying materials like NOx, SOx and $NH_3$ leads to the damage of flora and fauna. In addition ground level ozone causes physical damage and decreases agricultural crop growth. Air pollution also plays a role in the corrosion of buildings and constructions (Thematic strategy on air…, 2005).

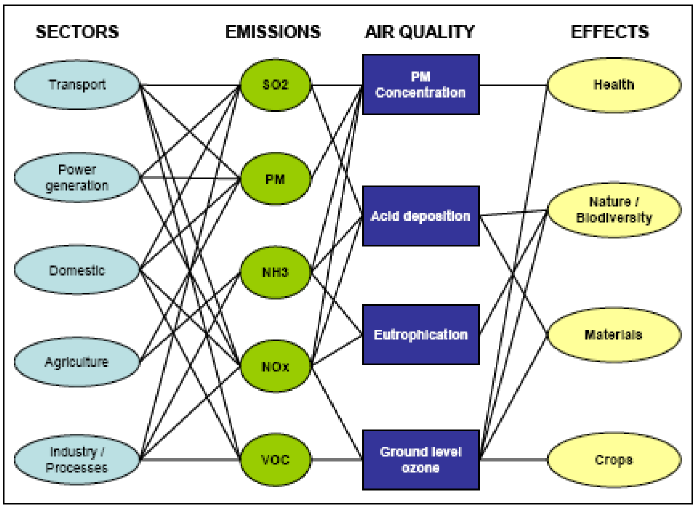


**Figure 1 Interaction between pollutants and impacts**

Source: Commission of the European Communities (2005). *Communication from the Commission to the Council and the European Parliament: Thematic Strategy on air pollution* (COM (2005) 446 final). Brussels: Author

As stated, ships are contributing to a large percentage of air pollution on a global and regional scale. Globally, ocean-going vessels emit 15-30% of the total world nitrogen oxides (NOx) emissions and 5-7% of sulphur dioxides (SOx) emissions world wide (IMO, 2007). On the regional scale, ships in Europe, for example, emit 150-300 times more sulphur per ton-kilometer than trucks and the average sulphur percentage in marine heavy fuel is 27,000 ppm (parts per million) while in trucks it is 50 ppm (European Environmental Bureau (EEB), 2004).

Moreover, the levels of air pollution from ships are increasing (in spite of the new strengthened regulations in MARPOL Annex VI) in contrast to the declining air pollution emitted from land-based sources. A study made in 2004 by the International Institute for Applied Systems Analysis (IIASA) for the European Commission's CAFE program estimated that the levels of SOx emitted by international shipping in the European region will increase by 42% by 2020 and NOx will increase by two thirds by the same year as shown in figure (2).

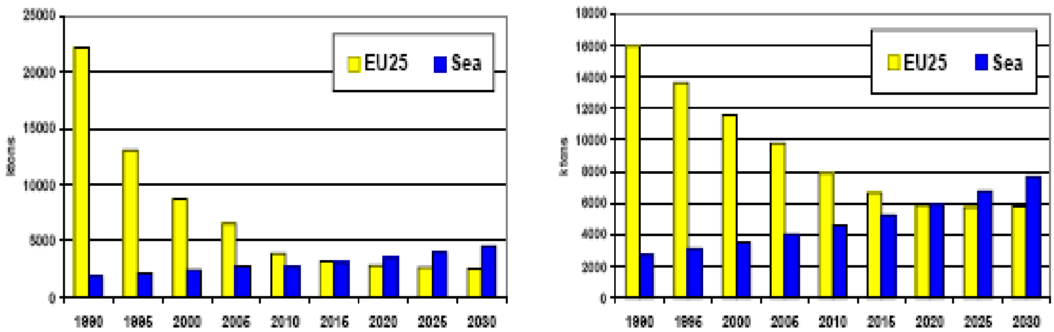


**Figure 2 Estimation of SOx and NOx emissions from vessels and their comparison with land sources in Europe**

Source: European Environmental Bureau (EEB). (2004). Air Pollution from ships: A briefing document. Brussels: Author. Retrieved July 13, 2007 from: http://www.eeb.org/activities/air/ship-briefing-nov04-(1).pdf

Sulphur emissions from ships participate in climate change due to the rapid growth of the worldwide vessel fleet. Emissions from ships may be responsible for 50% of the sulphur created over the world's oceans. While, for the North Pacific and North

Atlantic it represents about 60%. At any rate, it rivals the sulphur emissions of the world's largest economies, resulting in a strange ratio when compared to sulphur generated from land sources. For example, the total worldwide ship sulphur emissions equal 43 % of USA's total sulphur production and 53 % of Europe's total sulphur production (Bluewater Network, 2000). As is shown in figure (3), 85% of ships' routes are concentrated in the Northern hemisphere with 70% within 400 kilometers of land.

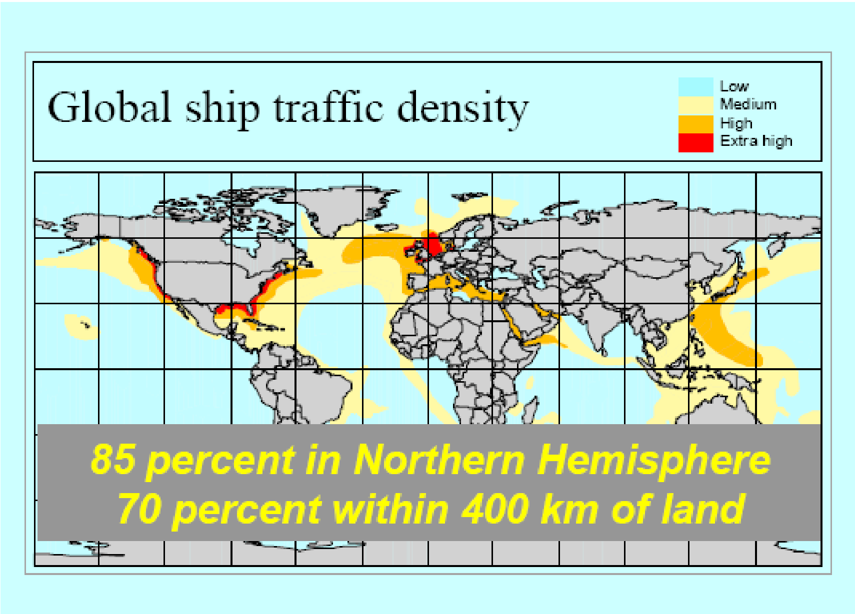


**Figure 3 Distribution of global ships density distribution**

Source: Gregory, D.M. (2005). *Marpol Annex VI: Is there a future for marine fuels?* Paper presented at the Sustainable Shipping Forum, 17-18 May 2005, Amsterdam. Retrieved July 07, 2007 from: http://www.seaat.org/media/lib/BP%20Green%20Shipping.ppt

To conclude, emissions from ships are substantial and increasing. By 2020 the expectations of shipping emissions is to outpace the fleet wide reductions of 60% or less, depending on the levels of reductions (IMO, 2007). Promoting and encouraging emission reductions from the world fleet are crucial to prevent the continuous increase of ships emissions over future decades.

## 1.2 Definition of the research problem

The increasing trend of emissions from mobile sources and its contribution to global warming highlights the importance of controlling these hazards. This has led the IMO (International Maritime Organization) to implement MARPOL Annex VI which deals with controlling emissions from vessels. The implementation of this annex raises a lot of questions among maritime parties, dividing them into two groups.

The first group claims that the share of emissions from the maritime industry is small in comparison with other activities. Moreover, implementing such environmental regulations will impose burdens on the maritime industry, in particular the ship owners. On the other hand, the second group finds the IMO emission cap limits are not sufficient. Moreover, the downbeat of vessels emissions contributes to more impact on health and environment than estimated and that the IMO regulations could reduce emissions in the short run only but it have no effect in the long run.

The air pollution problem from maritime activities triggered parties in the maritime industry to work on evaluating its exact potential. The Port section is one main maritime section which was put under huge pressure from local jurisdictions to adopt proper measurements to reduce air pollution. Therefore, some ports, particularly in developed countries, started to take some initiatives to trim down such emissions.

Canals and waterways show an increase in transiting vessels both in size and tonnage. This could increase the impact of air pollution on them as well as impose more responsibility to help and cooperate with the international community in reducing air emissions from maritime activities.

## 1.3 Objectives and Scope

The purpose of this research is first to review the air pollution from ships and secondly to understand the exact importance of such a problem for the Suez Canal using emission inventory methodology applied for the last 10 years. It also studies the Suez Canal tariff system and how it could be related to ships emissions. It finally highlights in which way the Suez Canal could be used to promote the implementation of environmental regulations.

### 1.4 Research methodology

The research adopted two main methodologies. The first was a literature review and analysis of research papers, regulations, and consultancy reports mainly obtained from published materials, the World Wide Web and annual reports from the Suez Canal. Moreover the Fairplay data base is used for the vessels specifications.

The second methodology used was the calculation of the amount of air pollution emitted from Ocean-Going Vessels in a particular area. The methodology prepared by ICF consultant and submitted to the U.S. Environmental Protection Agency (which describes the best practices for preparation of port inventory) was used to estimate the amount of air pollution from ships in the Suez Canal area. Moreover, another methodology to evaluate the amount of savings between different routes for the same destinations was done to stand on the importance of the usage of the Suez Canal.

### 1.5 Limitation of the study

This study is limited to the estimation of emissions from Ocean-Going Vessels transiting through the Suez Canal area. Efforts were made to collect data from the Suez Canal Authority on the exact transiting vessel’s names and particulars, but due to the long time required to provide such data, the data published in the Suez Canal annual reports was used. The study period was 10 years from 1997 to 2006.

### 1.6 Thesis plan

In order to have a view of the air pollution problem a review on the existing legislations, in particular IMO regulations, that control air pollution from ships (MARPOL 73/78 Annex VI) was first investigated (Chapter 2). An examination of the proposed solutions to reduce emissions from vessels was made and their impact on ship owners was examined.

To have an idea about the procedures and practices applied in ports to reduce air pollution within their regions, a review of the existing practices obtained by ports was then conducted (Chapter 3).

An evaluation of the Suez Canal importance among its users was important to be known, in order to help choose the proper action to be taken by the Canal authorities. This was evaluated by the aid of methodology to calculate the savings provided by the Canal in comparison with the alternative routes (Chapter 4).

An estimation of the air pollution inventory was essential to know the exact magnitude of emissions. This was calculated by using the previously mentioned methodology (Chapter 5). Moreover, estimation for the same pollution levels during the last 10 years was mentioned in order to know the trend of air pollution. Examining the relation between emission levels from vessels and tariff system was made to evaluate the levels of success in proposing a green tariff (Chapter 6). Finally, recommendations including proposed solutions to be applied by the Canal Authority were highlighted.

# CHAPTER TWO

# IMO AIR POLLUTION CONTROL REGULATIONS AND THEIR IMPACT ON SHIP-OWNERS

## 2.1 Introduction

Reduction of air pollution from ships has been one of the priorities of the International Maritime Organization's (IMO) agenda and is reflected within MARPOL Annex VI. These regulations have influenced all parties involved in the shipping industry, including manufacturers and shipping companies.

This chapter emphasizes the IMO's actions to reduce air pollution from ships, explains the proposed solution and offers an analysis on what the impacts of such regulations for ship owners could be.

## 2.2 The IMO actions to reduce air pollution from ships

On 19 May 2005 MARPOL 73/78 Annex VI, "Regulations for the Prevention of Air Pollution from Ships," entered into force. This Annex met the IMO ratification requirements with a minimum of 15 flag states collectively controlling not less than 54.57% of the world merchant gross tonnage. All vessels belonging to a flag that has ratified the 1997 MARPOL 73/78 protocol and ships of non-signatory states while operating in waters under the jurisdiction of parties to the 1997 protocol must follow the regulations stated within annex VI. It was formed on a similar background as other international agreements dealing with international air pollution such as the Convention on Long-range Tran boundary Air Pollution, as well as the Montreal Protocol on Substances that Deplete the Ozone Layer (Bennett, 2006).

MARPOL 73/78 Annex VI sets a maximum cap on sulphur and nitrogen oxides emissions from ship exhausts and prohibits intentional emissions of ozone depleting materials. Annex VI deals with engines with a production power of more than 130 kW fitted in new ships constructed after January 1, 2000 (date of keel laying).

From all the 19 regulations[1]included within MARPOL Annex VI, regulation 13, 14 and 18 are explicitly dealing with Nitrogen oxides (NOx), Sulphur Oxides (SOx) and fuel quality standards, which represent the main air pollution from ships. This section then focuses on these regulations.

Regulation 13 sets guideline rules on the allowable Nitrous oxides (NOx) levels from the marine vessel's engines. Nitrous oxides are considered to be the most difficult air pollutant to control and monitor. This is due to the nature of NOx and its direct relationship to internal engine combustion temperature which depend on the engine output and size (Cooper, 2003). This regulation divides the engines and NOx acceptable levels, for Output power greater than 130 kW installed on vessels build after January 2000 as follows:

– 17.0g/kWh when the rated engine speed is less than 130 RPM [2]

– 45 RPM g/kWh when the rated engine speed is 130 or more but less than 2000 rpm

– 9.8 g/KWh when the rated engine speed is 2000 rpm or more

Due to the fact that NOx emissions levels are in direct relationship with the engine design and engine emission performance level (Cooper, 2003), previous regulations are complemented by the NOx emission code which explains the measurements

[1] Reg. 1: Applications, Reg. 2: Definitions, Reg. 3: General exceptions, Reg. 4: Equivalent, Reg. 5: Surveys and inspection, Reg. 6: Issue of International Air Pollution Prevention Certificate, Reg. 7: Issue of certificate by another Government, Reg. 8: Form of certificate, Reg. 9: Duration and validity of certificate, Reg. 10: Port state control on operational requirements, Reg. 11: Detection of violation and enforcement, Reg. 12: Ozone-depleting substances, Reg. 13: Nitrogen Oxides (NOx), Reg. 14: Sulphur Oxides (SOx), Reg. 15: volatile organic compounds (VOC), Reg. 16: Shipboard incineration, Reg. 17: Reception facilities, Reg. 18: Fuel oil quality, and Reg. 19: Requirements for platforms and drilling rigs

[2] Revolutions Per Minutes

required to test, survey and certify marine diesel engines. This code provides guidance to the engine manufacturers and marine administrations to ensure that all marine diesel engines are complying with Annex VI of MARPOL 73/78. Moreover, NOx emission code provides details regarding regulations 5 and 6 which are concerned with the issuance of required Environmental International Air Pollution Prevention Certificate (EIAPP certificate) and of the International Air Pollution Prevention Certificate (IAPP certificate).

MARPOL Annex VI also enforces the presence of an IAPP Certificate showing the level of engine emissions depending on the size of engines. Ships of 400 gross tons and above engaged in international voyages involving countries that have ratified the conventions, or ships flying the flag of those countries, are required to have the above certificate on board. IAPP Certificate must be on board at delivery of any ship after 19th May 2006, while for the ships built before; the IAPP certificate must be on board on the 1st dry dock after 19 May 2006 until maximum 19 May 2008.

The EIAPP certificate is provided by the administration after a pre-certification survey of the engine in a test-bed before installation, to confirm that it complies with NOx limits mentioned in regulation 13. After installation of the engine, another survey is to be carried out to confirm that the NOx limit does not exceed the allowable limits due to any modifications made during engine installation; consequently the IAPP certificate can be issued. Accordingly, the IAPP certificate will be used by the authorities to determine the actual NOx level emitted by each individual engine. Moreover, it could be used as a tool to provide statistics on the exact emissions from all marine engines (IMO, 1998).

Regulation 14 of MARPOL 73/78 Annex VI is concerned with SOx emissions and includes a global sulphur cap of 4.5%, which is the maximum limit on sulphur content in fuel oil. All vessels covered by this annex must carry onboard operating fuel oils containing sulphur not exceeding the permissible value. The more important stringent parts concern the SOx Emission Control Areas (SECAs). Regulation 14 states that when any ship is inside these areas it must ensure that sulphur in the fuel does not exceed the allowable limit of 1.5% or that it must utilize an exhaust gas cleaner system approved by the ships register administration (MARPOL 73/78). The existing Sulphur content in residual marine fuel is approximately 2.7%. (Wilson, 2005)

A Sulphur Emission Control Area (SECA) is a specific area where sulphur emissions must not exceed the limits declared by the jurisdiction of this area. For instance the Baltic Sea (which is the existing SECA area) maximum sulphur emission cap is 1.5% when the ship is sailing and 0.2% when berthing or sailing in inland water ways. Figure (4) shows that the North Sea SECA will follow in November 2007, and a 0.1% sulphur emission limits will begin in 2010 for all European ports. Consequently, it is expected that the Mediterranean and Black Sea will be declared as SECA areas by 2015. Furthermore, more restrictive limits on emissions from 1.5% to 0.5% may enter into force in the existing SECAs from 2014 (Young, 2006).

Regulation 18 is concerned with the fuel oil quality work on standardizing the fuel oil quality process from examining a various samples of fuel. It aims at considering the unique feature of shipping industry for which the bunkering of merchant marine vessels takes place in different ports all over the globe. This examination process could help to reduce the emissions, as the fuel quality has a direct effect on the engine emission levels (Lin, B., & Lin, C, 2006). Therefore, this regulation is to emphasize the presence of a fuel quality certificate where all the fuel oil on board vessels must be free of any inorganic acids and should not contain any chemical wastes. Moreover, the sulphur contents must not exceed 4.4% outside the SECA areas and 1.5% inside SECA area. All bunker details have to be recorded through a bunker delivery notice which includes the Sulphur content percentage.

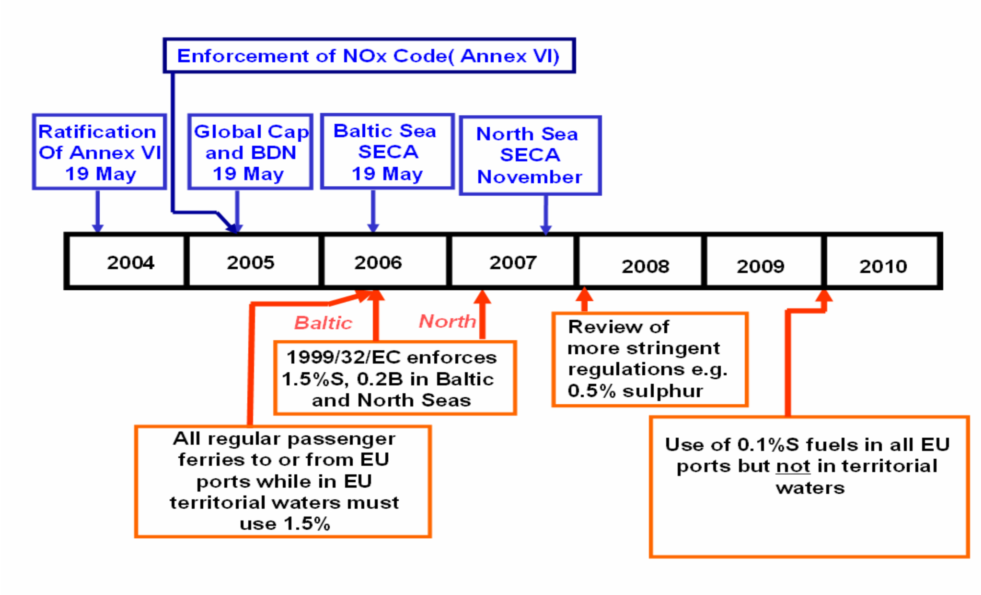


**Figure 4 Implementation time table of Annex VI and Future SECA Areas rules**

Source: Adapted from, Taylor, R.B. (2005). *Charting the Course: Marine Fuel Efficiency and Emissions Conference: A report on the proceedings, Toronto, ON, Canada, January 18-19, 2005*. Retrieved March 27, 2007 from: http://www.tc.gc.ca/programs/environment/Freight/training/marine/pdf/Chart.pdf

To conclude, although controlling air pollution from ships is complex by the variety of air polluting substances as well as the variety of cap limits in different zones, it appears that IMO through Annex VI of MARPOL and the NOx technical code has succeeded in reducing air pollution sources on various aspects.

## 2.3 The proposed amendments on air pollution regulations

Since 1997 the increase in public awareness and the enhancement in technology regarding emissions and tracing of ships emissions have led to various initiatives to amend the regulation (IMO, 2006a).

The increase in public awareness is mainly coming from the presence of major ports generating high traffic in dense population area such as around the Mediterranean Sea where 250 million inhabitants are living within less than 150 km of the sea coast (Schinas, O. & Papadimitriou S., 2003). The continuous increase in the number of ships, the growth in the number of calls at port per ship and the rise of average ship's time at ports are driving factors. For instance, the average time a ship stays in a European port has increased by 20% in the last decade (Entec UK Ltd, 2005) leading to a negative effect on air quality in ports.

These elements have led Finland, Germany, the Netherlands, Norway, Sweden, and the United Kingdom to submit in 2005 additional documents to the IMO sub-committee on bulk liquids and gases (MEPC 53/4/4) stressing that shipping exhaust emissions are having a significant impact on human health and the environment and should be seriously considered. Similarly, Friends of the Earth International (FOEI) submitted documents containing similar concerns (MEPC 53/4/1) (IMO, 2006a). A report from the European Commission[3] about the effectiveness of reducing emission from ships in comparison to land-based sources also indicates that the cost of reducing one ton of NOx by ships is 13 times less than for trucks and buses (IMO, 2006).

New techniques for emission reduction have also encouraged those countries to submit new proposals. For example Man B&W Company declared the presence of humid air motors (HAM) technology that reduces the NOx by about 75-85% and gives the possibility to reduce NOx in 2 stroke engine by 40% and 90% in using the sea scraper (SCR).

New navigational equipment can also help in providing more accurate positioning and in enhancing the tracing and monitoring of ships activities world wide. For example, the Global Positioning System (GPS), a standard now for merchant fleet vessels and its combination with a data-logger facility has provided new opportunities. In addition, the Automatic Identification System (AIS) which will be compulsory on board all ships starting from July 2008 and the Continuous Emission

[3] Entec UK Limited (August 2005), Final Report for European Commission Directorate-General-Environment. Service Contract of Ship Emissions: Assignment, Abatement and Market-based Instruments.

Monitoring Systems (CEMS) could provide high accuracy on the emissions monitoring and positioning, resulting in more precise and relevant data on emissions.

On November 2006 during the IMO Sub-committee on bulk, liquids and gases, a trend for more strengthened measurements in reviewing Annex VI appeared. The committee proposed three options for the future. Option A was to leave the regulations as it is. Option B was to leave the SOx cap of 4.5% unchanged, while the SECA cap will move down from 1.5% to 1.0% by 2010 and 0.5% by 2015. Option C is to enforce the usage of distilled fuel oil with sulphur less than 0.5% or using residual oil of 4.5% sulphur in combination with exhaust gas cleaning system.

Option C was re-discussed during the BLG committee on the 9 of February 2007. The International Petroleum Industry Conservation Association (IPIECA) stated that option C would be impossible to apply for several reasons. Firstly, it would incur a huge investment ($38 billion only for the 25 European countries). Secondly, the new requirement and/or the modification of existing oil refineries could take more than 10 years. Finally, from an environmental point of view these changes will lead to an increase in CO2 emitted from refineries by nearly 15% (IMO, 2007).

From the previous proposals we can, however, predict that more restrictive measures, especially for SOx and NOx emission levels, could come into force in the future (IMO, 2006b).

## 2.4 Methods being used to reduce air pollution from ships

The way to reduce SOx and NOx emissions are numerous. These include the use of low sulphur fuel (LSF), sea water scrubbers with high sulphur fuel (HSF), and shore power supply while berthing and emission trading.

LSF is a debatable solution to reduce SOx levels in exhaust emissions as its availability is limited and its price rather high. LSF has a positive impact on engine maintenance programs as well as the reduction of sludge quantity formed on board ships. It can be produced by one of the following methods: blending, processing or desulphurization. Blending means mixing low sulphur fuel with high sulphur fuel which can be done for an average cost of €10-16/ton. The second option is by processing low sulphur fuel at approximately €40-45/ton, while the third option is desulphurization of the high sulphur oil at an average cost of €50-90/ton (Macqueen, 2005). In 2004, less than 6% of LSF produced had a sulphur content equal to or less than 1.5%. Nearly 90% of worldwide deliveries contained 2% sulphur or higher and approximately 44% of all deliveries was 3% or higher (Brewer, 2005).

Seawater scrubber is another solution to reduce SOx emissions and to comply with Annex VI. It allows ships to burn HSF. Historically the liquid scrubbers were used on land in the 1930s. The first sea water scrubber was fitted on passenger ferry *M/S Kronprins Harald* in 1991. Nevertheless, nowadays seawater scrubbers on ships have not been commercially exploited (Entec UK Ltd, 2005).A seawater scrubber is an onboard unit for clarifying the ship's exhaust and removing $SO_2$ before it is released into the atmospheric air. Simply, the operational principal allows the hot exhaust gases in their last stage to pass through a flow of seawater before being released into the atmospheric air. Therefore the $SO_2$ is transferred to the seawater, where the seawater is recycled and the solid particles are removed and placed in a sludge tank. The main advantage is to provide the ship with the possibility to burn HSF. Seawater scrubbers are believed to have significant potential as a technical means to decrease ships' emissions. It is considered to be one of the largely versatile cost effective scrubbing methods because of the alkaline nature of sea water which already contains a great sulphur amount (around 0.1% on weight) and which can be a safe sulphur reservoir.

In the autumn of 2004, Marine Energy Ltd (MEL) in co-operation with MAN B&W conducted some tests on a new seawater scrubber (Eco-Silencer) which was fitted on a passenger ferry *Pride of Kent.* The following results were achieved in operating with 2.5% sulphur fuel. $SO_2$ emissions were reduced by 68-94% where the effective rate was related to the seawater flow rate. The lowest $SO_2$ reduction rate was 65%, while the maximum reduction rate was 94%. Marine Energy Ltd (MEL) believes that with some improvements in the scrubber design the sulphur emission could be reduced at more or less 90% (Entec UK Ltd, 2005).

The major problems with the seawater scrubber, which occur especially when it is operating when the ship is at berth, are the quality of the discharging water, the sludge disposal, and the sulphuric acid mist after the scrubber treatment on the ship. The discharged water contains petroleum hydrocarbons at less than 15 ppm which complies with IMO OILPOL, but the question raised here is the effect in congested ports or traffic rivers. When it comes to sludge, some disposal problems exist because of its acidity (Entec UK Ltd, 2005). In addition, the sulphuric acid mist, which causes corrosion to the surrounding material, may affect in the long run the ship or the shore cranes and gantry equipment used for cargo operations.

Furthermore, when vessels are docked in port, auxiliary engines (diesel generators) that are used to provide electricity to the ship for operating refrigerators, pumps, mooring winches and ship's cargo operating gears are generating emissions. Through cold ironing and shore power supply for their electrical needs could be a way to eliminate these effects. This shore power supply is likely to reduce emissions, due either to the type of electricity production methods (e.g. wind, hydro, nuclear … etc) or to the stricter emission control regulations applying for land powered generators.

Cold ironing has been used in a few ports worldwide with a positive impact on reducing air pollution. For example, the port of Goteborg has been using it for one of its ferry service terminals since 1981. More recently, Los Angeles Port has adapted the China Shipping Terminal for this purpose. It has been found that cold ironing reduces NOx by 97% and SOx by 96%. The cost for its implementation varies with the infrastructure and with the question of whether it will be a newly fitted or retrofitted existing terminal (Entec UK Ltd, 2005).

Another way to reduce pollution is emission trading. This allows the low emitters (below the legislation cap limit) to sell the value difference to other (high) emitters. The Marine Environment Protection Committee 54 explains it as follows: "emission trading is an economic instrument for reducing greenhouse emissions that enable participants to achieve emissions reductions in the most cost-effective manner. Participants are allocated tradable emission `allowance´ (similar to quotas) that they can trade to help them meeting their emission reduction goals" (2005a).

Emission trading is beneficial for both the shipping industry and the environment. It offers financial incentives for the ship owners to implement and use advanced technology to emit less than the cap limit. It will also push the industry towards new innovative environmental technology.

Another important advantage, especially for ship owners operating multi-age vessels, is that instead of paying £2-3 million for old ships to fit abatement technology, they could add newer ships to their fleets with advanced technology to gain credits to counterbalance the older ships (Offsetting the project under way, 2005).

On the other hand, emission trading still faces many obstacles. One of the major problems is the global fleets' co-ordination and administration, as well as the absence of an internationally recognized structure for developing ship emission trading. In addition, there is still a lack of emission monitoring technology (IMO, 2005a). Even though the shipping industry is facing all these difficulties, some specialists are optimistic about reaching an international agreement within the next three years. Timothy Wilson, Manager of Lloyd's Register EMEA FOBAS, expects emission trading to be available from 2010 (Achieving low-sulphur container…, 2005).

Most of the previous solutions are effective for reducing SOx emissions to comply with MARPOL 73/78 Annex VI and probably, with future regulations. However, most ship owners and bunker suppliers are complaining about the financial burdens brought about by these new regulations and the implementation of SECA for instance.

## 2.5 Impact of air pollution regulations on ship-owners

The compliance with MARPOL 73/78 annex VI regulations, especially when entering SOx emission control areas (SECAs), has lots of implications for ship-owners. They have first to ensure that the exhaust values of SOx are not exceeding the convention limits by either receiving low sulphur fuel, or by accepting high sulphur fuel but in making the required mechanical modifications. Another option is to use an on-shore power supply while berthing, or by emission trading as stated previously. Nevertheless, most of the choices are bringing financial and technical burdens to ship owners. Another obstacle is the limited availability of low sulphur fuel world wide, especially before entering SECAs.

One of the major impacts for the ship owner in complying with the new regulations is on the financial aspect of LSF or HSF. The price difference between high and low sulphur fuel significantly increases the running cost for a vessel. For instance, the increase in the running costs for a vessel spending 10 days in a SECA is estimated to be up to $129,000 for a Suezmax, to $99,000 for an Aframax and to $87,000 for Panamax (Smith, 2005).

The other option is using HSF, but this requires modifications to the main engine and fitting exhaust gas scrubbers. The sea water scrubber cost varies according to the ship's size and whether it is fitted in a new ship or retrofit in an old one. For example, the price for the Eco silencer model varies from €418,656 to €4,838,400 with some additional annual running costs varying according to ship's size from €50,266 to €533,309. Noting that the lifespan of the Eco silencer model is 15 years (Entec UK Ltd, 2005) while the average ship's life is 25 years, the cost is then doubled. Furthermore, it uses space that can not then be used for freight earning, and reduces the profit in the long run (Reynolds, 2004). It is estimated that the shipping industry would pay annually $3 billion extra to reduce air pollution by 40 % (Cockett, 2004).

Furthermore, for the dual fuel system ships that use LSF inside the SECAs and HSF fuel outside SECA, lube oil for engine lubrication has to be changed according to the kind of fuel oil used, which represents another additional cost as lube oil price is expected to rise due to the increase in demand and shortage in supply (Lube oil shortage looms, 2005).

The usage of shore power supply is the most expensive solution especially for long berth stay vessels. This can cost double or more the price of power generated on board ship (Helsinki Commission, 2005b); and shore electricity costs may also differ from port to port (IMO, 2005b). Furthermore, and as mentioned during the Maritime Environmental Committee 54 (2005, b), there is no guarantee that “the ship adaptation for one port is of use in another, or for the port that an adaptation for one ship is of use in another”. In addition, there is a high probability of short power interruption which would directly affect the ship’s navigational and electronic equipment, which are currently fitted in most new ships (IMO, 2005b).

It then appears that unfortunately ship owners face many technical problems and obstacles to reduce SOx either by using a single fuel system by burning LSF or HSF, or a dual fuel system by burning both grades of fuel, HSF outside the SECA limits and LSH inside, where both require training for the crew familiarize themselves with.

For the single fuel system, LSF causes less technical problems because it requires only engine and tank modifications. While using HSF, treatment to the exhaust gas steam is essential. This can be done by fitting an exhaust gas cleaning system, with the huge disadvantage of generating diluted sulphuric acid which causes decay problems (Reynolds, 2004).

A dual fuel system is the best solution for ships with short stays inside SECA, but the main problem is how to properly store, segregate and handle different grades of fuels, as well as different grades of cylinder lubricating oils. Besides, many ships operating nowadays can find difficulties in bunker tank spaces to separate the two fuel grades all the way to the main engine (Getting used to SECAs, 2005). Other problems could occur if an improper operation is taking place in switching between HSF and LSF, which could cause serious engine damage and power loss (Macqueen, 2005).

A study conducted by the EU also stresses that we would need about 20 million tons of low sulphur oil in 2007, while the supply was only 6.5 million tons in 2005, with less than 1 million tons consumed by the maritime industry (SAI, 2005). The demand for LSF will increase by one third by 2015; with an expected shortage of one million barrels per day as SECAs come into force (MARPOL knocks your SOx off, 2005). Another factor is the availability regarding logistic issues, as the refiners capable of producing such fuel quality (LSF) are far from the coastal areas. Nevertheless, there is also a shortage in the blending marine fuel tank spaces and difficulties in LSF blending because low sulphur fuels are hard to blend to the right quality (Traffic spurs low…., 2006).

To conclude, ratification of MARPOL 73/78 Annex VI was a very important step towards a cleaner environment and led the shipping industry towards green shipping. The strengthened proposals made by some countries could work to improve the proposed solutions to reduce air pollution with fewer technical and financial problems for shipping companies.

Moreover, the previous discussions have shown that although different solutions exist, it is yet difficult to find a comprehensive solution for which all parties involved in the shipping industry could agree.

# CHAPTER THREE

## SOURCES OF AIR POLLUTION IN MARINE PORTS AND PRACTICES FOR THEIR CONTROL

### 3.1 Introduction

Ports are attracting all the modes of transportation: foreign and domestic-going vessels, road trucks, railway trains and inland waterway transportation units. In addition, ports use various types of handling equipment to load and unload cargo between the previous modes. The majority of equipment runs on diesel power engines which are negatively affecting air quality in ports and increasing the level of air emissions. Therefore, protecting the port from such pollutants has always been a challenge for all the port stakeholders.

This chapter will firstly review the sources of air pollution in port areas and secondly, the measures taken by different ports to tackle this air pollution threat.

### 3.2 Air pollution sources in marine ports

The economical growth in marine ports is leading to environmental problems. For instance, ports operate ocean-going vessels and tug boats that run on heavy fuel (the dirtiest grade of diesel fuel) and imply cargo handling operations that make use of hundreds of types of diesel powered equipment as well as millions of diesel trucks for land transportation causing an array of environmental degradation.

In the year 2000, the air pollution generated by the 10 largest American ports[4] was for instance estimated to contribute 7 percent of NOx and 6 percent of PM (Particulate Matters) emissions from all transportation activities in the United States (U.S EPA, 2002). Figure (5) shows the average source of pollution within a container terminal with respect to NOx and PM (Particulate Matters) only. We can see that marine vessels and trucks contribute more than 70% of the air pollution.

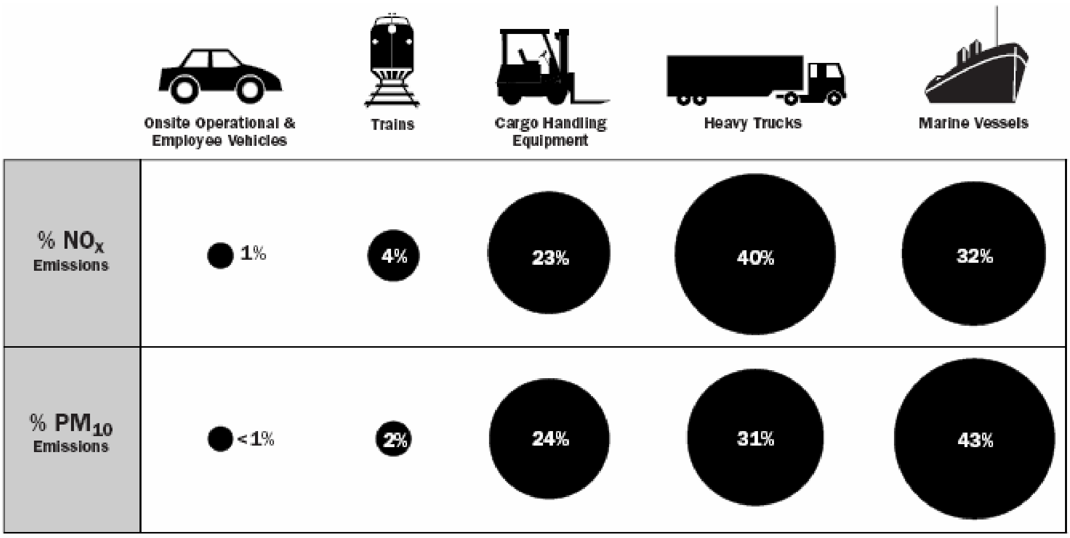


**Figure 5 sources of pollution within a container terminal**

Source: Bailey, D., Plenys, T., Solomon, G., Campbell, T., Feuer, G. Masters, J. & Tonkonogy, B., (2004). *Harbouring pollution*, Strategies to clean up U.S Ports. National Resource Defence Council, New York

Furthermore, the increasing size of vessels multiplies the amount of air pollution generated by the thousands of horse power required. It was estimated that each post Panamax container vessel emits nearly one ton of NOx and PM, and half a ton of SOx in every port call which is equivalent to 69,000 diesel truck miles or enough to drive 3 times around the earth (Port of Los Angeles, 2004). Accordingly, these mega carriers require powerful tug boats to assist them while berthing alongside the quays,

[4] Los Angeles, Long Beach, New York& New Jersey, Charleston, Oakland, Hampton Road, Seattle, Savannah, Houston and Miami.

for which a similar relationship between power and pollution exists (U.S. EPA, 2003).

Heavy trucks are contributing the most to air pollution and are also essential for port operations and in particular for container ports. They are used during the transferring process (in some port operating systems) and within the port between the quays to the container yards as well as for land transportation to and from the port.

Cargo handling within the port is also carried out by special handling equipment that requires heavy duty machines with powerful diesel engines in order to load/unload and move cargo. Examples of the cargo handling equipment in a container terminal berth are quay cranes, straddle carriers, forklifts, front-end loaders and others. The regulations and emission standards that apply to such equipment is not restrictive like for other on-road vehicles. In the United States and in 2007 for example, the PM and NOx emissions from such equipment are expected to be 15 times more than for highway trucks (Starcrest Consulting Group, 2003).

To conclude, the nature of ports as transportation nodes that link the sea transport and the land transportation modes make them vulnerable in generating more air hazards than other types of industries or services, especially after the era of containerization leading to faster and more frequent transport.

## 3.3 Measures to improve environmental managing practice in ports

Ports have implemented different means to reduce the air pollution generated by the previously explained sources. They have mainly focused on the emissions from the floating units, foreign going vessels (FGV) port service boats and tug boats, from the cargo handling equipment as well as from heavy trucks used in land transportation.

### 3.3.1 Floating units

Floating units can be categorized into two categories. Firstly, the ones that are service boats within the port area such as mooring boats, pilot boats and other power driven boats. Secondly, the Foreign Going Vessels (FGV) which represent the ship that calls at the ports either for loading or unloading cargo. Enforcement of any measures by the port to regulate air emissions from FGVs is much more difficult than controlling the air hazards from port service boats. At the same time, regulating air pollution from FGVS is more important due to the huge amount of polluted materials emitted from their engines compared to the pollution generated by the service boats.

The main reason for this is that service boats are easy to control as they have to follow the regulation enforced by the port authority or by the government's regulation. The pollution emitted from port service boats changes according to various factors. One of the main factors is the age of the unit that could reach more than 30 years in some ports, especially for tug boats that are "high fuel consumers". Therefore, some ports have started to encourage tug boat owners to retro-fit their tugs with new environmental-friendly engines. The Port of Los Angeles for instance is going through an incentive program implemented by the state to retro-fit 60 tug boats with new diesel engines with low air emission hazards. A similar procedure is taking place in San Francisco Bay and New York harbour (Bailey, D., Plenys, T.…, 2004).

Different practises have been made in other ports like Rotterdam. These ports are using the cold ironing system to provide the tugs with shore side power while berthing. Moreover, tugs are enforced to burn fuel with lower Sulphur contents in Europe and in some American ports (Bailey, D., Plenys, T.…, 2004).

As stated previously, the foreign-going vessels that call at the ports are more difficult to control than harbour service boats due to the nature of their business, in which most of the ports are competing to attract cargo volumes. The reduction in environmental constraints for ship calling could represent a competitive advantage.

Economical incentives have been implemented to tackle this dilemma of pollution control. In 1996 the Swedish Maritime Administration, the Swedish Ship-owners'

Association and the Swedish ports agreed on the implementation of a maritime economical incentive. This was done by differentiating fairway dues in having a portion of the port dues related to the ship's emissions of sulphur and nitrogen oxides. Ships, which have taken environmentally protective measures are charged less, while ships with higher emission levels will pay higher dues (the polluter pays principle).

For instance, a tanker loading mineral oil products in bulk and emitting below or equal to 2 grams per kilowatt-hour (g/kwh) will pay the minimum dues, and a linear increasing scale of 6 percent applies for every additional g/kwh. If the amount of emissions reaches 12 g/kwh, the vessel pays 60 % more. For other types of vessels, the increase is set at 7 percent. The global aim of the previous incentives is to reduce the air pollution from ships by 75% within a 2-year period (Helsinki commission, 2005a). The system has been successful and the number of vessels operating on low Sulphur oil has increased to reach 1450 vessels in 2000 (Kommunenes Internasjonale Miljøorganisasjon (KIMO), 2001).

Moreover, the Finnish and the Norwegian ports have proposed and implemented similar programs to reduce the port dues for environmentally friendly vessels (Helsinki commission, 2005a). It could be a recognition of the success of the Swedish system in reducing air emission as well as the spreading of the 'polluter pays' concept.

Furthermore, the introduction of a green award certificate granted for vessels that meet a high degree of safety standard and are manned by highly qualified and trained crews is a good example of the economical incentives that are provided to the environmental friendly vessels. The quality of fuel used, which represents the amount of hazards emitted, is one of the conditions to be examined before providing the green award certificate. Then the vessels holding the green award certificate will have a rebate in the port dues as well as other port services in various ports world wide. Table (1) shows the green award economical incentives applied by some ports. (Stevens, H, 1999).

**Table 1 Economical incentives provided to the green award certified vessels**

| Country | Port | Incentive given |
|---|---|---|
| Belgium | Port of Ghent | 6% premium on the port fees for Crude oil/Product Tankers and for Dry Bulk Carriers |
| Lithuania | Klaipeda State Seaport Authority | 5% premium on vessel dues for Crude oil/Product Tankers |
| New Zealand | Westgate Port Taranaki | 5% discount on its marine tariff |
| Portugal | Administração do Porto de Sins | 5% premium on Tariff of port use (TUP) for Crude oil/Product Tankers |
| | Administração dos Portos do Douro e Leixões | 3% premium on Tariff of port use (TUP) for Crude oil/Product Tankers |
| | Administração do Porto da Lisboa | 5% premium on Tariff of port use (TUP) for Crude oil/Product Tankers |
| | Administração do Porto de Setúbal | 3% premium on Tariff of port use (TUP) for Crude oil/Product Tankers and for Dry Bulk Carriers |
| South Africa | National Ports Authority of South Africa (Richards Bay, Durban, East London, Port Elisabeth, Mossel Bay, Cape Town, Saldanha) | 5% port dues rebate in all South African national ports if not enjoying a 5% rebate in terms of double-hulled/SBT scheme. |
| Spain | Puertos del Estado (Bilbao, Santander, A Coruña, Huelva, Bahia de Cádiz, Bahía de Algeciras, Málaga, Cartagena, Valencia, Castellón, Tarragona, Barcelona, S.C. de Tenerife and other ports) | As from 1st January 2004 a new port law has become effective in Spain. The reimbursement for Green Award certified vessels has been postponed until after implementation of modifications to the new law. |
| The Netherlands | Port of Amsterdam | 6% premium on the port fees for Crude oil/Product Tankers and for Dry Bulk Carriers |
| | Port of Rotterdam | 6% premium on the port fees for Crude oil/Product Tankers |
| | Port of Dordrecht | |
| | Moerdijk Port Authority | |
| | Zeeland Seaports (Vlissingen, Terneuzen) | |

Source: Green Award. Incentives for green award vessels. Retrieved 28 May 2007 from the World Wide Web http://www.greenaward.org/defaulthome.htm . Author.

Another method to reduce air pollution from ships is shore side power which is supplied to ships by cold ironing in order to provide them with the essential power required to operate the ship's cargo handling gears, refrigerators, air conditions, etc. This method is very effective in producing zero emissions from ships. On the other hand it cannot be used while the ship is in any other place in the port rather than along side. In other words the emissions from the ships while maneuvering or anchoring would still not be controlled.

Many ports world wide like Los Angeles, California, Juneau, Alaska and Goteborg have implemented shore power supply measures. This electric power is generated through more environmentally friendly generators due to the fact that the main electrical power supply generated from local power plants is highly regulated in terms of hazard emissions. Similarly, the alternative source of power, like for example fuel cells[5], is considered to be one of the cleanest sources of energy as shown in table(2) (Bailey, D., Plenys, T.…, 2004).

**Table 2 Comparison of emission rates of power generated from auxiliary diesel engines, conventional power plants and fuel cells (lb/MW-hr)**

| Pollution | Diesel fuel | average USA power plants | Fuel cells |
|---|---|---|---|
| NOx | 18.3 | 3.52 | 0.002-0.03 |
| CO | 25.4 | 0.33 | 0.002-0.142 |

Source: Bailey, D., Plenys, T., Solomon, G., Campbell, T., Feuer, G. Masters, J. & Tonkonogy, B., (2004). *Harbouring pollution*, Strategies to clean up U.S Ports. National Resource Defence Council, New York

The disadvantage of the cold ironing system is that it is not suitable for all ships calling at the port as it requires special modification on board the vessel in order to use the shore side power connection. Therefore, most shipping companies that frequently call at ports, with container vessels and cruise ships, can provide their vessels with such expensive fittings as they cost the Princess Tour cruise lines $ 4.5

[5] Fuel cells are an electrochemical energy conversion device which produces electricity through a chemical reaction.

million to retrofit 4 vessels and prepare the shore side construction at Juneau and Alaska terminals (Plenda, 2001).

On the regulatory side the European Union has also taken measures to enforce the use of lower Sulphur fuel while vessels are in port. The European Union adopted a directive (E.U. Directive 99/32/EC) to strengthen the limits of Sulphur contents in marine fuel within the inland water ways, not to exceed 1.5%. Moreover, a proposal was submitted on January 2007 to the European parliament and council prepared by the Commission of the European Communities to reduce the acceptable percentage of Sulphur within the European inland water including ports to reach less than 300 ppm, equivalent to 0.03% of Sulphur (Commission of the European Communities, 2007). On applying such new regulations significant improvement of the air quality within European ports will be gained.

We can conclude that the emission control from the floating units have been tackled by different polices world wide, and more specifically in Europe and North America. This was by introducing economical incentives or using the cold ironing system in addition to proposing more strengthened regulations on the regional scale. The controlling of air emissions from the floating units cannot be separated from a more integrated system to reduce air pollution on the quay and yard side.

### 3.3.2 Terminal handling equipment and trucks

Ports are using a vast amount of cargo handling equipment for loading, unloading and transferring cargo from the quay apron to the yard area. Container terminals in particular are on the spot in terms of air pollution resulting from the diesel engines cargo handling equipment operated to handle the enormous amount of container movements every day.

Handling container equipment is classified as off road vehicles which were less controlled several years ago. Therefore the older engines are emitting air hazard levels beyond the limits authorized for on road vehicles (Bailey, D., Plenys, T.…, 2004). Some European ports like Barcelona have started already to use hybrid driven straddle carriers which reduce fuel consumption by 30%. The Port of Los Angeles is using LPG (liquefied petroleum gas) yard tractors. Other ports have shifted to using electric forklifts like the port of New York, New Jersey and the port of Houston.

Moreover, the use of exhaust cleaners like Diesel Oxidation Catalysts (DOC) has been widely used for container handling equipment. The Port of Long Beach fitted 600 DOCs to its yard equipment in its major 7 container berths in 2004. Similar steps were taken to approximately 800 pieces of equipment in Los Angeles. On the European side the Port of Goteborg installed DOCs in one third of its container handling equipment with the use of low Sulphur fuel. One of the main obstacles preventing the wide use of the DOCs is the equipment's year of build. In other words the machines built before 1994 are mechanically controlled engines; therefore it was difficult to fit the DOCs on such engines (Bailey, D., Plenys, T.…, 2004).

Consequently, the use of clean fuel like low sulphur diesel, diesel emulsions[6], biodiesel [7] and fischer-tropsch diesel[8] was the best alternative to reduce air pollution from equipment. The Copenhagen Malmo port uses low sulphur diesel 50 ppm. Helsinki uses fuel with a sulphur content not exceeding 30 ppm. The Port of Oakland in the United States converted most of its equipment to use 15 ppm fuel. Diesel emulsions are also widely used in Los Angeles port running 600 items of handling equipment with this fuel, while the Port of Houston is running 40 pieces and Long Beach port is using it in two items of terminal equipment (Bailey, D., Plenys, T.…, 2004).

The introduction of new container handling techniques also helps in reducing air pollution like the use of the multitrailer system which is a single flexible trailer capable of towing 5 yard tractors combined, that can move 5 containers at a time.

[6] A mixture of diesel and water used together and injected in the combustion chamber in order to reduce air pollution
[7] Biodiesel is fuel made from vegetable oils or animal fats.
[8] fischer-tropsch diesel is a high-quality diesel fuel that can be made from any organic material such as coal, natural gas, or municipal waste

This was initially used in Rotterdam and can be found now in various major ports like Felixstowe, Singapore and Vancouver (Savenjie R, 2000).

Trains and trucks are necessary for container transportation from and to the ports. Trucks in particular are more preferred in some countries because of their flexibility in providing the door-to-door service or due to the absence of appropriate railway systems to connect the hinterland. Consequently trucks are essential in providing good customer services to all the port customers but induce a huge amount of hazards emitted inside and nearby the port area for several reasons. The main ones are the age of the trucks that are still in service and the waiting time the trucks spend inside the ports waiting to load or unload containers. To overcome the problem, some ports in cooperation with some incentive programs have started to renew their truck fleets.

For instance, the Gateway city program applied in Southern California USA has proven to be a great success. This program was funded by a group of nearly 30 local cities and government agencies with a budget of approximately $14 million to remove old and uncontrolled trucks operated within the region. The port of Long Beach was granted $4 million to clean up trucks operating within the port area. These renewal processes for trucks will eliminate more than 160 tons of NOx and 40 tons of PM every year within the port area. The port of Oakland is applying a similar incentive program by investing nearly $2 million for the sake of having environmentally-friendly trucks within the port area (Bailey, D., Plenys, T.…, 2004).

Reducing the truck idle time is also an effective tool to limit air emissions. California has implemented an innovative legislation to reduce the time trucks are waiting inside the ports. The port will have to pay a fine if a truck has to wait more than 30 minutes within the port area (State Environmental Resource Center (SERC), 2004).

To sum up, air pollution generated in the port area is one of the major pollution problems that need to be tackled by all the port stakeholders. Furthermore, the reduction of air pollution has to be organized integrally, in other words through the emission reduction from the port handling equipment, the ships calling at the port and the trucks that connect the port with its hinterland, all in a comprehensive and harmonized pattern.

# CHAPTER FOUR

## SUEZ CANAL STRATEGIC LOCATION AND ECONOMIC IMPORTANCE IN ENHANCING AIR POLLUTION ENVIRONMENTAL POLICY

### 4.1 Introduction

Canals are playing a crucial role in facilitating trade on a global scale. The Suez and Panama Canals are considered to be the nodes in connecting world trade moved by ocean-going vessels. The Suez Canal in particular connects the world routes in the east west direction as well as the north south routes.

This chapter highlights the importance of the Suez Canal. The objective is to show that the huge savings for ship owners in using the Canal instead of sailing around the Cape of Good Hope induce that even if drastic measures were taken that would increase the transit fee for instance; it would still be beneficial for ship-owners to transit through Suez.

Firstly, an illustration to the Suez Canal’s position and characteristics will be presented. Secondly, the economical importance of the Canal will be highlighted. Finally, the evolution of the Suez Canal’s economical importance in the previous decade will be illustrated.

### 4.2 Suez Canal geographical location importance

The Suez Canal is an artificial channel running north to south across the Isthmus of Suez in Egypt. It connects two oceans and two seas, the Atlantic and Mediterranean, through Gibraltar to Port Said, and the Indian Ocean and the Red Sea passing through Bab Al Mandab. It is about 190.3 km long with no locks. Most of the Canal has only a single traffic lane, with several passing bays (Rodrigue, 2006).

Figure (6) shows the strategic position of the Suez Canal, in which it lies in the middle of the main Europe Far East route providing a significant saving in time as well as cost in sea freight. Moreover, table (3) represents the distance saved by using the Suez Canal between countries representing the main trading regions in Europe, the United States of America and Asia.

The Suez Canal's strategic importance lies in the fact that it is vital for world trade. In 2003 approximately 14% of the total world trade passed through the Canal, 26% of oil exports, 41% of the whole volume of cargo that arrived at the  Arab Gulf ports (Rodrigue, 2006).

**Table 3 Distance saving in using Suez Canal routes**

| From | To | Distance in nautical miles | | Distance saved | |
|---|---|---|---|---|---|
| | | Suez Canal | Cape of good hope | miles | percentage |
| Ras Tanura | Constansa | 4144 | 12094 | 7950 | 66% |
| | Lavera | 4684 | 10783 | 6099 | 57% |
| | Rotterdam | 6436 | 11169 | 4733 | 42% |
| | New Orleans | 9645 | 12299 | 2654 | 22% |
| Jeddah | Peoria | 1320 | 11207 | 9887 | 88% |
| | Rotterdam | 6337 | 10743 | 4406 | 41% |
| Tokyo | Rotterdam | 11192 | 14507 | 3315 | 23% |
| Singapore | Rotterdam | 8288 | 11755 | 3647 | 29% |

Source: Higazy, A. (2005a). *Suez Canal role in developing the national economy and its future development plan*. Ismailia, Egypt: Suez Canal Authority

The Suez Canal can accommodate enormous ships of 500 meters in length, 70 meters in width and a draught of 66 feet. The present capacity of the Canal has reached more than 25.000 vessels yearly (Rodrigue, 2006).

Historically, the idea of linking the Mediterranean and Red Seas first occurred during the Pharaonic age; they dug a canal linking both Seas through the eastern branch of the Nile Delta, which is lying west of the existing Canal. Later the canal was neglected until the Greeks, followed by the Romans, then the Arabs dug it several times but it was again abandoned (Dessouki, 1982).

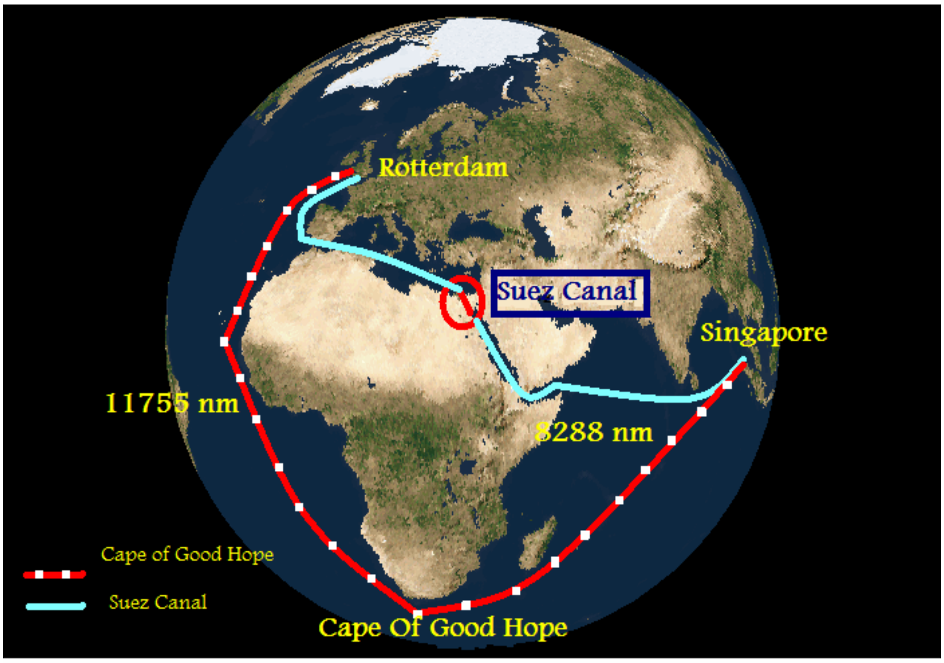


**Figure 6  Suez Canal geographical location**
Source: Author, derived from various sources.

On November 30, 1854 the French engineer Ferdinand De-lesseps signed a concession with the Egyptian authorities to start digging the Suez Canal. On April 25, 1859 the digging of the Canal started for a non-stop period of 10 years. On November 17, 1869 the Suez Canal was opened for navigation. Since then the canal has passed through several development plans in order to satisfy the demands of the shipping industry. Table (4) shows these developments during the previous century.

The canal development plans were interrupted several times through its history due to political conflicts in the Middle East. These conflicts resulted in the need of seizing the Canal two times against international as well as domestic passages.

Moreover, the maritime industry has strongly been affected during these two times in which the Canal was closed.

**Table 4 the development in the Suez Canal characteristics from 1868 till 2007**

| | **year** | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1868 | 1956 | 1962 | 1981 | 1994 | 1996 | 2007 |
| Length (km) | 164 | 175 | 175 | 187.5 | 190.3 | 190.3 | 190.3 |
| Length of two way lanes(m) | zero | 29 | 29 | 78 | 78 | 78 | 78 |
| Depth (m) | 8 | 14 | 15.5 | 19.5 | 20.5 | 21 | 22.5 |
| Area of water sector | 304 | 1200 | 1800 | 3600 | 3800 | 4200 | 5000 |
| Maximum Draft (m) | 6.7 | 10.7 | 11.6 | 16.2 | 17.1 | 17.7 | 20.1 |
| Maximum DWT (1000) | 5 | 30 | 80 | 150 | 175 | 190 | 220 |

Source: Higazy, A. (2005a). *Suez Canal role in developing the national economy and its future development plan*. Ismailia, Egypt: Suez Canal Authority

### 4.3 Suez Canal economic importance

The economical importance of the Suez Canal can be identified through reviewing the economical impact on the world's economy during these previous periods. The maritime industry suffered an increase in transportation costs and time especially for the oil trade between the Middle East and Europe. Moreover, the seaborne trade between Europe and South East Asian countries and East African countries has also been affected.

In 1966, which was the last year before the second closing, 242 million tons of cargo including 176 million tons of oil products has passed through the Suez Canal. Consequently after the seizing of the Canal, this huge amount of trade used the alternative routes via the Cape of Good Hope, which resulted in an increase in the transportation cost. Moreover, the world's fleet struggled to provide the required transportation capacities to overcome the demand for this new sea haulage: (Higazy, 2005a).

In 1973 the United Nations prepared a report explaining the economic impacts resulting from the Suez Canal closure. These reasons can be summarised as follows. The tremendous increase in transportation route distances with the shortage in world fleet capacity led to an increase in investments for building new vessels, especially tankers, by approximately $2600 million. Moreover, the maritime transport expenses increased by $4400 millions in 5 years (1967 to 1971) with an increasing rate of $875 millions annually (Higazy, 2005b).

Furthermore, the eastern African countries and south East Asian countries lost 20% of their exporting trade and 22.5% of the developing countries except oil exporting countries. Moreover, the loss in trade between Europe and East African countries as well as South East Asian countries reached $560 million, which is equivalent to 13% of these countries export values. The direct loss from the Canal closure was the increase of sea freight cost by $7080 millions from mid 1967 to 1971 with an increasing rate of $1715 million annually (Higazy, 2005b).

The previous facts stress what the world economy lost due to the Canal closure; the next question is what the world gains from the Suez Canal existence. These gains can be explained by showing the following indicators. First is to quantify the amount of cargo transiting the Suez Canal, which represents the Canal's importance to its users. Second is to estimate the savings provided by the Canal in terms of cargo tons per miles.

The amount of cargo transiting the Suez Canal in the previous 10 years as shown in figure (7) has increased tremendously to reach double the volume in the 10-year period (from 1997 to 2006). Moreover, the cargo moving from the eastern regions towards the West increased at a higher accelerating rate than that moving from the West to the East.

The cargo tons per mile saved by the Suez Canal route compared to the alternative route via the Cape of Good Hope can be estimated by the following methodology. First, we select ports representing the regions served by the Canal. Second, we calculate the route distance between these representing ports via the Suez Canal route and via the Cape of Good Hope. Then we calculate the cargo tons per mile on both routes. Finally, the gains from the Suez Canal can be quantified by the difference in terms of cargo tons per mile between both routes (Higazy, 2005).

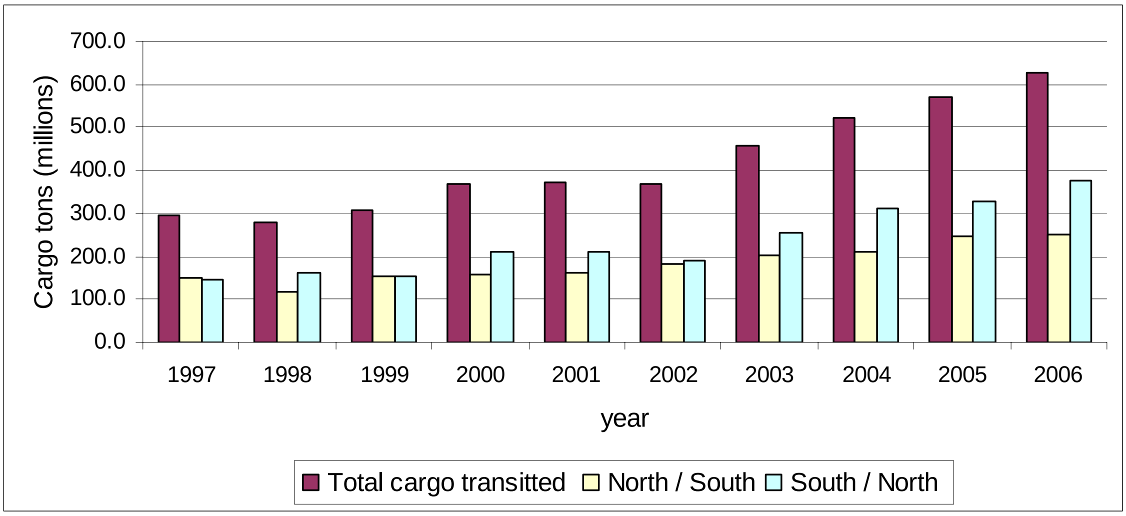


**Figure 7 Amount of cargo transited Suez Canal from 1997 to 2006**

Source: Suez Canal yearly report (various issues).

By applying the previous methodology the gains made in 2006 due to the Canal's existence are shown in table (5). By analysing the data presented in this table, the tons per mile saved in the total regions served on both sides of the Canal exceeded 3 tera[9] tons/mile.

Moreover, these calculations are for the main regions served by the Suez Canal while other regions were not considered. The main reason for neglecting these regions is the small cargo volume transited to them as well as the difficulty in obtaining a representing port to calculate distances for these regions.

In comparing the savings achieved in both areas west and east of the canal, the western regions gain more than double the benefits than the eastern regions. This is due to the difference in distance between the Cape of Good Hope and the western areas in comparison to the Suez Canal.

[9] Tera = $10^{12}$

For the western regions, the Northern Mediterranean and Northern West Europe regions have gained the biggest benefit due to the saving in distance and the big volume of cargo respectively. On the other hand, regions with the least benefits are the American regions as well as the Baltic regions due to the smaller saving in distance and the small volume of cargo transiting the Suez Canal respectively.

In the Eastern regions, there is a huge variation in the amount of savings made by the Canal. Southeast Asia and the Far East countries are trading with huge amounts of cargo reaching nearly half the cargo passing from or to the Western regions. Therefore, they are gaining the maximum benefits. In addition, the Arabian Gulf regions are gaining a lot of savings due to the volume of trade as well as the close location to the Suez Canal in comparison to the Cape of Good Hope. On the contrary, Australia could gain more savings when using the Cape of Good Hope routes but the reason for using the Canal is definitely the savings gained in its trade with the western regions of the Canal.

To sum up we can realise that the Suez Canal provides tremendous savings in terms of tons per mile for both regions east and west of the Canal. These savings are more significant to regions with big cargo volumes or regions with a close geographical location with the Suez Canal in comparison with the Cape of Good Hope.

### 4.3.1 Evolution of Suez Canal economic benefits for its users

To understand more about the Suez Canal’s importance for its users, the previous methodology was used to see the trend in savings for the Eastern and Western regions for the 10 years from 1997 to 2006 as shown in Figures 9 and 11. In addition, Figures 8 and 10 illustrate the progress of cargo volumes which are classified according to a regional segmentation.

The cargo volume trend for the Western regions show in figure (8) a slight increase for all regions in the last 5 years except for North West Europe that shows a significant increase. On the other hand, the Baltic region is using the Canal with a steady volume of cargo.

**Table 5 Savings in (tons/mile) when using Suez Canal route in 2006**

| Region | Ports representing the Regions | Distance to Cape of Good Hope (miles) | Distance to Suez Canal (miles) | Cargo tons(millions) | Tons/mile via Suez Canal | Tons/mile via Cape | Difference |
|---|---|---|---|---|---|---|---|
| | | Dc | dz | t | zt = t * dz | ct = t * dc | ct - zt |
| Western regions to the Suez Canal | | | | | | | |
| East & S.E. Mediterranean | Iskenderun (Turkey) | 7112 | 463 | 61.2 | 28,336 | 435,254 | 406,919 |
| North Mediterranean | Toronto ( Italy) | 6323 | 1027 | 121.4 | 124,678 | 767,612 | 642,934 |
| West & S.W. Mediterranean | Algeria (Algeria) | 5502 | 1590 | 78.3 | 124,497 | 430,807 | 306,310 |
| Black Sea | Istanbul ( Turkey) | 6890 | 873 | 51.6 | 45,047 | 355,524 | 310,477 |
| North, West Europe | Rotterdam (Netherlands) | 6163 | 3361 | 245.5 | 825,126 | 1,513,017 | 687,891 |
| Baltic Sea | Goteborg (Sweden) | 6607 | 3805 | 7.3 | 27,777 | 48,231 | 20,455 |
| America | New York (USA) | 6769 | 5206 | 53.6 | 279,042 | 362,818 | 83,777 |
| | | Total | | 618.9 | 1,454,501 | 3,913,263 | 2,458,762 |
| Eastern regions to the Suez Canal | | | | | | | |
| Red Sea | Jeddah (KSA) | 4653 | 636 | 76.6 | 48,718 | 356,420 | 307,702 |
| East Africa & Aden | Aden (Yemen) | 3959 | 1307 | 16.7 | 21,827 | 66,115 | 44,288 |
| Arabian Gulf | Ras Tanura (KSA) | 5025 | 3075 | 122.6 | 376,995 | 616,065 | 239,070 |
| South Asia | Mumbai (India) | 4599 | 2959 | 68.5 | 202,692 | 315,032 | 112,340 |
| South East Asia & Far East | Singapore (Singapore) | 5611 | 4927 | 307.1 | 1,513,082 | 1,723,138 | 210,056 |
| Australia | High Point (Australia) | 7489 | 8171 | 34.9 | 285,168 | 261,366 | -23,802 |
| | | Total | | 626.4 | 2,448,481 | 3,338,136 | 889,655 |

Source: Author's own calculations, derived from various sources.

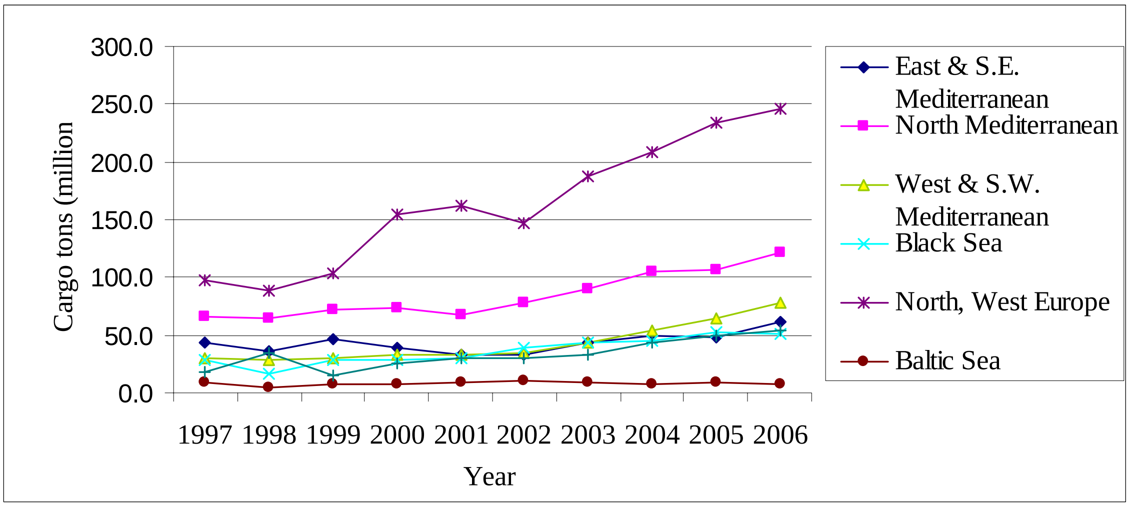


**Figure 8 Suez Canal western regions cargo volume from 1997 to 2006**

Source: Author, derived from Suez Canal yearly report (various issues).

Meanwhile, figure (9) shows the amount of cargo tons per mile saved in western regions due to the usage of the Suez Canal routes. It is clear that all regions are gaining an ascending pattern in savings. Moreover, the north Mediterranean and North West Europe regions are both gaining the maximum benefits due to the great amount of cargo and their close position respectively.

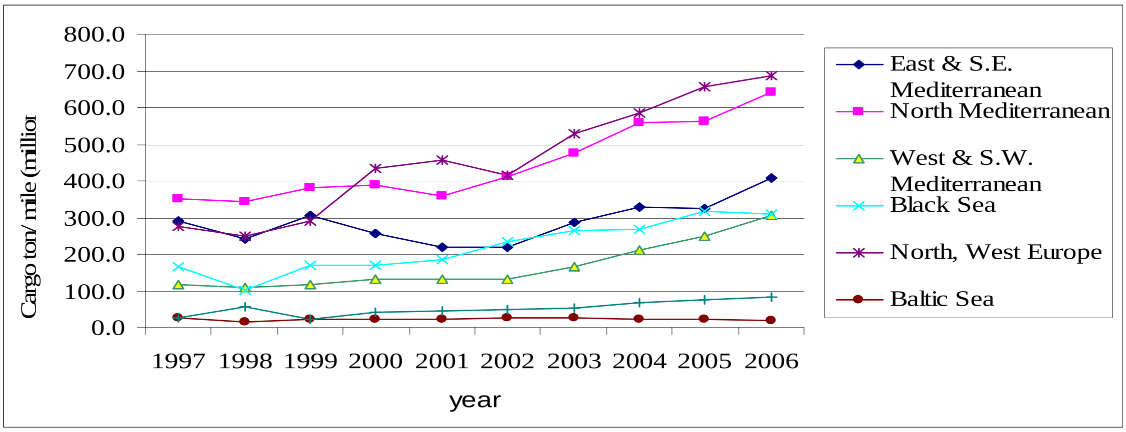


**Figure 9 Savings (tons/miles) provided by the Suez Canal usage for the western regions from 1997 to 2007**

Source: Author, derived from Suez Canal yearly report (various issues).

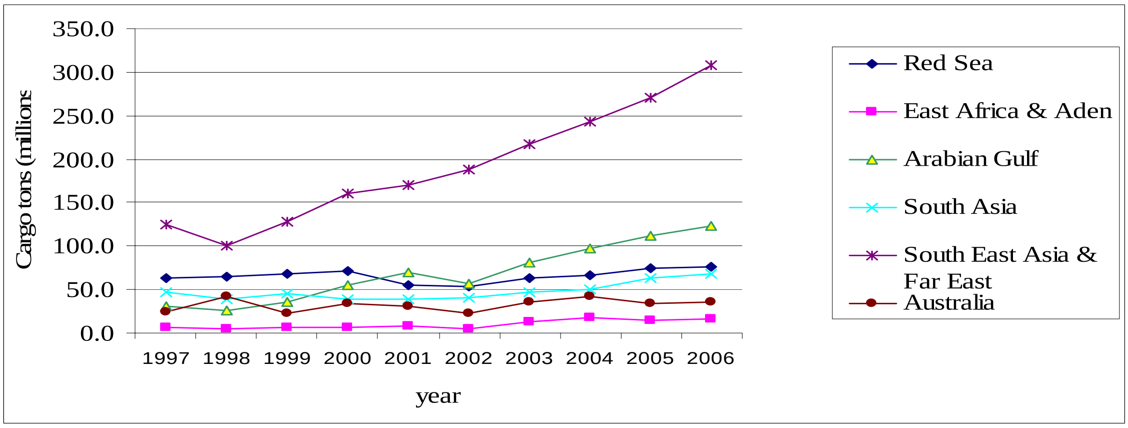


**Figure 10 Suez Canal Eastern regions cargo volume from 1997 to 2006**

Source: Author, derived from Suez Canal yearly report (various issues).

For regions east of the Suez Canal, figure (10) shows a rising cargo volume trend for South East Asia and the Far East regions, while the Arabian Gulf area shows a slight increase. For the rest of the regions cargo volume has an almost steady trend.

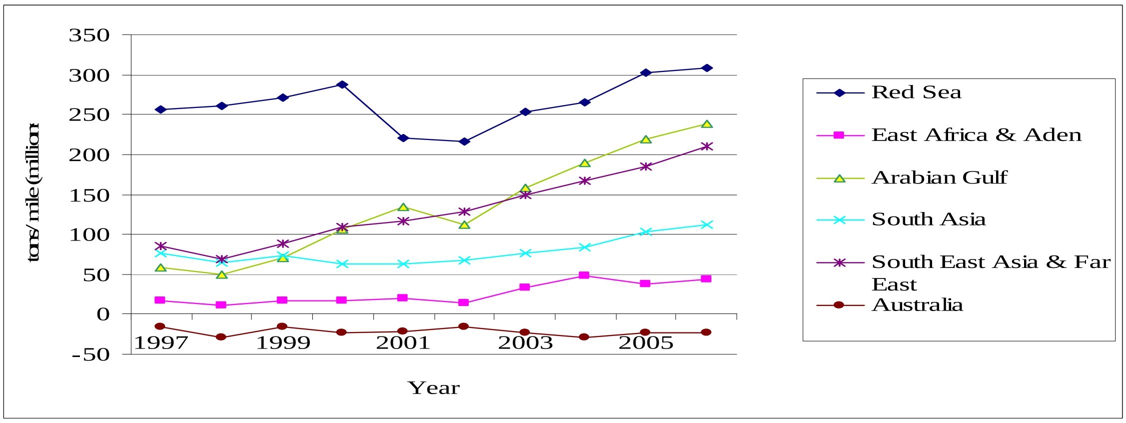


**Figure 11 Savings (tons/miles) provided by the usage of Suez Canal route for the Eastern regions from 1997 to 2007**

Source: Author, derived from Suez Canal yearly report (various issues).

For the savings gained in the eastern regions figure (11) shows an enormous variation in the saving levels. This variation is due to the vast geographical area served, in which the served regions are scattered by a huge distance difference from the Canal. In other words the Red Sea region is 600 nautical miles from the Canal, while Australia is nearly 8000 nautical miles away. Therefore, the Red Sea region is gaining the maximum savings with a steady trend; while the Australian region is having a constant negative savings when using the Suez Canal routes. Moreover, the rest of the Eastern regions have gained a slight increase in savings, especially in the last 5 years.

To sum up, the Suez Canal has proved to be a very important water-way for major regions world wide. The increasing trend pattern of international trade stresses the importance of this Canal for its users. Moreover, the rise in cargo volume and traffic in the Suez Canal is parallel to the potential increasing trend in air pollution.

On the one hand, the Suez Canal could be a very powerful place to implement an environmental policy to reduce air pollution from vessels. This is due to the fact that ship-owners could find that the gains provided in using the Suez Canal overweigh complying with such environmental policies. On the other hand, the application of environmental policies in ports could face more difficulties due to the competition reasons and the fear of losing traffic in favour of neighbouring ports, while this fear is absent in the Canal's case.

Therefore, estimating the levels of air pollution from transiting vessels will be very important to stand up against the magnitude of such a threat. Therefore, Next chapter discusses the methodology used to estimate air emission inventory in Suez Canal area.

# CHAPTER FIVE

# METHODOLOGY TO ESTIMATE AIR POLLUTION FROM OCEAN-GOING VESSELS

## 5.1 Introduction

Decisions or regulations made to prevent or reduce pollution have to be based on either measurements or estimations. Air pollution in particular has a unique feature of having a variety of sources of which many are mobile sources, as well as having the cross border feature. Therefore, quantification of the emission inventory in a particular area or from a particular source requires a certain methodology.

This chapter identifies the importance of the vessels emission inventory and explains the methodology used in calculating the amount of air emissions within a designated area.

## 5.2 Importance of air emission inventory

Air pollution from ships is having a local, regional and global impact on the environment (Capaldo, K. Carbett, P…., 1999). Its potential environmental impact is quantified by the emission inventory. This is defined as, "the quantification of all emissions of criteria and other pollutants (including toxics and greenhouse gases) that occur within a designated area by their sources" (U.S. Environmental Protection Agency…., 2006). For example in a port it can be quantified by calculating the emissions resulting from each source (FGV, yard equipment, trucks... etc) within the port boundary.

Emission inventories are extremely important in providing crucial information to atmospheric scientists, pollution modellers and policy makers. In addition, emission inventories are an essential input in evaluating the potential impacts of emission hazard on the environment as well as on human health.

Furthermore, reducing air pollution regulations are mainly focused on reducing total emissions (on source-by-source bases). The policy maker's approach in setting pollution control regulations focuses on either sources that cause high impact (the largest sources) or on the least regulated sources. In recent times, controlling emissions from ships has come under highly domestic and international regulations because emission inventories have shown them to be both large sources of air pollution as well as the most unregulated (European Commission, 2002).

In applying the emission inventory, three general elements have to be considered. First, the combustion source activity level in terms of power or/and fuel consumption has to be measured or estimated (Corbett, J. Koehler, H., 2003). For example, if we want to calculate the FGV activities within the port then the ships engine power in kw (kilo watt) or/and the total fuel consumed from ships within the port area has to be measured or estimated.

The second step is to compute the emissions resulting from the previous sources. This can be obtained by using an emission factor which is defined as follows. "The value that indicates the amount of pollutant emitted to the air with an activity related with the release of that pollutant". Marine emission factors are generally expressed as the weight (usually weight in gram) of pollutant divided by the engine energy (usually measured in kilowatt-hours, (kWh)) used to generate such emission (U.S. Environmental Protection Agency…., 2006). Finally, the results have to be allocated to a geographical area in order to determine the air quality impact.

Researchers are facing two problems in providing accurate data on vessels emission inventories. The first one is the limited information about the marine engines emission factors (Corbett, J. Koehler, H., 2003). This is due to the variety of ship types and sizes as well as the variety of engine makers with a variety of models. Moreover, the presence of various marine engine technologies due to the existence of a mixture of multi-age fleet (ship age varies from more than 30 years old vessels to newly built ones).

The second problem is the uncertainty in vessel locations and activity levels (Corbett, J. Koehler, H., 2003). In other words the allocation of vessels within a certain area or region is very difficult due to the nature of this industry where ships are continuously moving from one place to another. Moreover, another difficulty comes from the exact ship activity (sailing mode, manoeuvring, waiting on anchor…etc) that plays on the vessel speed and engine load, and consequently affects the emission factor calculation.

Nowadays there are four main inventory programs to calculate ship emissions and their environmental impacts. Two of these programs are on a global scale; the first one is the RIVM's EDGAR database which is made by the Netherlands Environmental Assessment Agency and the second one is made by the University of Delaware's Ship Emission calculations (SECalc.). The remaining two programs are on a more regional scale, which are the RAINS-ASIA (International Assessment of Energy Use Impact on the Environment in Asia) and the Lloyd's Marine Exhaust Emission Research Program (Corbett, J. Koehler, H, 2003).

Methodologically, the programs have similar objectives. All of them estimate emissions from the vessels within the study boundary either globally or regionally. However, global inventory programs retain less detailed vessel activity data and/or try to integrate several regional inventories, while the regional inventories can better use vessel traffic estimates, vessel statistics or full port specific trade. For example, Lloyd's uses actual vessel arrival and departure data in a voyage routing model that produces the most accurate figures of regional vessel traffic (Corbett, J. Koehler, H, 2003).

## 5.3 Methodology used to calculate ship's emission

There is no specific guidance in calculating the ship emission inventory; therefore we have a variety of methodologies to make such calculations (U.S. Environmental Protection Agency…, 2006). In this research the methodology prepared by the ICF consultant and submitted to the U.S. Environmental Protection Agency which describes the best practices for preparation of port inventory will be represented.

Calculating emissions from ships is made by using energy-based emission factors and the activity profile for each ship. Therefore, the main part of the work is to determine the engine power and activity profile for each ship to provide information to calculate emissions generated by each ship using the following equation formatted by U.S. Environmental Protection Agency (2006).

$$E = P.\ LF.\ A.\ EF$$

*Where E = Emissions (grams [g])*

*P = Maximum Continuous Rating Power (kilowatts [kW])*

*LF = Load Factor (percent of vessel's total power)*

*A = Activity (hours [h])*

*EF = Emission Factor (grams per kilowatt-hour [g/kWh])*

The emission factor is in terms of emissions per unit of energy from the engine (gram/kilowatt) and is multiplied by the power necessary to move the vessel in a particular activity.

To calculate the emission inventory some key elements have to be determined. Gathering vessel characteristics is an essential part that requires knowing the various data sources. Moreover, the activity profile of each vessel in terms of time and speed (time with full away speed, time in manoeuvring speed and waiting time) is also necessary. Consequently, the load factor of each previous activity has to be identified in order to have accurate emission data. Finally, calculating the emissions from auxiliary engines and boilers with their approximated emission factor has also to be considered to calculate the emission inventory in a port with a congestion situation. Various data sources are available in order to identify the required information. Figure (12) illustrates these available data sources and the use of data extracted from them.

**Table 6 Types of ocean-going vessels**

| Ship Type | Description |
|---|---|
| Auto Carrier | Self-propelled dry-cargo vessels that carry containerized automobiles. |
| Barge Carrier | Self-propelled vessel that tows lashed barges. |
| Bulk Carrier | Self-propelled dry-cargo ship that carries loose cargo. |
| Container Ship | Self-propelled dry-cargo vessel that carries containerized cargo |
| Cruise Ship | Self-propelled cruise ships. |
| General Cargo | Self-propelled cargo vessel that carries a variety of dry cargo. |
| Miscellaneous | Category for those vessels that do not fit into one of the other categories or are unidentified. |
| Ocean-going Tugs/Tows | Self-propelled tugboats and towboats that tow/push cargo or barges in the open ocean. |
| Reefer | Self-propelled dry-cargo vessels that often carry perishable items. |
| Roll-on/Roll-off (Ro-ro) | Self-propelled vessel that handles cargo that is rolled on and off the ship, including ferries. |
| Tanker | Self-propelled liquid-cargo vessels including chemical tankers, petroleum product tankers, liquid |

Source: U.S. Environmental Protection Agency. Office of Policy, Economics and Innovation. (2006). Current methodology and best practices in preparing port emission inventories: Final report. Fairfax, Virginia: ICF Consulting.

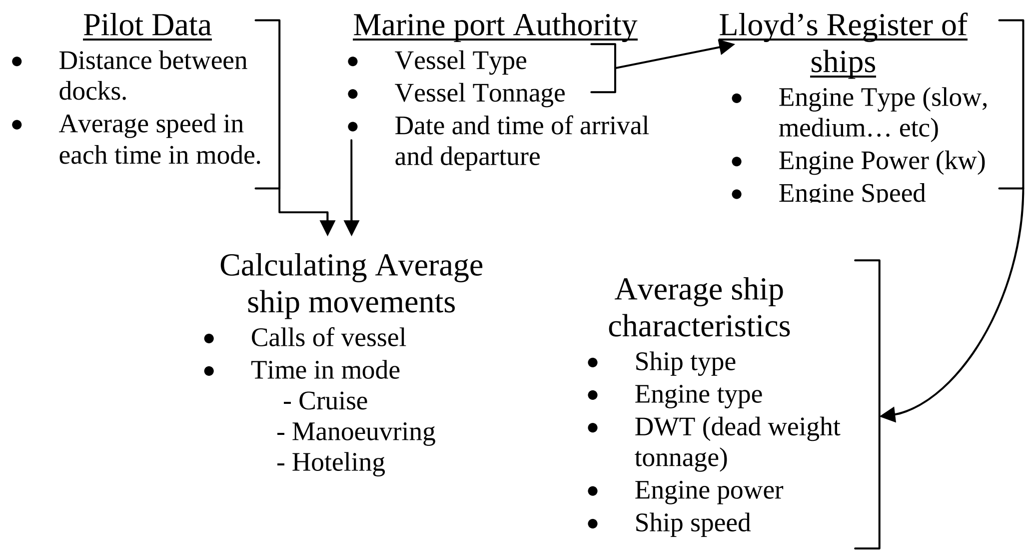


**Figure 12 Data required estimating air pollution from ships**

Source: U.S. Environmental Protection Agency. Office of Policy, Economics and Innovation. (2006). Current methodology and best practices in preparing port emission inventories: Final report. Fairfax, Virginia: ICF Consulting.

FGV represent a huge variety in tonnage as well as sailing speeds which all depends on the type of vessel. Table (6) lists the various ship types that should be described when preparing any emission inventory (U.S. Environmental Protection Agency…, 2006).

Moreover, other ship characteristics from the Lloyd's Database are needed such as the propulsion engine power, engine speed, maximum vessel speed as well as the auxiliary engine power and engine speed. The U.S. Environmental Protection Agency has categorised marine engines according to their speed (revelations per minute) as shown in table (7).

**Table 7 Marine Engine Speed classification**

| Speed | Engine RPM10 | Stroke Type |
|---|---|---|
| Slow | < 130 RPM | two |
| Medium | 130 – 1,400 RPM | four |
| High | > 1,400 RPM | four |

Source: U.S. Environmental Protection Agency. Office of Policy, Economics and Innovation. (2006). Current methodology and best practices in preparing port emission inventories: Final report. Fairfax, Virginia: ICF Consulting.

### 5.3.1 Vessel mode determination

A ship calling at a port is sailing at various speeds while entering or leaving the port. Accordingly, the level of emission generated from the ship varies due to the variation in engine load[11]. Therefore the ship call has to be broken down into different sequences with similar speed. Roughly the ship activity can be grouped into three categories. The first category is the cruising speed, the second is the manoeuvring speed and the last is the hotelling or waiting time.

The cruising speed can be explained as the speed maintained by the vessel through normal sailing conditions, normally 94% of the maximum service speed listed in the Lloyd's Data (U.S. Environmental Protection Agency…, 2006). Vessels are usually sailing at such speeds in open sea or in the unconfined water. Table (8) represents the average cruising speed for different vessel categories as reported by the port of Los Angeles.

Maneuvering speed is the safe speed at which the vessel steams within confined waters. This speed varies according to the type of vessel and the direction of sailing (moving inside the port or leaving the port). For example, the inbound average maneuvering speed in Los Angeles port varies from 7 to 5 Knots, in which containerships, car carriers and cruise vessels have 7 knots while the remaining

[10] RPM ( Revolutions per minute)
[11] Load can be expressed as a percentage of the vessel's total power

vessel types maneuver at 5 knots. While leaving the port of Los Angeles, all vessels maneuver at 8 knots. Generally in most ports, canals and confined waters the outbound average maneuvering speed is higher than the inbound maneuvering speed (U.S. Environmental Protection Agency…, 2006).

**Table 8 Average ship cruising speed by type**

| Vessel type | Average speed in knots (1.853km/h) |
|---|---|
| Auto Carrier | 13.8 |
| Bulk | 17.58 |
| Container Ship | 21.26 |
| Cruise Ship | 18.06 |
| General Cargo | 14.69 |
| Miscellaneous | 14.10 |
| Ro-ro | 13.9 |
| Reefer vessels | 18.9 |
| Tanker | 13.6 |

Source: U.S. Environmental Protection Agency. Office of Policy, Economics and Innovation. (2006). Current methodology and best practices in preparing port emission inventories: Final report. Fairfax, Virginia: ICF Consulting.

Hotelling is the time when vessels are at berth or waiting at anchorage. Vessels are operated on auxiliary engines to provide the necessary power for operating the essential equipment and machinery while the main engine is not running. If the port is equipped with a cold ironing system, then the time the vessel is connected to it must be recorded separately from the time the vessel operates its auxiliary engines.

In determining the time in mode calculations, different variables must also be taken into consideration. Traffic conditions, for instance, may cause a reduction in a vessel's speed, especially in channels. Weather conditions also affect the vessels sailing and maneuvering speed according to the presence of current and wind factors that must be taken into account.

### 5.3.2 Load factor

The load factor can be expressed as the percentage of ship's total power. At full vessel's cruising speed the power is on average 83% of the total engine capability (Corbett, J. Koehler, H., 2003). When the ship reduces its speed the propeller law should be maintained. The propeller law states that the load changes with the cube of speed as mentioned in the following equation formatted by U.S. Environmental Protection Agency (2006).

$$\boldsymbol{LF = (AS/MS)^3}$$

*Where **LF** = Load Factor (percent)*

***AS** = Actual Speed (knots)*

***MS** = Maximum Speed (knots)*

### 5.3.3 Engine emission factors

The most difficult part in determining emission inventory is the identification of the appropriate emission factor, especially for the ocean-going vessels. A recent study by Entec is used in most of the emission inventory calculations. Entec analyses data from 142 vessels including two of the main research programs: Lloyds register engineering survey in 1995 and the IVL Swedish Environmental Research institute in 2002. The Entec study listed individual emission factors for three speed categories of marine engines (slow, medium and high speed) and steam turbine engines. Moreover, the study also includes the emission factor for the three fuel types used in marine engines: residual oil, marine diesel oil and marine gas oil. Table (9) shows the emission factor determined by Entec.

It should be noted that the values mentioned in table 9 were obtained for fuel containing sulphur content of 2.7% which represents the average world sulphur content in 2003 (Corbett, P. Koehler, H, 2003).

**Table 9 Emission factors for OGV main engine using residual oil g/kwh**

| Engine | NOx | CO | SOx |
|---|---|---|---|
| Slow Speed | 18.1 | 1.4 | 10.3 |
| Medium speed | 14 | 1.1 | 11.1 |

Source: U.S. Environmental Protection Agency. Office of Policy, Economics and Innovation. (2006). Current methodology and best practices in preparing port emission inventories: Final report. Fairfax, Virginia: ICF Consulting.

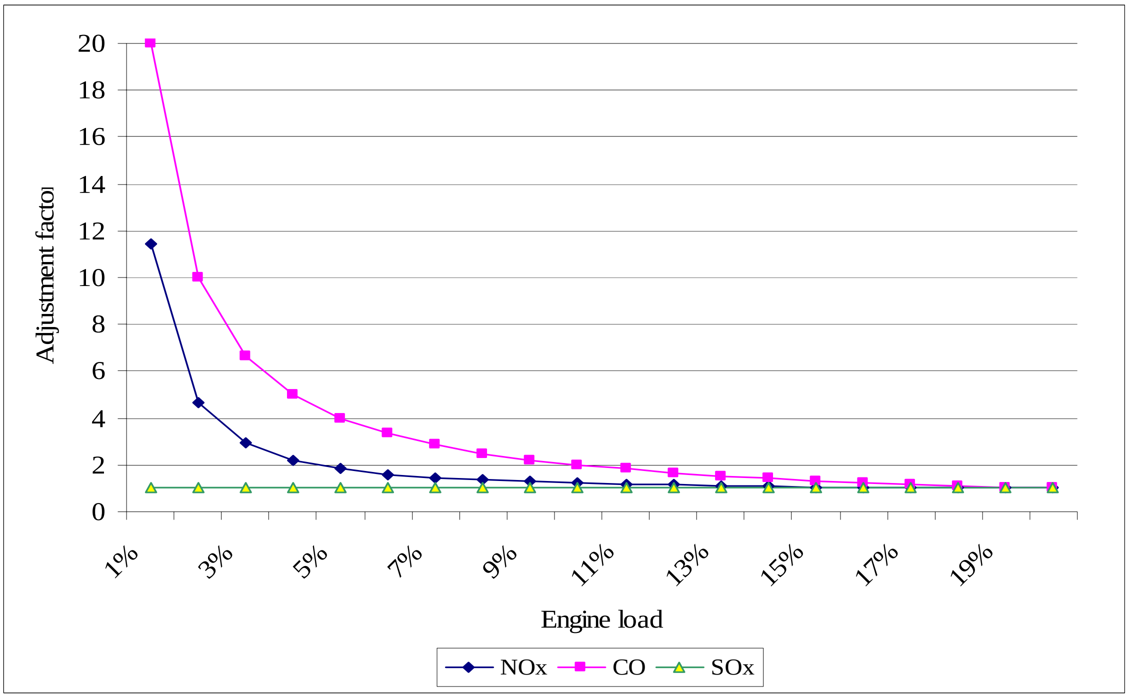


**Figure 13 The emission factor adjustment values at low loads below 20%**

Source: Graph data based on the figures represented in ICF Consulting,(2006). Current methodology and best practices in preparing port emission inventories. EPA United States Environmental Protection Agency).

Emission factors are nearly invariable in engine loads above 20%. Below the 20% load, the emission factor tends to increase with the decrease of load. This is due to the fact that diesel engines are less efficient at low load with the increase in fuel consumption. The Energy and Environmental Analysis Inc (EEA) verified this relationship in a study prepared for the U.S. Environmental Protection Agency (EPA) in the year 2000 (United States. Environmental Protection Agency, 2000). Starcrest Consulting Group (LLC) used the previous equations developed by the Energy and Environmental Analysis Inc (EEA) and calculated the emission factor adjustment based on different load factors.

The emission factor adjustment values are shown in figure (13). These factors should be multiplied by the value mentioned in the previous table (the emission factor for FGV main engine using residual oil g/kwh) in order to find out the emission factors below 20% load. When the propulsion is driven by an electric motor like the diesel electric systems, the previous load factor adjustment should not be applied. This is due to the fact that several engines are used to produce power, while others can be stopped to allow other engines to operate at a more efficient way.

To sum up, the estimation of ship emission inventory has to be done according to a variety of categorization processes. Firstly, vessels have to be categorized according to their types in order to determine the engine speed. Secondly, vessels in each type have to be segmented according to engine speed type. Then the activity according to speed or mode (cruising speed, maneuvering speed and waiting or Hotelling) has to be considered to calculate the engine load formula. Finally, the amount of hazard materials generated by the engine by using the emission formula has to be estimated. Figure (14) illustrates these successive steps.

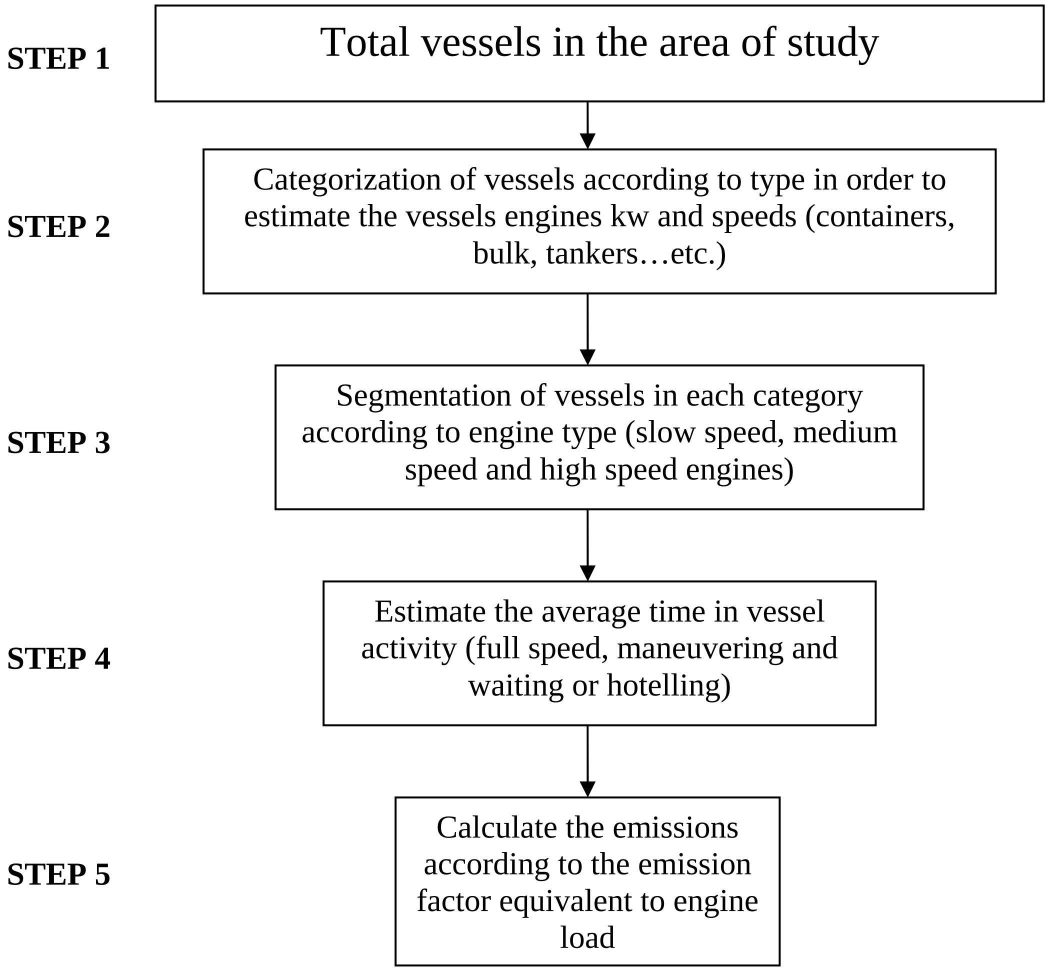


**Figure 14 The categorization sequence to estimate air pollution**

Source: Author, derived from different sources.

Moreover, the calculation process and formulae to be used are shown in figure (15). The inputs required to obtain such calculations in terms of data required and sources are also illustrated.

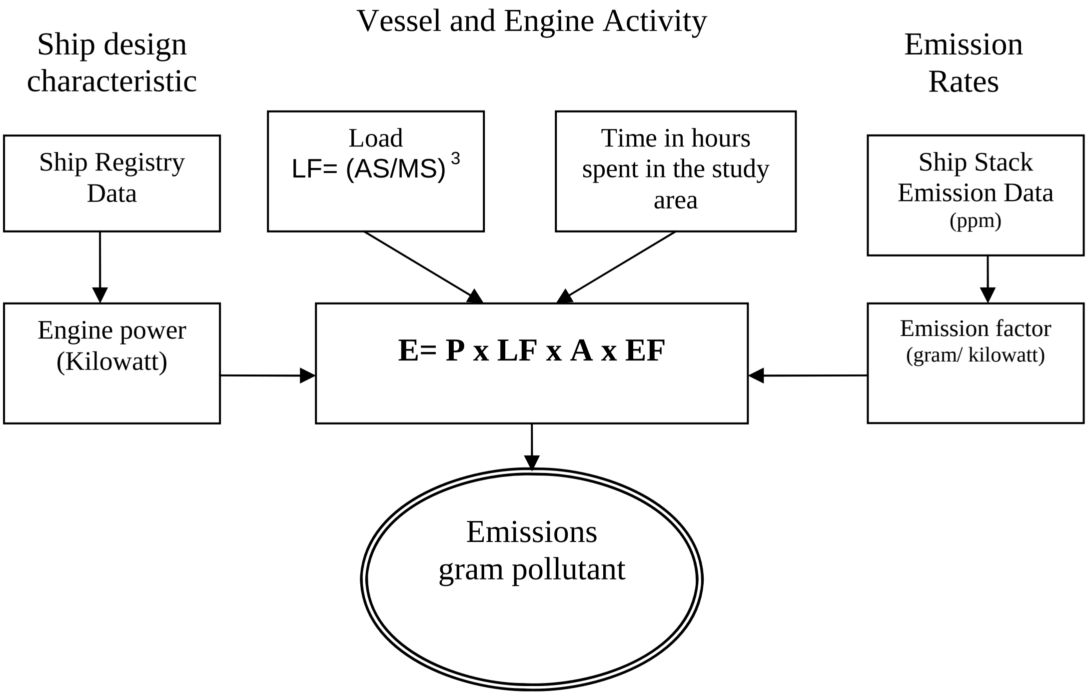


**Figure 15 The equations and inputs required to calculate engine pollutants**

Source: adopted from: Corbett, J.J. (2004). Verification of ship emission estimates with monitoring measurements to improve inventory and modeling: Final report. Report prepared for the California Air Resources Board and the California Environmental Protection Agency (Contract Number 01-328). Newark, Delaware: University of Delaware

# CHAPTER SIX

## ESTIMATING AIR POLLUTION INVENTORY IN THE SUEZ CANAL AND ITS RELATION WITH TRANSITING DUES

### 6.1 Introduction

The Suez Canal has been environmentally affected by the increase in the daily passage of larger ocean-going vessels. Therefore, the estimation of the amount of air pollution emitted in the Canal area is important in order to understand the magnitude of such pollution from transiting vessels.

This chapter will apply the previously explained methodology to estimate the amount of air pollution, in particular nitrogen oxide; sulphur oxides as well as carbon oxides emitted from vessels within the Suez Canal area. Moreover, a calculation for the air pollution inventory in the last 10 years is made to understand the trend. Consequently, an application of the Suez Canal tariff system on vessels transiting the Canal in 2006 is studied. Finally, the relation between air pollution levels and tariff system is examined.

### 6.2 Calculating air emission caused by FGV transiting Suez Canal

Estimating the levels of air emission generated by the ocean-going vessels transiting the Suez Canal is difficult due to the unavailability of data. Receiving detailed transiting vessel data (ship engine power (kW), and detailed transiting movements) from the Suez Canal Authority would also require a long time due to bureaucratic and security reasons. The data available in the Suez Canal yearly report were the main source of information used to estimate the number of vessels, vessel types and total tonnages of each vessel type.

Accordingly, to have an idea about the relationship between the vessels net register tonnage (NRT), (which is the available information in the Suez Canal yearly report) and the vessel's engine output (required for calculating vessel's emissions), an analysis of correlation was made using the Lloyds Register Fairplay database as shown in table (10).

**Table 10 Correlation between vessels NRT and engine output (kw) by vessel types**

| Ship types | No. of vessels | Min. NRT | Max. NRT | Correlation |
|---|---|---|---|---|
| Tankers | 10,758 | 101 | 111,977 | 0.84 |
| General Cargo | 14,500 | 100 | 16,187 | 0.89 |
| Containers | 4,240 | 341 | 59,000 | 0.95 |
| Bulk | 6,995 | 107 | 73,372 | 0.85 |

Source: Author's own calculations, derived from different sources.

The correlation varies between 84% and 95% depending on the vessel type. Therefore, the vessels net register tonnage was considered to be used as a proxy for the engine power in Kilowatts. The second step was to estimate the size of vessels (NRT) passing through the Canal. This was obtained by dividing the total recorded net register tonnage per year for each vessel type over the number of vessels in this category.

The estimation of the average engine output (kilowatts) was made difficult by just knowing the net register tonnage only. This was due to the presence of vessels with various designs and various operation speeds, all of which play an important role in determining vessel engine output power.

Nevertheless, the engine kilowatt was estimated by taking the average kilowatt for recorded vessels[12] that lies in a range of 500 tons NRT above and below the average net register tonnage. This estimated engine output (kilowatt) was considered to be fixed for all vessels in this type. These results of estimating the total engine kilowatts for each type of vessel for 2006 are shown in table 11.

[12] In the Lloyds register Fairplay database.

**Table 11 Estimation of average net registers tonnage and engine output (kw) of vessels transiting the Suez Canal in 2006**

| Ship type | Average Ship Tonnage[13] | No. of vessels | Engine kilowatt[14] | Total megawatts |
|---|---|---|---|---|
| Tankers | 45,134 | 3,592 | 13,837 | 49,703 |
| Bulk carriers | 31,260 | 3,676 | 13,533 | 49,747 |
| General cargo | 10,240 | 1,670 | 9,465 | 15,807 |
| Containers | 52,559 | 6,974 | 72,031 | 502,344 |
| Car carrier | 50,646 | 1,222 | 52,200 | 63,788 |
| Passenger ships | 19,631 | 84 | 35,237 | 2,960 |
| Ro-ro vessels | 21,298 | 433 | 15,994 | 6,925 |
| Others | 9,146 | 1,013 | 13,669 | 13,847 |
| Total | | | | 705,121 |

Source: Author's own calculations, derived from different sources

As previously mentioned, marine engines are sailing according to three speeds: slow, medium and high speed. Consequently, the total engine output ( kilowatts) obtained in table 11 was categorized according to respective speeds relying on the breaking down percentages (table 12) made by Corbett & Koehler in their research and based on information obtained from manufacturer engine files and from the consultation of large vessel operators (2003). The unknown values were assumed to be on the medium speed engine mode, due to the assumption that they are small vessels which usually use medium speed engines.

To estimate the engine load, the previous average ship cruising speed table (8) identified by the port of Los Angles was used. The manoeuvring speed while transiting the Suez Canal was estimated to be 7 knots due to the information extracted from the Suez Canal transit Guide that mentioned it to be 13 kilometres per hour (Gulf Agency Company Egypt, 2005). Similarly, the time spent in transiting was fixed to 14 hours according to the information extracted from the previous source and stated in the Suez Canal Annual Report 2006 (mentioning that the

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[13] = Total annual NRT (Suez Canal year book) / Number of vessels.

[14] = Average output of all vessels between the range of + & - 500 NRT from the average ship tonnage.

duration varies from 12 to 16 hours according to the number of vessels in the convoy).

**Table 12 Summary of engine profiles from manufacturers and operators survey**

| Ship type | Installed main engine speed | | |
|---|---|---|---|
| | slow | Medium | Unknown |
| bulk carriers | 91% | 6% | 3% |
| tankers | 91% | 6% | 3% |
| containers>1500TEU | 100% | 0% | 0% |
| containers<1500TEU | 55% | 45% | 0% |
| general cargo | 55% | 32% | 13% |
| passenger ships | 0% | 100% | 0% |
| ro-ro vessels | 11% | 77% | 12% |

Source: Corbett, J. Koehler, H. (2003), Updated emissions from ocean shipping, *Journal of Geographical Research, 108*, 4650-4663

In calculating vessel engine load estimates, engine load for all vessels while transiting the Canal did not exceed 20%. Therefore, the emission factor used in the calculations was corrected by the aid of the emission adjustment factor at low loads which was shown in figure (13). The calculated amounts of pollutants emitted from vessels are represented for Nitrogen oxides, Sulphur oxides and carbon oxides and are shown in tables (13, 14&15).

From the previous results, the amount of pollution from the ocean-going vessels within the Canal area can be estimated. These figures show that in 2006, the largest emissions are estimated for nitrogen oxides at 16,000 tons, for carbon oxides at nearly 2,800 tons and for sulphur oxides at around 6,000 tons.

**Table 13 Estimation of NOx emission in Suez Canal in 2006**

| Calculation of NOx emissions for slow speed engines | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ship type | % of KW Slow speed | actual speed | maximum speed | load factor | activity hour | NOx emission factor adjustment load factor | NOx emission factor | NOx emissions ( tons) |
| | P | AS | MS | $LF=(AS/MS)^3$ | A | F | CEF=18.1 x F | E=P x LF x A x CEF |
| Tankers | 45229279 | 7 | 13.6 | 13.64% | 14 | 1.08 | 19.548 | 1688 |
| Bulk carriers | 45270050 | 7 | 17.58 | 6.31% | 14 | 1.6 | 28.96 | 1159 |
| General cargo | 8693603 | 7 | 14.69 | 10.82% | 14 | 1.17 | 21.177 | 279 |
| Containers | 502344194 | 7 | 21.26 | 3.57% | 14 | 2.21 | 40.001 | 10042 |
| Car carrier | 0 | 7 | 13.8 | 13.05% | 14 | 1.11 | 20.091 | 0 |
| Passenger ships | 0 | 7 | 18.06 | 5.82% | 14 | 1.6 | 28.96 | 0 |
| Ro-ro vessels | 761794 | 7 | 13.91 | 12.74% | 14 | 1.11 | 20.091 | 27 |
| Others | 0 | 7 | 14.1 | 12.24% | 14 | 1.14 | 20.634 | 0 |
| Total NOx emissions from slow speed engines (Tones) | | | | | | | | 13194 |
| Calculation of NOx emissions for medium speed engines | | | | | | | | |
| Ship type | % of KW medium speed | actual speed | maximum speed | load factor | activity hour | NOx emission factor adjustment load factor | NOx emission factor | NOx emissions ( tons) |
| | P | AS | MS | $LF=(AS/MS)^3$ | A | F | CEF=14 x F | E=P x LF x A x CEF |
| Tankers | 4473225 | 7 | 13.6 | 13.64% | 14 | 1.08 | 15.12 | 129 |
| Bulk carriers | 4477258 | 7 | 17.58 | 6.31% | 14 | 1.6 | 22.4 | 89 |
| General cargo | 7112948 | 7 | 14.69 | 10.82% | 14 | 1.17 | 16.38 | 176 |
| Containers | 0 | 7 | 21.26 | 3.57% | 14 | 2.21 | 30.94 | 0 |
| Car carrier | 63788400 | 7 | 13.8 | 13.05% | 14 | 1.11 | 15.54 | 1811 |
| Passenger ships | 2959908 | 7 | 18.06 | 5.82% | 14 | 1.6 | 22.4 | 54 |
| Ro-ro vessels | 6163608 | 7 | 13.91 | 12.74% | 14 | 1.11 | 15.54 | 171 |
| Others | 13846697 | 7 | 14.1 | 12.24% | 14 | 1.14 | 15.96 | 379 |
| Total NOx emissions from slow speed engines (Tones) | | | | | | | | 2809 |

Source: Author's own calculations, derived from different sources

**Table 14 Estimation of SOx emission in Suez Canal in 2006**

| Calculation of Sox emissions for slow speed engines | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ship type | % of KW Slow speed | actual speed | maximum speed | load factor | activity hour | Sox emission factor adjustment load factor | Sox emission factor | Sox emissions ( tons) |
| | P | AS | MS | $LF=(AS/MS)^3$ | A | F | CEF=10.3 x F | E=P x LF x A x CEF |
| Tankers | 45229279 | 7 | 13.6 | 13.64% | 14 | 1.0 | 10.3 | 889 |
| Bulk carriers | 45270050 | 7 | 17.58 | 6.31% | 14 | 1.0 | 10.3 | 412 |
| General cargo | 8693603 | 7 | 14.69 | 10.82% | 14 | 1.0 | 10.3 | 136 |
| Containers | 502344194 | 7 | 21.26 | 3.57% | 14 | 1.0 | 10.3 | 2586 |
| Car carrier | 0 | 7 | 13.8 | 13.05% | 14 | 1.0 | 10.3 | 0 |
| Passenger ships | 0 | 7 | 18.06 | 5.82% | 14 | 1.0 | 10.3 | 0 |
| Ro-ro vessels | 761794 | 7 | 13.91 | 12.74% | 14 | 1.0 | 10.3 | 14 |
| Others | 0 | 7 | 14.1 | 12.24% | 14 | 1.0 | 10.3 | 0 |
| Total Sox emissions from slow speed engines (Tones) | | | | | | | | 4037 |
| Calculation of Sox emissions for medium speed engines | | | | | | | | |
| Ship type | % of KW medium speed | actual speed | maximum speed | load factor | activity hour | Sox emission factor adjustment load factor | Sox emission factor | Sox emissions ( tons) |
| | P | AS | MS | $LF=(AS/MS)^3$ | A | F | CEF=11.1 x F | E=P x LF x A x CEF |
| Tankers | 4473225 | 7 | 13.6 | 13.64% | 14 | 1.0 | 11.1 | 95 |
| Bulk carriers | 4477258 | 7 | 17.58 | 6.31% | 14 | 1.0 | 11.1 | 44 |
| General cargo | 7112948 | 7 | 14.69 | 10.82% | 14 | 1.0 | 11.1 | 120 |
| Containers | 0 | 7 | 21.26 | 3.57% | 14 | 1.0 | 11.1 | 0 |
| Car carrier | 63788400 | 7 | 13.8 | 13.05% | 14 | 1.0 | 11.1 | 1294 |
| Passenger ships | 2959908 | 7 | 18.06 | 5.82% | 14 | 1.0 | 11.1 | 27 |
| Ro-ro vessels | 6163608 | 7 | 13.91 | 12.74% | 14 | 1.0 | 11.1 | 122 |
| Others | 13846697 | 7 | 14.1 | 12.24% | 14 | 1.0 | 11.1 | 263 |
| Total Sox emissions from slow speed engines (Tones) | | | | | | | | 1964 |

Source: Author’s own calculations, derived from different sources

**Table 15 Estimation of CO emission in Suez Canal in 2006**

| Calculation of CO emissions for slow speed engines | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ship type | % of KW Slow speed | actual speed | maximum speed | load factor | activity hour | CO emission factor adjustment load factor | CO emission factor | CO emissions ( tons) |
| | P | AS | MS | $LF=(AS/MS)^3$ | A | F | CEF=1.4 x F | E=P x LF x A x CEF |
| Tankers | 45229279 | 7 | 13.6 | 13.64% | 14 | 1.43 | 2.002 | 173 |
| Bulk carriers | 45270050 | 7 | 17.58 | 6.31% | 14 | 3.33 | 4.662 | 187 |
| General cargo | 8693603 | 7 | 14.69 | 10.82% | 14 | 1.82 | 2.548 | 34 |
| Containers | 502344194 | 7 | 21.26 | 3.57% | 14 | 6.00 | 8.4 | 2109 |
| Car carrier | 0 | 7 | 13.8 | 13.05% | 14 | 1.54 | 2.156 | 0 |
| Passenger ships | 0 | 7 | 18.06 | 5.82% | 14 | 3.33 | 4.662 | 0 |
| Ro-ro vessels | 761794 | 7 | 13.91 | 12.74% | 14 | 1.54 | 2.156 | 3 |
| Others | 0 | 7 | 14.1 | 12.24% | 14 | 1.67 | 2.338 | 0 |
| Total Sox emissions from slow speed engines (Tones) | | | | | | | | 2505 |
| Calculation of CO emissions for medium speed engines | | | | | | | | |
| Ship type | % of KW medium speed | actual speed | maximum speed | load factor | activity hour | CO emission factor adjustment load factor | CO emission factor | CO emissions ( tons) |
| | P | AS | MS | $LF=(AS/MS)^3$ | A | F | CEF=11.1 x F | E=P x LF x A x CEF |
| Tankers | 4473225 | 7 | 13.6 | 13.64% | 14 | 1.43 | 1.573 | 13 |
| Bulk carriers | 4477258 | 7 | 17.58 | 6.31% | 14 | 3.33 | 3.663 | 14 |
| General cargo | 7112948 | 7 | 14.69 | 10.82% | 14 | 1.82 | 2.002 | 22 |
| Containers | 0 | 7 | 21.26 | 3.57% | 14 | 6.00 | 6.6 | 0 |
| Car carrier | 63788400 | 7 | 13.8 | 13.05% | 14 | 1.54 | 1.694 | 197 |
| Passenger ships | 2959908 | 7 | 18.06 | 5.82% | 14 | 3.33 | 3.663 | 9 |
| Ro-ro vessels | 6163608 | 7 | 13.91 | 12.74% | 14 | 1.54 | 1.694 | 19 |
| Others | 13846697 | 7 | 14.1 | 12.24% | 14 | 1.67 | 1.837 | 44 |
| Total CO emissions from slow speed engines (Tones) | | | | | | | | 318 |

Source: Author's own calculations, derived from different sources

Furthermore, the analysis of the Suez Canal traffic for the last 30 years stressed that the number of vessels transiting the Canal is slightly decreasing, while the total vessels NRTs transiting is in a continuous increase. Consequently, the average vessel tonnage crossing the Canal is increasing. This is confirmed by the fact that vessel average tonnage has increased 4 times from 9 thousand to nearly 40 thousand in the previous 30 years.

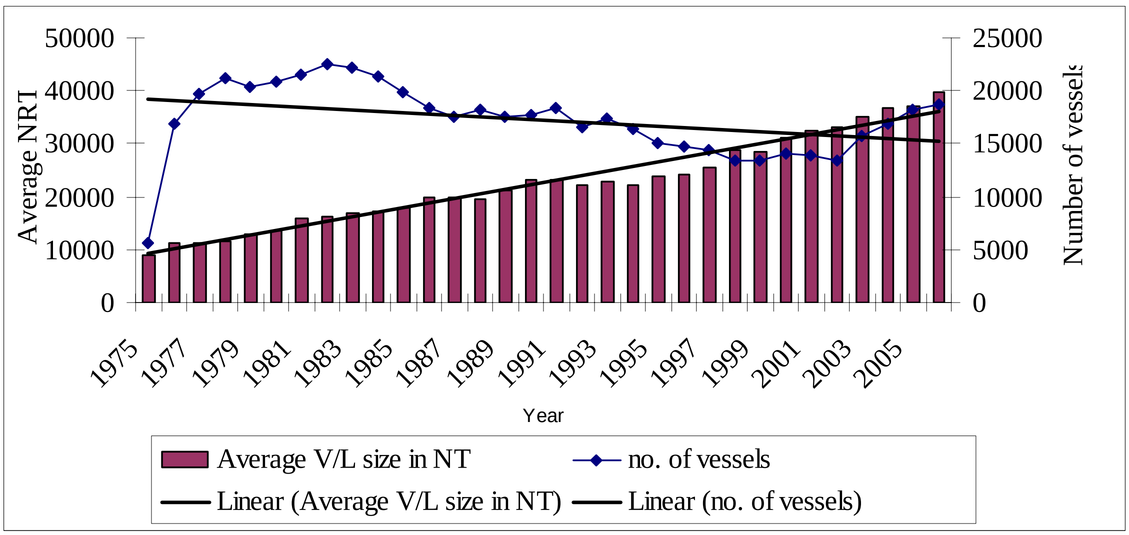


**Figure 16 Relation between number of vessels transiting the Suez Canal and their NRT**

Source: Author's own calculations, derived from different sources

Figure (16) highlights an important question: how does this trend affect the level of air pollution? Therefore, using the previous methodology and assumptions a calculation was made to estimate the level of pollution for the last 10 years, from 1997 to 2006. Moreover, a calculation of pollutants emitted in the previous period according to ship type was also made. Finally a trend in the evolution of NOx, SOx and CO resulting from each vessel type was also estimated.

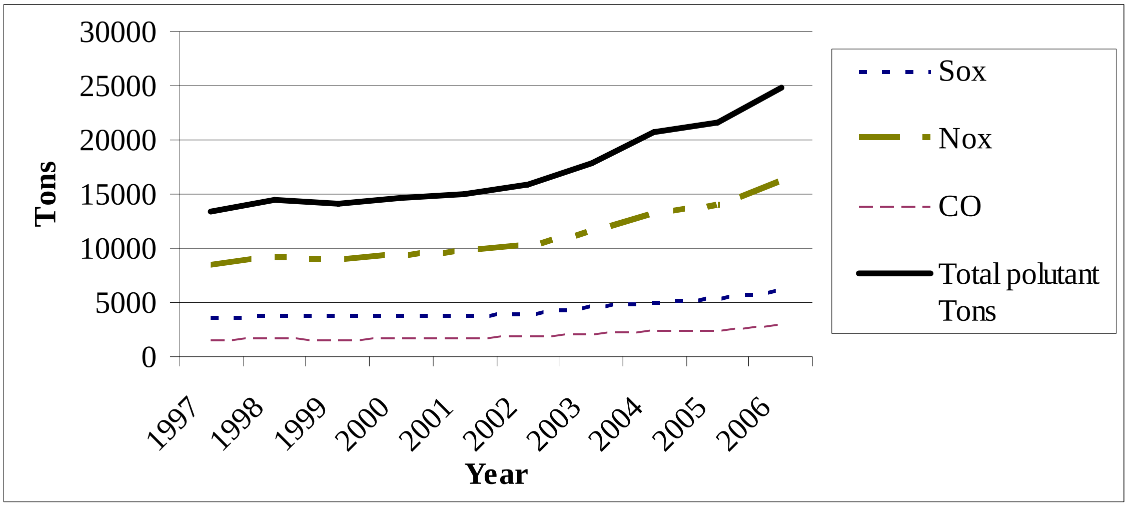


**Figure 17 Amount of NOx, Sox and CO emitted by vessels transiting the Suez Canal from 1997 to 2006**

Source: Author's own calculations, derived from different sources

Figure (17) shows the trend of NOx, SOx and CO emitted by vessels transiting the Suez Canal in the previous 10 years. It shows that the total pollutants are emitted in huge amounts with an increasing trend for the last 5 years in especially NOx levels. In the last decade the total emissions of these 3 pollutants increased from 15000 tons in 1997 to 25000 tons by 2006.

From figures (18, 19 & 20) container vessels proved to be the highest source of pollution for the Canal, with an accelerating trend for the last two years. Moreover, the nitrogen oxides emission levels are also increasing in general and in particular from container vessels. This is due to the type of mammoth engines (slow speed engines) used by containerships, with their design to power these vessels with speeds exceeding 20 knots. Those engines are of low efficiency with high fuel consumption at low load levels.

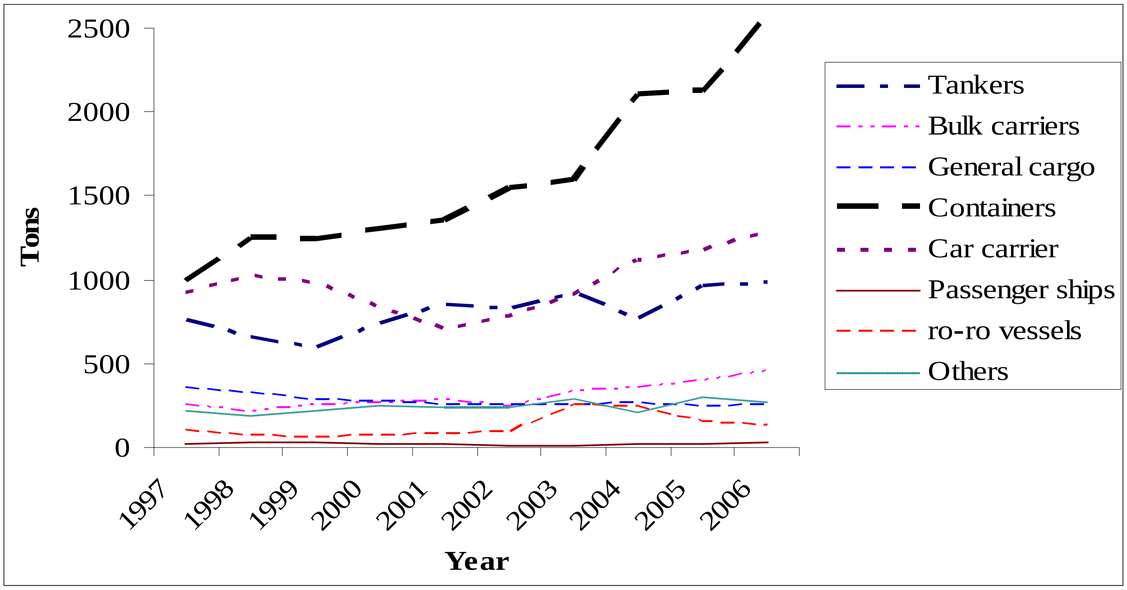


**Figure 18 SOx emissions by vessel type from 1997 to 2006**

Source: Author's own calculations, derived from different sources

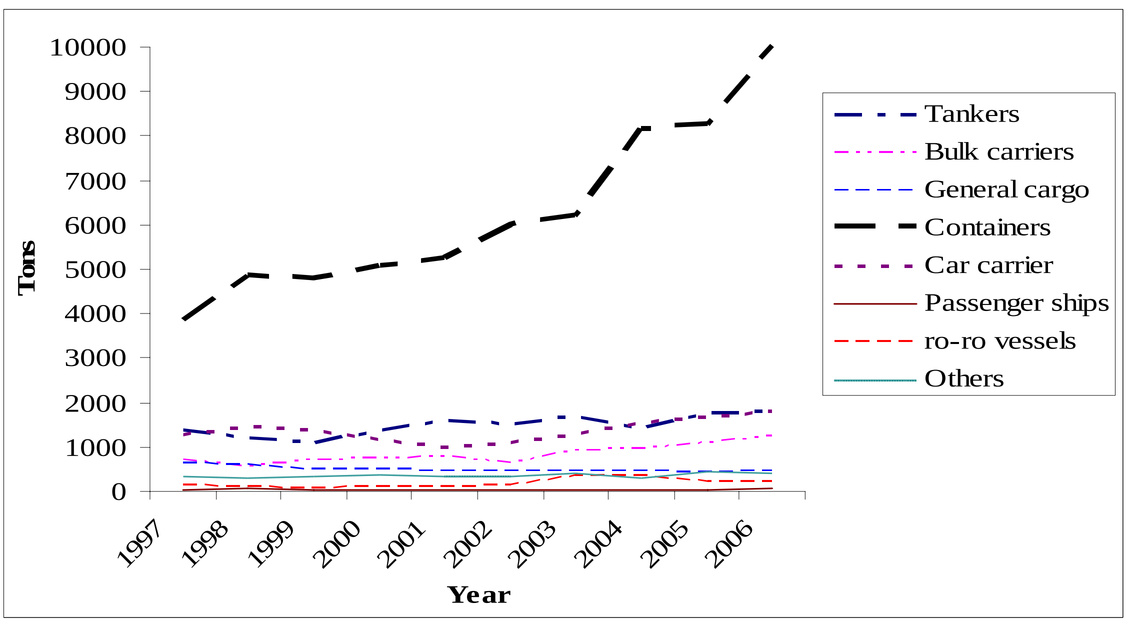


**Figure 19 NOx emissions by vessel type from 1997 to 2006**

Source: Author's own calculations, derived from different sources

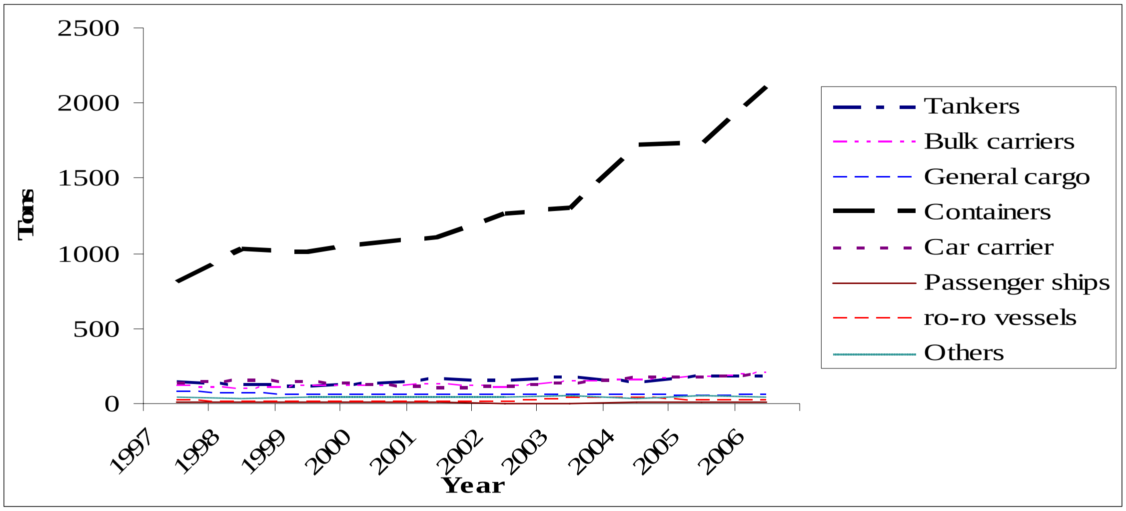


**Figure 20 CO emissions by vessel type from 1997 to 2006**

Source: Author's own calculations, derived from different sources

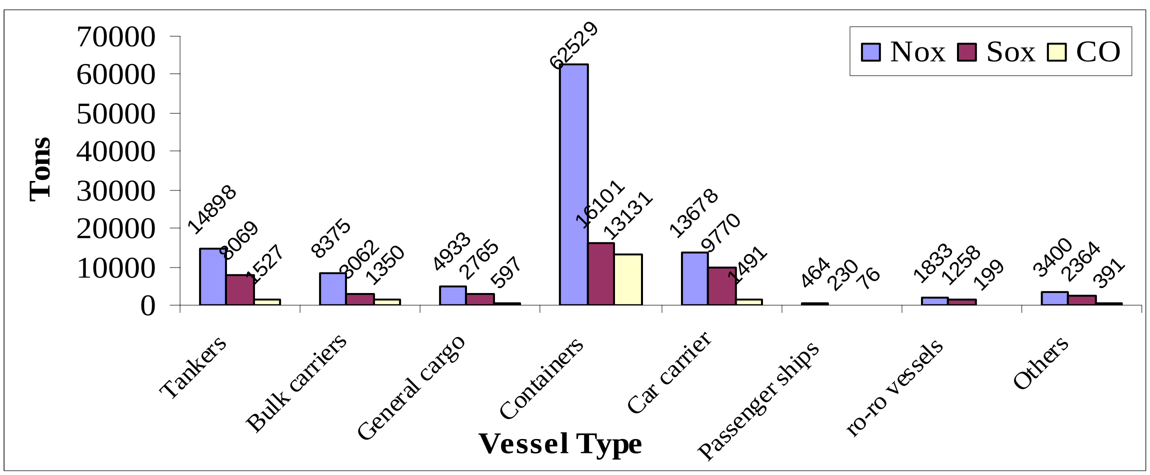


**Figure 21 Total NOx, Sox and CO emitted by vessel type in 10 years (1997 - 2006)**

Source: Author's own calculations, derived from different sources

Figure (21) shows that the total pollutants in the last 10 years are mainly generated by containers, while passenger vessels are the least source of pollution. This is due to the low number of passenger vessels. On the other hand container vessels are in continuous increase in both number and size.

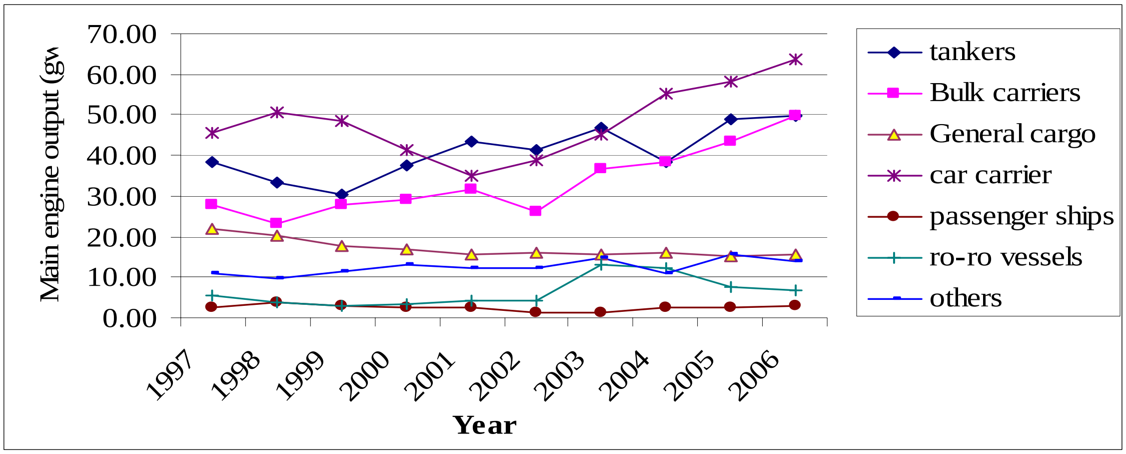


**Figure 22 Total engine output (gigwatt) by vessels type except containers from 1997 to 2006**

Source: Author's own calculations, derived from different sources

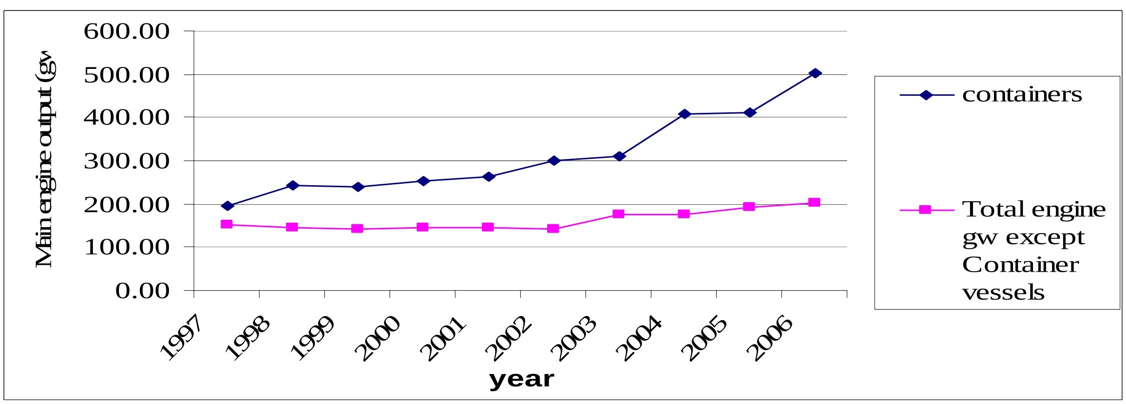


**Figure 23 Relation between total engine output (gigwatt) for all vessels types and container vessels from 1997 to 2006**

Source: Author's own calculations, derived from different sources

Furthermore, figures (22&23) confirm the previous results. They show that the container vessel annual total engine output (kilowatts) exceeds the total engine output of the remaining total types combined. Furthermore, the gap between container engine power and the rest of the vessels is in continuous increase where container vessels were using 2.5 times the engine output power of all vessel types in 2006.

Moreover, figure (24) shows the share of vessel types in total air pollution. It stresses that container vessels have an increasing share trend in the last 10 years. Container vessels share increases by nearly 50% in the last decade from 42.6% in 1997 to 59.4% in 2006. On the contrary, general cargo shares in air pollution generated in the Suez Canal area declined by more than 50% from 7.9% in 1997 to 3.1% in 2006. The remaining types also show a slightly decreased trend except bulk carriers which maintain a constant share around 8 % through the study period.

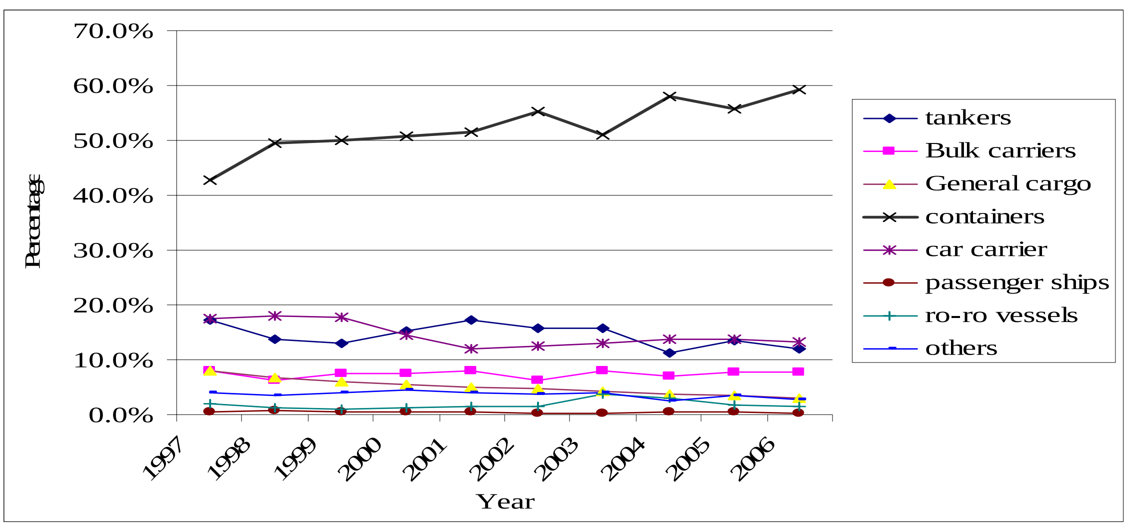


**Figure 24 Share of air pollution for vessel types from 1997 to 2006**

Source: Author's own calculations, derived from different sources

The previous results show the *total* pollutions emitted from every vessel category. However, comparing emissions per one ton of NRT as a unit for estimating pollution from vessel types, different results were obtained. Figure (25) shows that the share of each ton of NRT in container vessels is not the highest pollution source. It shows that pollutants per ton of NRT in the unknown vessel types, which are reflecting a mixture of small vessels, are the highest with 74 grams of pollutants per ton. On the other hand, the share of bulk carriers is the least represented by 16.6 gm / 1 NRT, followed by tanker vessels with 18.4 gm/1 NRT.

Furthermore, passenger vessels, car carriers and general cargo vessels are contributing to more emissions per ton of NRT than container vessels in values of 54.4, 53.4 and 44.8 grams respectively, while; containers are emitting 40.2 gm/1 NRT.

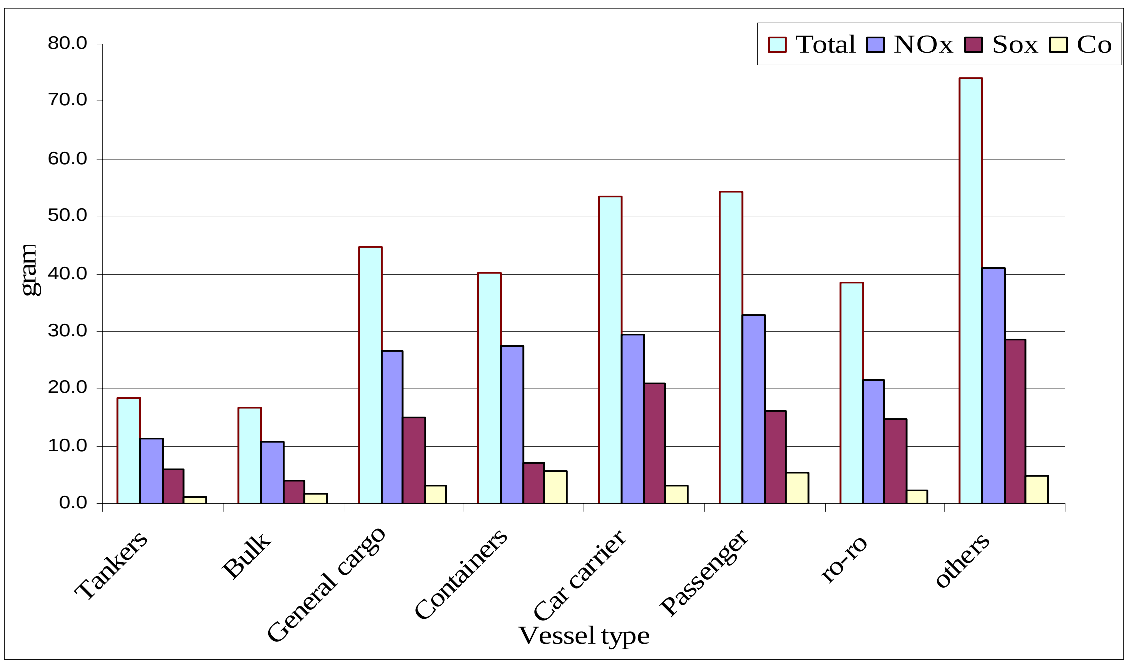


**Figure 25 Amount of Pollutants per one ton of vessels NRT in 2006**

Source: Author’s own calculations, derived from different sources

To sum up, the air pollution from ships in the Suez Canal is increasing in the last 10 years. Container vessels are the main source of air pollution with respect to other vessel types. This could be the reason why container vessels have a main engine high output with respect to other types. In addition, the number of containers continuously increased over the period of study.

Moreover, the share of every ton of NRT shows that passenger vessels, car carriers and general cargo vessels are contributing to the highest levels, while bulk and tankers are the lowest sources of pollution per ton of NRT.

### 6.3 Suez Canal tariff system

The Tariff system is considered to be a very important item in any port or canal success; it must compromise between covering the port or Canal expenses by providing a profit margin and satisfying the port or canal Clint by offering a good service at a reasonable cost. Finding the intersecting areas between the previous two parties is crucial in providing a tariff system. Accordingly the tariff system in most ports is not homogeneous; in other words every port is applying its own system which satisfies itself and its clients. Therefore, there is no common tariff system or rules to be applied for all ports or canals.

The tariff system in ports is generally divided into three categories: general tariffs, facilities tariffs and service tariffs. Each one of the previous categories reflects charges for specific activities provided by the port. General tariffs, reflect the port dues which are based on the vessels net register tonnage (NRT), gross register tonnage (GRT) or vessel dimensions (length, breadth and draft)

Facilities tariffs indicate the hiring of a berth according to the berth area per hour which differentiates according to berth type. Moreover, the transit storage for a vessel’s cargo is also categorized as facilities tariff which is paid per day and differentiates according to its type (open, close storage). Finally, the service tariffs are charges upon the services provided by the port, for example navigational services (pilotage, tugs ...etc), cargo operation (stevedoring, equipment hire ...etc.). The service tariff is paid according to vessel tonnages, time of service or amount and type of cargo.

The canals dues system is different from the port dues system. It can be explained by the nature of services provided by the canals which is summarized into the savings offered by a canal in comparison with alternative routes and does not contain cargo handling or service facilities.

The Suez Canal in particular is using a unique tariff system in terms of charging units used in tariff calculation and payment. The Suez Canal tariff is calculated according to the Suez Canal net tonnage of a vessel. This tonnage is different from gross register tonnage, net register tonnage and dead weight tonnage. It is a volumetric measurement unit used only to determine Suez Canal Dues. While the tariff is paid in SDR (Special Drawing Right) according to a vessel's Suez Canal net tonnage (SCNT), the payment can be done in one of the following 9 currencies (US Dollar, Sterling Pound, Euro, Japanese Yen, Canadian Dollar, Swedish Krona, Danish Krona, Norwegian Krona and Swiss Franc). Moreover, the tariff differentiates mainly according to vessel types, in which the tariff rates are shown in table (16). It was difficult to identify the details of items included in the Suez Canal tariff due to the unavailable sources providing them.

Moreover, in reviewing figures (26&27) representing the tariff assigned to vessel categories of different tonnages, it appears that tanker vessels and bulk carriers pay the least tariff per vessel tonnage for all size categories. Passenger vessels, general cargo and the unidentified categories that represent small special purpose vessels are paying the highest tariffs.

**Table 16 Suez Canal transiting Dues in 2006**

| Suez Canal tariff in SDR according to vessels SC NRT | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Suez Canal NT | First 5,000 | | Next 5,000 | | Next 1,0000 | | Next 20,000 | | Next 30,000 | | Rest | |
| Ship type | L | B | L | B | L | B | L | B | L | B | L | B |
| Tankers | 6.88 | 5.86 | 3.84 | 3.27 | 3.45 | 2.94 | 1.48 | 1.27 | 1.48 | 1.27 | 1.29 | 1.09 |
| Bulk carriers | 7.65 | 6.50 | 4.39 | 3.74 | 3.15 | 2.69 | 1.11 | 0.96 | 1.06 | 0.91 | 1.06 | 0.91 |
| General cargo | 7.65 | 6.50 | 4.39 | 3.74 | 4.00 | 3.41 | 2.79 | 2.38 | 2.79 | 2.38 | 2.79 | 2.38 |
| Containers | 7.65 | 6.50 | 4.35 | 3.70 | 3.57 | 3.05 | 2.56 | 2.18 | 2.56 | 2.18 | 1.94 | 1.66 |
| Car carrier | 7.65 | 6.50 | 4.35 | 3.70 | 3.57 | 3.05 | 2.56 | 2.18 | 2.56 | 2.18 | 1.94 | 1.66 |
| Passenger ships | 7.65 | 6.50 | 4.39 | 3.74 | 4.00 | 3.41 | 2.79 | 2.38 | 2.79 | 2.38 | 2.79 | 2.38 |
| Ro-ro vessels | 7.65 | 6.50 | 4.35 | 3.70 | 3.57 | 3.05 | 2.56 | 2.18 | 2.56 | 2.18 | 1.94 | 1.66 |
| Others | 7.65 | 6.50 | 4.39 | 3.74 | 4.00 | 3.41 | 2.79 | 2.38 | 2.79 | 2.38 | 2.79 | 2.38 |

L = Loaded Vessels B = Ballast vessels (not loading any cargo)

Source: Suez Canal Yearly report, (2006). Suez Canal Authority, Arab republic of Egypt.

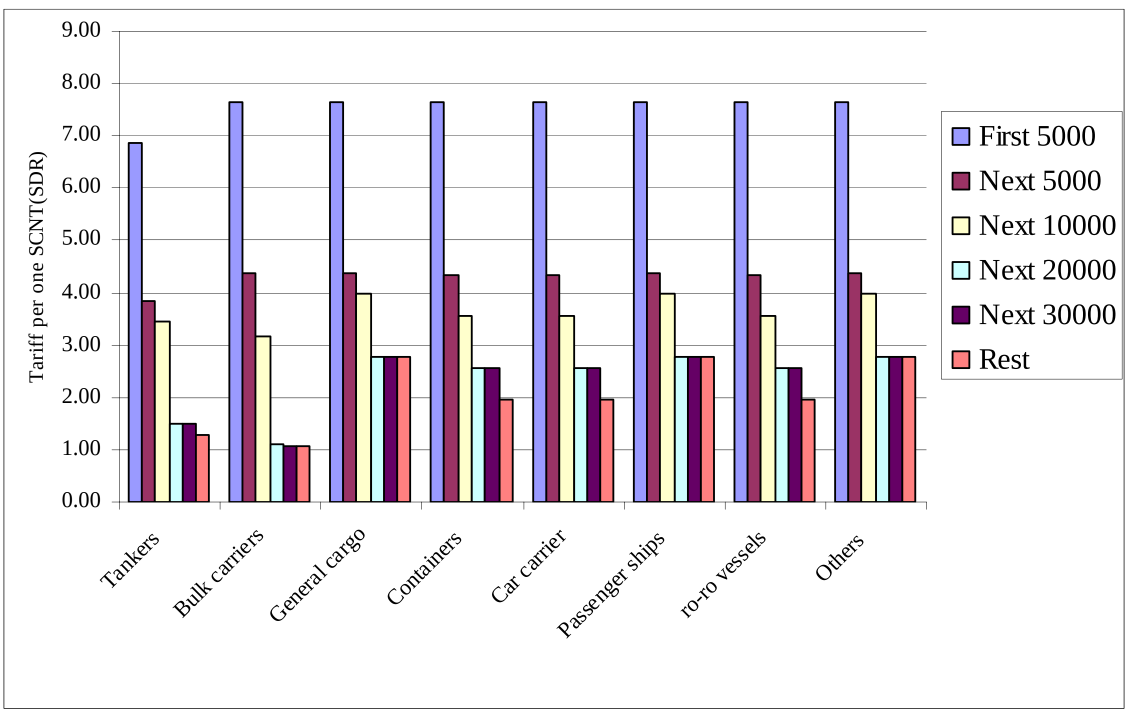


**Figure 26 Suez Canal tariff for loaded vessels**
Source: Author, Suez Canal Yearly report, (2006). Suez Canal Authority, Arab Republic of Egypt

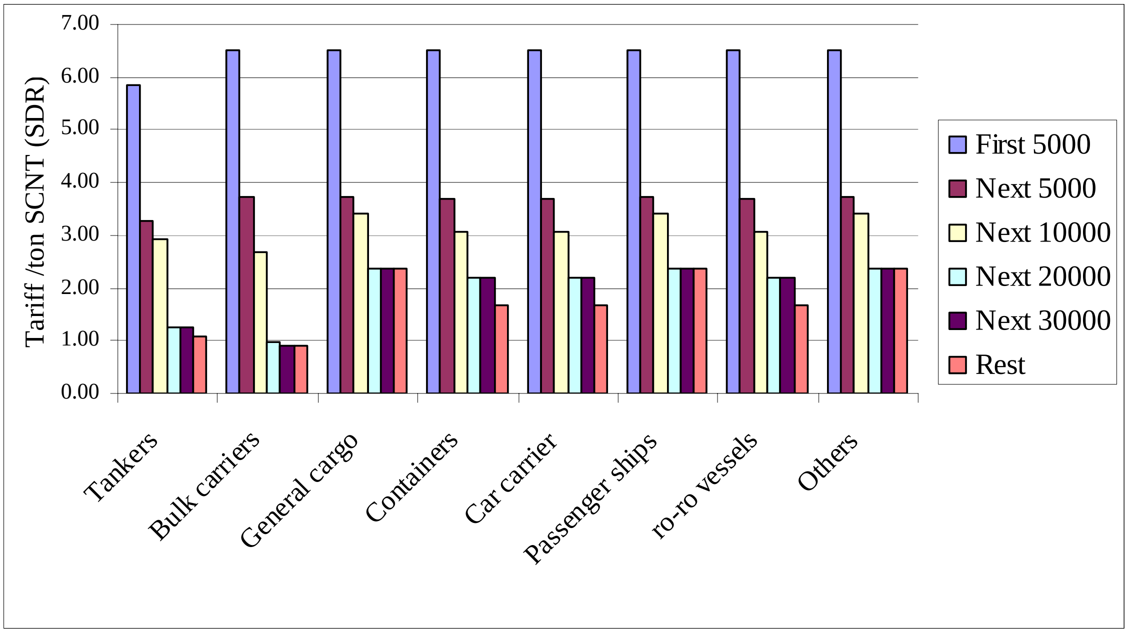


**Figure 27 Suez Canal tariff for ballast vessels**

Source: Author, Suez Canal Yearly report, (2006). Suez Canal Authority, Arab Republic of Egypt

Furthermore, the previous dues are not fixed for all vessels but are subject to increase or decrease. Vessels that could cause delays in the canal transiting system are the ones vulnerable to extra payments. Generally, vessels transit the Suez Canal in convoys. Daily 3 convoys transit the Canal in which two are from south to north and one from north to south. These convoys start at fixed timings declared to all Canal users and sail with fixed speeds in order to provide a safe and quick transit for all the vessels. Mainly vessels that arrive at the Canal after a dead time or vessels that sail with a speed below that required while transiting pay extra charges.

On the other hand, the Suez Canal authority offers some economical incentives in terms of dues reductions provided to some users. These economical incentives are due to either economical or environmental reasons. The economical reasons behind these reductions are to attract more vessel traffic, especially vessels using alternative routes or vessels transporting commodities with a competitive means of transportation.

For example, reductions are offered to vessels that do not use the Suez Canal, as the Canal tariff exceeds the savings that could be achieved when using other routes; this is done on a case by case basis. Moreover, 20% reductions are provided for ballast VLCC (very large crude carriers) more than 200,000 DWT coming from the Gulf of Mexico or the Caribbean zone and heading for the Arabian Gulf (Suez Canal Yearly report, 2006).

The loaded northbound LNG (Liquefied Natural Gas) carriers coming from the Arabian Gulf are also offered 35% rebate on Canal transit dues. The previous rebates are given in addition to further rebates provided according to transiting cargo quantity (cargo incentive) as shown in table (17). In addition, passenger vessels are offered rebates of 50% if they are calling at Egyptian ports and staying in port for not less than 72 hours; this incentive is to promote the Egyptian tourism industry.

**Table 17  Rebates provided on LNG cargo quantity**

| Rebate | Quantity of cargo |
|---|---|
| 5% | 0.5 million tons – 1 million tons |
| 10% | 1 million tons – 2 million tons |
| 15% | 2 million tons and above |

Source: Suez Canal Yearly report, (2006). Suez Canal Authority, Arab Republic of Egypt

Furthermore, the Suez Canal Dues reduction based on environmental reasons are mainly provided to tanker vessels. This is proved by offering 2% rebate for double hull tankers and 4% rebate on Canal dues for segregated ballast tankers. These economical incentives provided by the Suez Canal Authority are declared in order to encourage ship owners to operate environmentally-friendly vessels (Suez Canal Yearly report, 2006).

The Suez Canal dues charged for each vessel type are calculated by the use of the previously stated tariffs. This calculation was made without considering any extra charges or reductions. Accordingly, table (18) shows these dues with a significant share of 50.9 % to the container vessel category, while passenger vessels pay only 0.3% of the Canal total dues. The average tariff per vessel type shows containers and car carriers on the top tariff payers but the large number of containers significantly increases its share in the total tariff.

**Table 18 Tariff estimation by vessel types at 2006**

| Ship type | Average Ship Tonnage | No. of vessels | Average Vessel Tariff | Total Tariff (million) SDR | Share of total tariff |
|---|---|---|---|---|---|
| Tankers | 45134 | 3592 | 125,299 | 450 | 18.3% |
| Bulk carriers | 31260 | 3676 | 93,099 | 342 | 14.0% |
| General cargo | 10240 | 1670 | 61,158 | 102 | 4.2% |
| Containers | 52559 | 6974 | 179,052 | 1,249 | 50.9% |
| Car carrier | 50646 | 1222 | 174,153 | 213 | 8.7% |
| Passenger ships | 19631 | 84 | 98,724 | 8 | 0.3% |
| ro-ro vessels | 21298 | 433 | 73,423 | 32 | 1.3% |
| Others | 9146 | 1013 | 56,451 | 57 | 2.3% |
| Total | | | | 2,453 | 100.0% |

Source: Author's own calculations, derived from different sources

## 6.4 Relation between tariff and vessel's emission

Figure (28) shows the relation between *total* tariff and *total* air pollution emission, categorized according to vessel types. The graph indicates a strong correlation (97%) between both total tariff and total pollution levels from each vessel type. This could be due to the common factor of vessel tonnage which is a core aspect in charging the Canal dues as well as it is a main issue in determining engine output.

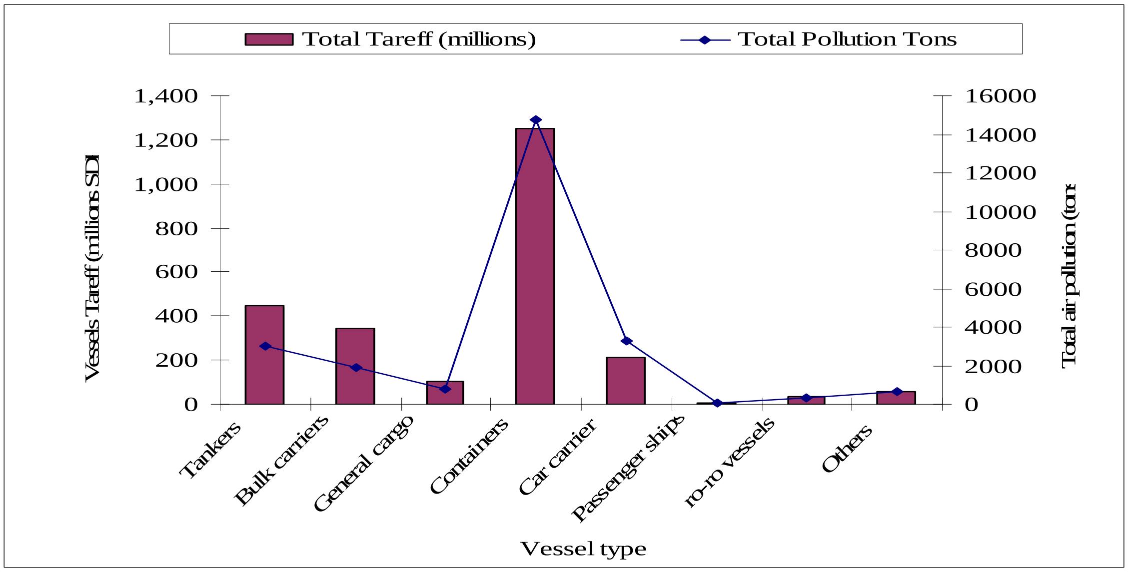


**Figure 28 Relation between total vessels tariff and total vessels air pollution in 2006**

Source: Author's own calculations, derived from different sources

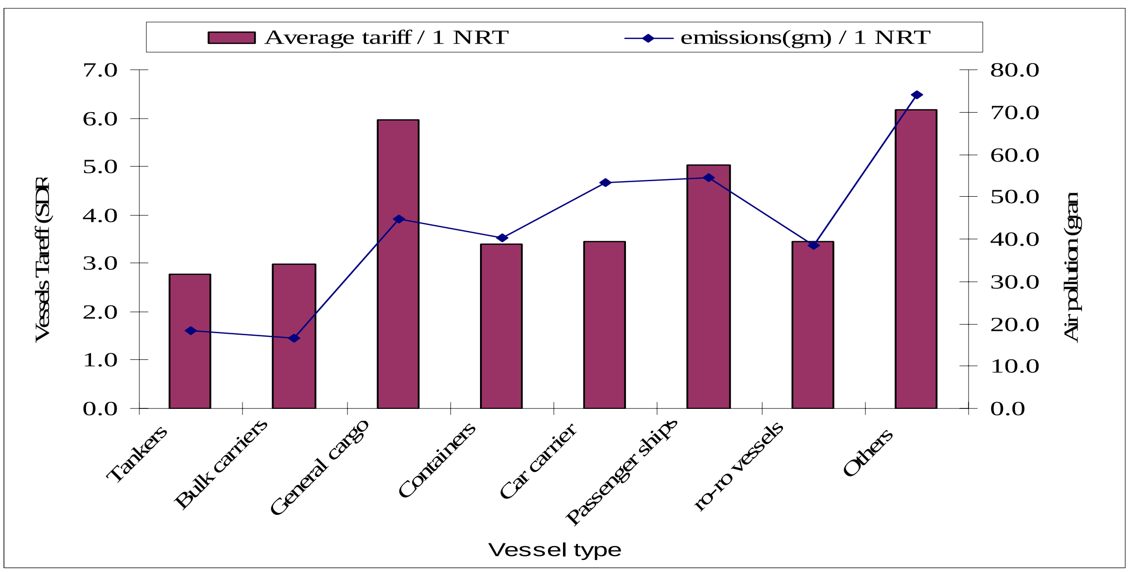


**Figure 29 Relation between tariff and emissions per one ton of NRT in 2006**

Source: Author's own calculations, derived from different sources

When calculating the correlation between emissions and tariff per one ton of NRT the correlation dropped to 76% as illustrated in figure (29). This means that the previous conclusions regarding the container vessel share in air pollution and tariffs is due to the *accumulation* of total container vessel tonnages only, regardless of any other reasons, such as vessel numbers or vessel size.

To sum up, in light of the available data vessels transiting the Suez Canal are emitting a vast amount of air pollution in an increasing trend. Container vessels are contributing to more than half of the air pollution generated from vessels in the Suez Canal area. The highest level of pollution generated among the three examined pollutants (NOx, Sox and CO) belongs to NOx due to the nature of generating such pollutants and its relation to engine power as well as vessel speed.

In analyzing the Suez Canal tariff system, container vessels are paying the highest share of dues which represents nearly half of the Canal income. Moreover, there is a strong correlation between total tariff income and total air pollution due to the fact that both of them depend on total vessel tonnage.

In analyzing the share for every ton of the vessels NRT in air pollution, the passenger vessels, car carriers and the small unidentified vessels come in the leading ranks; while, containers have intermediate values.

# CHAPTER SEVEN

## DISCUSSION AND RECOMMENDATIONS

This dissertation has reached several conclusions. Firstly, air pollution from ships is growing on the local, regional and global scale due to the increase in trade and vessel size. Secondly, that the implementation of MARPOL Annex VI is a step in the right direction in controlling this threat on a global scale while on a more regional scale, several ports worldwide, and especially in the United States of America and Europe, are also applying measures to reduce air pollution from port activities.

Moreover, canals are also placed under an increasing air pollution threat according to the continuous increase in transiting vessels in both terms of size and total tonnage. The Suez Canal in particular is receiving thousands of pollutant tones every year with a potential increase in the future. The main vessel type contributing to these pollution levels is the containership. The Suez Canal tariff was found to be related to the economical basis and shows no evidence of any relation to the levels of emissions.

Therefore, in light of the previous conclusions it appears that the Suez Canal should take certain precautions to control air emissions from ships. By reviewing and analyzing the previous mentioned solutions used to reduce air pollution from ships applied in ports, the best practice to be applied in the Suez Canal was investigated.

The physical instruments like cold ironing, reducing waiting time or readjusting the transiting speed to result in lower emissions are difficult to implement. The cold ironing system is impossible for transiting vessels due to the continuous moving of vessels while crossing the Canal. In light of the existing Suez Canal infrastructure the reduction of waiting time is applied to the minimum, as it is one of the Suez Canal's priorities for economic reasons. The readjustment of transiting speed requires adjustment in the Canal regulations and investment in the Canal infrastructure.

Therefore examining suitable market-based instruments to reach such environmental goals could be a better approach. The economic consultant, National Economical Research Associates (NERA) submitted a report to the European Commission on August 2003 prepared by a team of David Harrison, Daniel Radov and James Patchett. This report was to evaluate the feasibility of market-based instruments to promote low emission shipping in the European Union sea area.

This report emphasises on two major types of market-based approaches. The first is the trading alternatives approach that emphasises emission trading programs. The second is the charging alternative that emphasises pollution pricing or, in other words, pollution taxation.

The trading alternatives are mainly concerned with programs organizing emission trading mechanisms, in which each program has its criteria and rules. The Credit program, Benchmarking program and Cap-and-Trade program are examples of trading programs.

The credit program provides emission sources that emit emissions below the required levels to have the privilege of tradable credits. These credits could be counted towards compliance by other emission sources that have difficulties in complying with regulation requirements. These credits must be pre-certified before they can be traded.

The Benchmarking program works in assigning predetermined emission rates to a certain activity, in which the average emission rate attained does not go beyond this benchmark. For example, emissions from a maritime activity should not exceed a certain amount per mile or hour. This program does not limit the overall levels of emissions but it limits the rate of emissions. The Benchmarking program could provide ship owners with the opportunity of working together in trading consortiums to comply with emission regulations, where the total rates in this consortium are within the regulation levels.

The cap-and-trade program is based on providing the emitters with an allowance in terms of quantity. For example each facility is allowed to emit a certain amount in tons, grams, etc. Moreover, sources are free to trade between each other to fulfill the regulation requirements.

The second type of market-based approach is charging alternatives. It is based on the polluter pay concept in which the source that emits pollution more than the regulations has to be charged. The charging alternatives have three examples fuel taxes, en route emission charges and differentiated port fairway dues.

Fuel taxes are based on differentiating fuel prices according to the level of pollutants it contains, which could be a positive tool in promoting the use of low pollutant fuel at cheap prices. This approach could face some drawbacks in achieving its environmental goals due to the presence of bunkering places all over the globe with different fuel prices, where some vessels could receive their fuel needs from places not applying the fuel taxes system.

The en route emission charge is based on obtaining certain emission levels to vessels according to vessel activity. In other words, the emission charges could be calculated according to the trip distance or time in a certain region according to vessel size, weight, and distance from shore, average fuel consumption and grade of fuel. By applying such a system, the administrative procedures as well as the controlling mechanisms could be obstacles in implementation.

The differentiated port fairway dues system is the only example in the charging alternatives that provides green sources, with emissions below regulation limits, some privileges. This system is based on differentiating the port dues according to the emission levels of ships. In comparing the differentiated port fairway dues system with the previous two systems, fuel taxes and en route emission charges, it overweighs them in providing more control of emission sources and providing an easier administrative mechanism.

Therefore, by reviewing the previous market-based instrument the Suez Canal could implement a hybrid system. This system should compromise of the achievements of environmental targets, targeting the high pollution sources and sustaining the Suez Canal total revenue with minimum reductions.

Container vessels, which are the source of more than half of the air pollution in the Suez Canal, are mainly operating in liner service routes. The nature of this business is the operation of a series of vessels on a certain route on a fixed time service basis. This means that if a company is operating a weekly based service, each week one sister ship (same size) will transit the Suez Canal. Therefore, the Suez Canal could apply environmental differentiation dues not on a vessel basis but on a line basis or on a company basis.

This could be done by applying the concept of the cap-and-trade program in providing allowances to the shipping line according to the number of vessels and in addition, provide companies that have credits from operating vessels with total emissions below the approved allowance by one of two options. The first option is to trade these credits with other vessels transiting the Canal with more than the allowable credits. The second option is to benefit a rebate equivalent to their credits.

Regarding the tramp vessels that use the Canal on a charter or voyage basis the application of the environmental differentiation dues based on the level of emissions like the Swedish system, with the aid of the IAPP certificate, could be a good practice.

In applying this environmental policy the Suez Canal could achieve its environmental goals by reducing emissions from ships and work on reducing pollution from container vessels. Moreover, the importance of the Suez Canal among its users will counteract any fear of reducing the Suez Canal total income due to such an environmental policy. On the one hand, the application of such a green dues policy by the Suez Canal could offer a win-win situation for all parties.

By adopting such an environmentally friendly policy, gains could be achieved on both the regional and local scales. In the regional scope the Suez Canal could be promoting the implementation of controlling air pollution regulations. Also, by applying such a policy all transiting vessels would have to submit to the Suez Canal their emission level certificates (example IAPP certificate), in which the Suez Canal could be used as a check point for vessels entering the Mediterranean. As previously mentioned the English Channel and Mediterranean will be declared SECA areas in the near future. Therefore, submitting vessel emission levels to the Suez Canal authority prior to transiting will work in monitoring and controlling the implementation of required emission caps. This is especially advantageous for vessels passing the Mediterranean to a destination outside the SECA areas.

Moreover, adopting a green dues policy in the Suez Canal will integrate it with most of the global economic incentive polices in ports. This will encourage ship owners to reduce vessel emissions as well as reduce the economical stresses in complying with emission regulations. Furthermore, this could introduce new concepts, which is the integration between all shareholders (shipping companies, ports and Canals) in the maritime industry to control emissions that contribute to global warming.

On a local scale, applying green dues for transiting vessels could help in reducing emissions generated in the Suez Canal area by attracting more environmentally friendly vessels. Adopting such a policy will definitely promote the Suez Canal’s image world wide as an environmentally-friendly waterway.

Finally, the Suez Canal green policy is subject to more investigations in order for it to stand on its environmental and economical strengths and weaknesses. The thinking of solving air pollution problems in a more integrated and comprehensive manner could help in promoting air quality on a global scale. This will disobediently radiate on nature, living organisms and mankind.

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