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Recurrent atmospheric discharges from port operations: A problem of environmental management in the port of Santos, Brazil

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The objective of this research is to investigate the dimension of the problem of recurrent atmospheric emissions from the naval activity in the port of Santos, considering the future movements of ships and trucks and the consequences of the probable expansion of the port. In combination with an emission factor that states the mass of an emitted pollutant related to either the work produced by ships' engines or the mass of combusted fuel, the total emitted mass of a pollutant can be established. The size distribution of particles is potentially important in impact assessments since there are indications that fine and ultrafine particles are associated with higher health risks than coarse particles. The results from the impact assessments are in favor of abatement technologies like selective catalytic reduction (SCR), a shore-side electricity (SSE) connection, and the use of fuel with a low sulfur content from a local and regional cost–benefit perspective.

Key words: Atmospheric emission, naval activity, environmental management.

INTRODUCTION

The environmental impact and air pollution from ships have received increasing attention during the last decades. By viewing port activities as socio-economic activities that have the potential to introduce contaminants and pollutants into the environment and verifying that the sources of that pollution are correlated, due to the combustion characteristics of typical marine engines and the widespread use of unrefined fuel, the global fleet emits significant amounts of SO_2, NO_X and particles into the air.

The objective of this work is to investigate the dimension of the problem of recurrent atmospheric emissions of the naval activity in the port of Santos, taking into consideration the future movements of ships and trucks and the consequences of the probable expansion of the port. The concern about the environment occupies a dimension of significant importance in the management of businesses in the current world and includes the environmental management concept. Andrade et al. (2000) consider that the environmental preservation of companies became one of the influential factors of the 1990s, mainly in the companies' production of sustainable consumption and intensive capital.

Ships emit a volume of particulate pollutants equivalent to half of the pollution produced by the fleet of vehicles around the world. The conclusion is from an unpublished study by scientists at the University of Colorado, USA, one of the first studies to estimate the pollution emitted by the maritime fleet overall, from direct measurements of particulate emissions from ships in actual operation.

The authors estimate that ships produce about 1,100 tons of particulate pollution globally each year.

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"As more than 70% of shipping occurs within the line of 250 miles of shoreline, this is a significant source of concern for the health of coastal populations," says Lacks (2010), who participated in the study: *Impacts about opposition climate Impacts about opposites climate*. Commercial ships emit as much pollution in the form of particulates (soot) as in the form of carbon dioxide (CO_2). However, according to the researchers, these two types of pollution have opposite impacts on the climate.

The emissions result from the combustion of fuels used for international transport activities, termed international bunker fuels under the UN Framework Convention on Climate Change (UNFCCC), and are reported separately according to the country in which the fuel was sold. The decision to report emissions from international bunker fuels separately, instead of allocating them to aparticular country, was made by the Intergovernmental Negotiating Committee in establishing the Framework Convention on Climate Change. These decisions are reflected in the IPCC Guidelines in which countries are requested to report emissions from fuel sold to ships or aircraft that depart from their ports and are engaged in international transport separately from the national totals (IPCC/ UNEP/OECD/IEA, 1997).

The particles have a global cooling effect that is almost five times greater than the warming due to the CO_2 emissions of their own ships. This is due to the fact that the tiny particles suspended in the atmosphere end up working as micro mirrors, in part reflecting sunlight back into space. The CO_2 emitted by ships is about 3% of all the CO_2 emitted by human activities in the world. The global maritime fleet still produces nearly 30% of nitrogen oxides from anthropogenic (human) activity.

The survey, which included the monitoring of emissions of more than 200 vessels, including freighters, tankers and passenger ships, analyzed the chemistry of the particles and gases emitted by them. Ships emit sulfates, the same particles associated with diesel engines fitted into cars and trucks. These emissions vary in direct relation to the sulfur content of the fuel used.

LITERATURE REVIEW

Internationally, the sulfur content is regulated by the International Convention for the Prevention of Pollution from Ships CODESB (1999). As a result of this convention, some ships use cleaner fuels with low sulfur levels. However, many of them continue to use fuels with a high sulfur content. Particulate emissions depend on the non-sulfated engine operating speed and the amount of lubricating oil required for each type. This amount of lubricant is directly linked to the quality of the fuel used – the worse the fuel is burned, the more oil and the more pollution are emitted. However, even the use of so-called "clean fuel" yields conflicting results. In a surprising finding, scientists have discovered that, despite resulting in lower particulate emissions, the use of fuel with a lower sulfur content results in particles that stay longer in the air. It is precisely when they are in the air that these particles affect human health.

The soot emitted by ships is not the only concern of scientists studying the impacts of pollution on human health. Today, the main source of so-called particulate matter comes from the exhausts of vehicles, power plants and forest fires. In towns, diesel buses are the largest source of soot, as they emit, on average, one hundred times more particulate matter into the atmosphere than burning gasoline. Thermal power plants, which generate energy from oil, coal, or gas, are another major problem.

In Brazil, the use of this type of plant has increased in comparison with other less polluting sources such as hydroelectric, wind, or solar energy. The Ten-Year Energy Plan of the Federal Government plans to build 68 more fossil fuel power plants by 2017.

The transportation sector of many countries, including Brazil, has a national and international navigation component. Navigation is defined here as the transportation sector's water mode, which includes ocean-going, in-port, and inland water way activities. Ocean-going vessels are generally classified as cargo and passenger carrying, military, miscellaneous support ships, and smaller boats and recreational water craft. While in port, these vessels often continue to operate their main engines or separate shore or auxiliary engines to provide energy. Vessels operating in inland rivers, lakes, canals, and reservoirs include the categories listed for ocean-going ships. The combustion of fossil fuels for these activities produces emissions of various greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These activities also produce other air pollutants such as carbon monoxide (CO), oxides of nitrogen (NOx), non-methane volatile organic compounds (NMVOCs), particulate matter and sulphur dioxide (SO_2). Although these gases are not *direct* greenhouse gases, some (CO, NOx, NMVOCs) do contribute to climate change. Moreover, much of the emissions research for this source has focused on these pollutants (Winnes and Fridell, 2009).

Specific emissions of pollutant species differ between the operational modes due to the combustion characteristics at different loads and transient operations. The units of specific emissions, *g/kWh* fuel, are related to the specific fuel consumption, which differs among engine types and depends on the fuel type due to the differences in specific heat among fuels. The specific fuel consumption for modern marine engines ranges between *165 g/kWh* for most efficient two-stroke engines to around *230 g/kWh* for small four-stroke engines (Buhaug et al., 2009). The emission factors play an important role in inventories of air pollutants.The emissions from test bed engines can be suspected of deviating from the emissions from engines in operation due to wear on the engine and the manner in which it is operated. However, correlations of specific emissions are based on engine size or engine age (Winnes and Fridell, 2010).

However, the publications on environmental management of the last ten years refer especially to industrial, agro-industrial, and public organizations; an organization that operates in the interface of these groups – the organized port – has not received the necessary attention from researchers as regards its form of management and the environmental limitations to which it is subjected. Calixto (2000) points out that in the last two decades the development of international agreements, codes and instruments, such as Oil Pollution Preparedness, Response and Co-Operation (OPRC), a London Dumping Convention, the Ministerial Conference of the North Sea, and the MARPOL Convention 73/78, indicate increasing concerns and point out significant changes in marine pollution control compared with those of previous decades.

In the opinion of Porto and Teixeira (2002), managing the environment in the port zone is a complex challenge that involves several levels of knowledge. The majority of port environmental managers, when they exist, do not make use of a reference, either operationally or socially, appropriated for the implementation of adjusted management models in an environment marked by the complexity of the processes.

By viewing port activities as socio-economic activities that have the potential to introduce contaminants and pollutants into the environment, we verify that the sources of the pollution are correlated, according to Calixto (2000), with the following events:

1. The generation of solid residues by the ships that enter and leave the port;
2. The generation of effluent by the ships that enter and leave the port;
3. Atmospheric emissions of the ships that enter and leave the port;
4. Accidents occurring in the port;
5. Cargo movement and storage in the port;
6. Dredging of the access channel;
7. Repairs and maintenance of the ships in the port;
8. The installation of industrial complexes in the port zone.

There are no difficulties in diagnosing the causes of the pollution in the port environment, only their consequences. There are still more when the public managers of the port sectors, and even the authorities hire services, in particular civil engineering to attend to the demands of the politics of development connected to the increase in exportation, without adjustment of the vectors of modernization to the maintenance of the environmental quality in the proper port and adjacent areas.

The American Association of Port Authorities has been recommended since 1998 (AAPA, 1998) that port managers consider the following environmental concerns in their planning:

1. Located erosion and silting;
2. Exotic and endangered species;
3. Harmful and dangerous substances;
4. Oil spillage;
5. Emission of gases;
6. Dust and particulate material;
7. Solid residues and affluent liquids;
8. Noise.

According to Porto and Teixeira (2002), dust is the solid element present in air proceeding from port activities, launched by the movement of the cargo or its transformation in installations of the organized port. It produces damage to human health and constructions and inevitably reduces the air quality, with detrimental visual effects. In human beings, it can produce allergies, illnesses of the respiratory system, and other diseases. Inside port installations, such as silos and warehouses, the formation of gases can cause explosions, which are not uncommon when agricultural grains are concerned; they can cause the formation of gas methane. Porto and Teixeira (2002) consider that one of the main aspects to be observed as regards dust relates to the handling work of the burned cargo inside the bilges of the boats.

RESEARCH METHODOLOGY

According to the criteria considered by Vergara (1997), the present research can be classified as exploratory, as a case study; therefore, only one port was studied, in-depth. The port of Santos, the object of analysis, is one of the biggest Brazilian maritime ports with representation in its respective segment. According to Castro (1997), by adopting an exploratory and descriptive approach, the researcher should be open to his discoveries. Even though he initiates the work from some theoretical project, the researcher should keep himself alert to the new elements or dimensions that will appear in the elapsing of the work.

The research accomplished in the port of Santos was based on a set of documentary sources, centered on the Companhia de Docas do Estado de São Paulo (CODESP), extending data obtained from the CETESB, SABESP, Oceanographic Institute of the University of São Paulo, and Santos City Hall. This research also conducted interviews with the Supervision of Environment of the port of Santos and dock workers, chosen from the operational and administrative sectors.

The concept of the port of Santos for the present study, in its totality, is recognized by administrative rule number 1021, 20/12/93. It includes private terminals, that is, considering the port with 11.042 m of wharf alongside and depths varying between 6.6 and 13.446 m, a wharf for special ways with a 521 m extension and a minimum depth of 5 m, and a wharf for private use with a 1.883 m extension and a depth of 5 m, amounting to 13.446 m. Storage is assisted by 45 internal warehouses, 34 to the right edge and 11 to the left edge of the estuary, and 39 external warehouses.

The specialized terminal consists of the container terminal, located on the port's left edge, with an area of 350,000m^2, 510m of wharves, and 13m of depth, simultaneous mooring for 3 ships; the fertilizers terminal also on the left edge, with 567m of wharves, 2 piers alongside 283.5 and 17.5 m depth; the coal terminal installed in the Saboó, with a 10,800m^2 area and capacity of 50,000t; the liquid granaries terminal in the Alamoa, on the left edge of the

Table 1. Cargo fraction by means of operation.

Cargo fraction by means of operation as a percentage			
	Low-speed navigation	**Maneuver**	**Mooring***
Temporary	35	10	85
Others	20	20	40

Source: EPA (2000).

estuary, with 631 and 11 m depth linked to Barnabé Island by means of submarine ducts on the left edge, 341m of wharves, and 10 m depth; and finally the RO-RO terminal, which offers 6 cradles, being in the Saboó, 2 close to the 35 warehouse yard and 1on the wharf of 29 warehouses. The terminals for private use consist of companies' terminals Cutrale, Dow Química, Usiminas, Ultrafértil and Cargill.

DATA ANALYSIS

The atmospheric pollution in a port can result from both cargo operation and cargo discharge as industrial activity, but mainly from the atmospheric discharges of the ships (anchored or waiting to dock) and vehicles that carry the merchandise to the port, mainly by road and railroad, and the main gases emitted are:

1. Carbon Dioxide (CO_2): As fossil fuels are combusted, the carbon stored in them is almost entirely emitted as CO_2. The amount of carbon in fuels with a given energy content varies by fuel type and is a function of the carbon content of the fuel rather than the engine or combustion technology.
2. Nitrous Oxide (N_2O): Nitrous oxide is produced during fossil fuel combustion when nitrogen in the air or fuel is oxidized in the high temperature environment of the engine. However, the extent of emissions is uncertain: they are thought to be small. The emissions of N_2O from ships, boats and other navigation vessels are expected to be small, but may increase if post-combustion catalytic controls are installed.
3. Carbon Monoxide (CO): Carbon monoxide is produced by the incomplete combustion of carbon in fossil fuels. Emissions of CO are a function of the efficiency of both the combustion and the post-combustion emission controls. Emissions are highest when the air–fuel mixture is rich, a condition that generally occurs in idle, low-speed and cold-start conditions in spark ignition engines. Once emitted, CO contributes to tropospheric ozone formation before the molecules are further oxidized to CO_2 through natural processes in the atmosphere. Carbon monoxide also interacts with the hydroxyl radical, the major atmospheric sink for methane emissions to form CO_2.
4. Methane (CH_4): Small quantities of methane can be produced when the hydrocarbons in fuels are not completely combusted. In uncontrolled engines, the proportion of methane emissions is generally highest at low speeds and when the engine is idle. Poorly tuned engines may have a particularly high output of methane.
5. Nitrogen Oxides (NOx): Nitrogen oxides include the chemical species of NO and NO_2 and they also promote the formation of ozone in the troposphere. Emissions are related to the air–fuel mix and combustion temperatures. They are likely to be affected by the fuel type and engine type.

According to a report by the SwedishFoundation for Human Rights (NGO, 2011) Secretariat on acid rain in combination with the European Environmental Bureau and the European Federation for Transport and Environment denominated *Air pollution from ships*, the air pollution caused by ships is an increasing concern. The preliminary version of Annex VI of MARPOL 73/78, which deals with the atmospheric emissions produced by ships, was signed in 1997. For these European entities and also for the IMO, the main concerns again fall on the following emissions:

1. Emission of SO_2: This is estimated to be 4.5 to 6.5 million tons per year, which is equivalent to approximately 4% of the global emissions of SO_2. The emissions in open sea are understood to have a moderate effect; however, those emissions that occur along specific routes, such as the English Channel between France and England, the South China Sea, the strait of Malaca, and mainly in ports create serious environmental problems.
2. Emission of NOx: The emissions of nitrogen oxide are estimated to be 5 million tons per year, equivalent to 7% of the global emissions. The main problems generated are related to public health and acid rain in the port regions.
3. Emission of CFCs: It has been estimated that the worldwide fleet of merchant ships is responsible for the emission of approximately 3,000 to 6,000 annual tons, equivalent to approximately 3% of the global emissions.

In Brazil, we have not yet found any systematic study that deals with the problem of the atmospheric emissions by ships; however, our country is a signatory of the MARPOL, and some port environmental managers have taken steps in the direction of considering the recommendations defined by Annex VI of this convention, but following the recommendations will not occur so early. Besides the air pollution caused by gaseous emissions, pollution is caused by cargo movement, which is related to the handling of some solid grains, such as coal, soy in bran, fertilizer, bauxite and others. The handling of these cargos is an enormous source of dust generation.

The confinement of the cargo produces air that is extremely loaded with solid particles and provides poor visibility for dock workers, who frequently operate transport equipment inside the bilge. Operations in which the equipment is connected to the loading dock and ship to improve the work are highly polluting.

For the port of Santos, there are no statistical data referring to the air pollution caused by the boats that pass through the channel and anchor in the mooring cradles, so in order to evaluate the level of atmospheric emissions we necessarily made use of indirect methods, following a methodology developed by the EPA and described in a document entitled *Analysis of commercial marine vessel emissions and fuel consumption data*, published in February 2000.

In order to apply the calculation formulas for emissions contained in the methodology developed by the EPA, we adopted a cargo fraction for the main and auxiliary engines, with the following values presented in Table 1.

The population of boats was determined on the basis of statistical data supplied by CODESP.

The following calculation formulas for the emissions use the coefficients and exponents seen in Table 2. The emission tax (ET) for the pollutants, with the exception of SO_2 is calculated by:

Table 2. Factors of emission for naval propellants.

Factors of emission for naval propellants			
Pollutant	**Exponent (x)**	**Coefficient (a)**	**Coefficient (b)**
CO	1	0.8378	Not applicable
CO_2	1	44.1	648.6
HC	1.5	0.0667	Not applicable
Particulate material	1.5	0.0059	0.2551
NO_2	1.5	0.18865	15.5247
NO_x	1.5	0.1255	10.4496
SO_2	Not applicable	2.3735	Not applicable

Source: EPA (2000); (*) Along with ship-only operations with auxiliary engines.

Table 3. Emission tax of pollutants for the function of operation and type of ship.

Emission tax for each pollutant and method of operation in g/kWh						
Type of Pollutant	**Maneuver**		**Navigation at low speed**		**Mooring**	
	PAS	**OUT**	**PAS**	**OUT**	**PAS**	**OUT**
CO	8.38	4.19	2.39	4.19	0.98	2.09
CO_2	1089.60	869.10	774.60	869.10	758.90	700.50
HC	2.11	0.75	0.32	0.75	0.09	0.26
Particulate material	0.44	0.32	0.28	0.32	0.26	0.28
NO_2	21.49	17.63	16.44	17.63	15.76	16.27
NO_x	14.42	11.85	11.06	11.85	10.61	10.94
SO_2	229.45	217.58	212.50	217.58	208.51	211.65

Source: EPA (2000).

Table 4. Booz-Allen classification of ship power.

BOOZ-ALLEN classification of ship power for band of tonnage in kW		
Tonnage band (× 1000 ton)	**Barns (kW)**	**Others (kW)**
0 up to 25	16,862	8,560
25 up to 50	35,742	11,920
50 up to 75	59,342	16,120
75 up to 100	80,582	19,900
Above 100	104,182	24,100

Source: EPA – Analysis of commercial marine vessel emissions and fuel consumption data (2000).

$$CF = a \cdot (\text{Cargo Fraction})^{-x} + b \text{ g/kWh} \quad (1)$$

The SO_2 emission tax is given by:

$$ET = a \cdot [14{,}12/(\text{Cargo Fraction}) + 205{,}717] + b \text{ g/kWh} \quad (2)$$

By applying formulas (1) and (2) using the cargo fraction of Table 1, we obtain the data presented in Table 3.

To attain the annual volume of emissions, we cannot base the calculation only on the medium power by ton and the amount put into motion in the port of Santos. Based on a maritime guide that lists all the port arrivals and that exists for ships and destinations, it is apparent that, in the majority, they are medium-sized ships, of the order of 35,000 tons, for example the *MV Copacabana* of the Alliance Company. Thus, estimating medium power for the main engine of 35,742kW, according to Booz-Allen's classification in Table 4, is more cautious than when we consider 5,000 kW.

Most passenger ships that operate in the port of Santos are from international coastline long-distance lines, that is, ships for approximately 1,200 passengers and 800 crew members to 3,000 passengers and 1,000 crew members; for example the *Eugenio C* and *Splendour of the Sea*, with a capacity of 40,000 tons and a speed of approximately 26 knots or 47 km/h. Ships with such characteristics, according to the Booz-Allen classification, use main engines with medium power of 35,742 kW. By combining the medium time of ship operation, with medium power engines, main and auxiliaries, and cargo fraction, we obtain the following energy consumption as seen in Table 5. From the combination of the data

Table 5. Estimate of medium consumption of energy for cargo movement and passengers for ships in operation.

Estimate of medium consumption of energy for cargo movement and passengers in the port of Santos for ships in operation								
YEAR	**Maneuver (kWh)**		**Low-speed navigation (kWh)**		**Mooring (kWh)**		**TOTAL (kWh)**	
	PAS (0.10)	**OUT (0.20)**	**PAS (0.35)**	**OUT (0.20)**	**PAS (0.85)**	**OUT (0.40)**	**PAS**	**OUT**
1998	14,297	28,594	12,510	7,148	113,050	10,640	139,857	46,382
1999	14,297	28,594	12,510	7,148	110,075	10,360	136,882	46,102
2000	14,297	28,594	12,510	7,148	102,000	9,600	128,807	45,342
2001	14,297	28,594	12,510	7,148	107,950	10,160	134,757	45,902
2002	14,297	28,594	12,510	7,148	116,450	10,960	143,257	46,702
2003	14,297	28,594	12,510	7,148	122,050	11,490	148,857	47,232
2004	14,297	28,594	12,510	7,148	129,350	12,170	156,157	47,912
2005	14,297	28,594	12,510	7,148	133,000	12,520	159,807	48,262
2006	14,297	28,594	12,510	7,148	147,950	13,930	174,757	49,672
2007	14,297	28,594	12,510	7,148	161,450	15,190	188,257	50,932
2008	14,297	28,594	12,510	7,148	169,950	15,990	196,757	51,732
2009	14,297	28,594	12,510	7,148	177,450	16,700	204,257	52,442

Source: Elaborated by the author from data supplied by CODESP.

Table 6. Estimate of the total emissions of pollutants in the port of Santos associated with maritime transport in kg/h.

Estimative of total emissions of pollutants in the port of Santos associated to maritime transport (Kg/h)							
ANO	**NO_x**	**NO_2**	**SO_2**	**Particulate material**	**CO**	**CO_2**	**HC**
1998	18.2	27.0	349.2	0.5	3.9	1,269.7	0.5
1999	18.4	27.4	353.9	0.5	3.9	1,287.3	0.6
2000	19.0	28.2	364.1	0.5	4.1	1,327.3	0.6
2001	18.4	27.4	353.8	0.5	4.0	1,288.4	0.6
2002	17.0	25.3	326.9	0.4	3.7	1,192.8	0.5
2003	18.2	27.0	349.2	0.5	3.9	1,269.7	0.6
2004	18.4	27.4	353.9	0.5	3.9	1,287.3	0.6
2005	19.0	28.2	364.1	0.5	4.1	1,327.3	0.6
2006	19.6	29.2	371.8	0.5	4.3	1,388.4	0.6
2007	19.8	29.6	375.1	0.6	4.4	1,409.8	0.7
2008	20.4	30.2	385.8	0.6	4.5	1,468.4	0.7
2009	21.2	31.0	392.9	0.6	4.7	1,492.8	0.7
Average	19.0	28.2	361.7	0.5	4.1	1,334.1	0.6

Source: Elaborated by the author from data supplied by CODESP.

on the consumption of energy with the data on emission taxes, taking into consideration the total hours of all the operations, of maneuvering to mooring and unmooring, we obtain an estimate of the emissions for the port of Santos, in kg/h (Table 6). We opt to present the emissions in kg/h to allow a comparison with the data presented in the experts' report of the CETESB (1994) No. 002/02/EQ/EEA, which deals with the final analysis of the EIA/RIMA of the thermoelectric plant UGE Carioba II, in Americana City.

Based on these data, it is noticeable that the situation of the port of Santos is critical: the emissions of some pollutants surpass the emissions of a thermoelectric plant of 36 MW, such as the plant Carioba I. If we add the emissions of road and railroad transport, the situation is becoming increasingly worse. By the way, as regards air pollution, the emissions on the part of road transport (90% terrestrial logistics) represent a big risk as that caused by ships. The *Bundesamt für Umwelt, Wald und Landschaft* (BUWAL) report shows emission factors that allow us to estimate the amount of determinate emissions by means of transport (Table 7).

Table 7. Summary of total emissions in kg/h.

Summary of total emission (Kg/h) (For Carioba plant - entrepreneur proposal)							
Scenery	**Power (MW)**	**No_x (1)**	**SO_2**	**MP**	**CO**	**HC total (2)**	**HCNM (3)**
1	36	8.32	202.96	71.42	13.81	2.87	2.10
2	156	28.4	6.0	8.3	13.7	6.7	1.3
3	590	101.1	16.4	23.4	82.8	41.2	13.8
4	883	151.7	24.6	35.0	124.2	61.8	20.7
5	1200	202.4	32.8	46.8	165.6	82.4	27.6
6	945	113.6	24.1	34.8	54.7	26.8	5.2

Source: CETESB (2002). (1) NO_x expressed like NO_2, (2) Total hydrocarbons expressed like methane, (3) Non-methane hydrocarbons were considered as being volatile organic composites (VOCs), expressedlike methane, for the estimated effect, according to specific literature (EPA).

Table 8. Air liberation associated with the transport system.

Factors of emission (g/Km ton)					
Means of transportation	**Particulate material**	**SO_2**	**HC**	**NO_x**	**CO**
Heavy Vehicle	0.0840	0.1569	0.3347	1.0332	0.4031
Boats in River	0.0409	0.2080	0.1309	0.4057	0.2225
Oceanic Navigation					
Cargo Ship	0.0107	0.2341	0.0346	0.0259	0.0040
Tanks	0.0056	0.1190	0.0186	0.0129	0.0017
Ducts					
Gas	0.0003	0.0190	0.2759	0.0571	0.0279
Oil	0.0038	0.0485	0.0410	0.0240	0.0068
Railroad	0.0064	0.0813	0.0686	0.0401	0.0113

Source: Bundesamt für Umwelt, Wald und Landschaft (BUWAL, 1991).

The conditions for six scenarios are:

Scenario 1: Plant Thermoelectric Carioba I operating with 2 boilers using combustible oil type 2A, for vapor production with the generation of 36 MW in a vapor turbine, launching by a chimney, in operation currently.
Scenario 2: Plant Carioba II operating with 1 gas turbine, burning natural gas, in a simple cycle, total generation of about 156 MW and penalization of Carioba I, maximum values estimated for emissions being adopted, for 1 chimney.
Scenario 3: Plant Carioba II operating with 2 gas turbines, burning natural gas, in a combined cycle, with vapor generation by means of supplemental burning in the 2 respective boilers of recovery, with a maximum generation of about 590 MW, maximum values estimated for emissions being adopted, 2 chimneys.
Scenario 4: Plant Carioba II operating with 3 gas turbines, burning natural gas, in a combined cycle, with vapor generation by means of supplemental burning in the 3 respective boilers of recovery with a maximum generation of about 883 MW, the maximum values for emissions being adopted, 3 chimneys.
Scenario 5: Plant Carioba II operating with 4 gas turbines, burning natural gas, in a combined cycle, with vapor generation by means of supplemental burning in the 4 respective boilers of recovery, with maximum generation of about 1200 MW, the maximum values estimated for emissions being adopted, 4 chimneys.
Scenario 6: Plant Carioba II operating with 4 gas turbines, burning natural gas, in a combined cycle, without vapor generation by means of supplemental burning, with maximum generation of about 945 MW, maximum values estimated for emissions being adopted, 4 chimneys.

As seen in Table 8, and considering a sphere of influence of 10 km from the port, the 7,000 trucks that drive daily to the port of Santos, with a medium cargo of 20 tons, using the formula below, are responsible for air emissions, in kg/h, as presented in Table 9.

$$\text{QTY EMITTED} = \frac{\text{FactorEmis} \times \text{Qty Transp} \times \text{Dist} \times \text{NrVehicles}}{24000} \quad (3)$$

Overview of the impacts of air pollution caused by ships

The previously mentioned pollutants, NO_X, particles, ozone, SO_2, and CO_2, all of which are products of the combustion of fuel oil can be classified as either primary or secondary pollutants. The *primary pollutants* are the pollutants that are formed during the actual combustion process, while the *secondary pollutants* are formed in the atmosphere as a consequence of chemical reactions involving the primary species. The potential impact categories influenced by

Table 9. Emissions of pollutants by trucks in the port of Santos in kg/h.

Estimate of the emission of pollutants by trucks in the port of Santos in kg/h	
CO	23.5
HC	19.52
Particulate material	4.90
NO_x	60.27
SO_2	9.15

Source: Elaborate by the author from data supplied by CODESP and BUWAL parameters.

Table 10. Primary pollutants from the combustion of oil and the major potential impacts.

Impact category	Particle	SO^2	Nox	CO^2	HC	CO
Health effects	x	x	x			x
Acidification		x	x			
Photo-oxidant formation			x		x	
Eutrophication			x			
Climate change				x	X (CH_4)	

Source: Jackson and Jackson (1996).

air pollution from oil combustion are health problems, acidification, eutrophication, photo-oxidant formation and climate change, to name the most important (Jackson and Jackson, 1996). An overview of these pollutants and their corresponding impact categories are presented in Table 10.
The impacts of pollution on health are as follows:

1. Health risks: The correlation between adverse health effects and particulate matter is well established, and ozone, SO_2 and NO_2 have also been shown to alter lung function (World Health Organization, 2006). Particulate matter is a heterogeneous group that can be divided into subgroups based on characteristics that are believed to determine health risks – particle surface area, particle size, elemental composition, composition of organic compounds – and these are supposed to be more important than the particle mass for determining associated health risks (Lighty et al., 2000; World Health Organization, 2006). In addition to the mortality risks, there are several different types of health risk including cardiovascular diseases and respiratory failure.

2. Acidification: When sulphates or nitrates are abundant in aerosol particles, these particles become acidic and precipitate as acid rain. Acidification is tightly coupled to H2SO4 and HNO3, which are formed by the oxidation of SO2 and NO2. The associated environmental impacts range from effects from wears on buildings and materials to the release of metal ions from lake sediments, altering the life of water-living species and ultimately leading to fish death (Ottar, 1986).

3. Photo-oxidant formation: The term photo-oxidant formation or photochemical is used for atmospheric oxidants that are formed by photo-chemically induced processes of volatile organic carbons (VOC) and CO. Typically, the most important species is O_3 (Kley et al., 1999). In the presence of sunlight, VOC and NOX can lead to a net formation of O_3.

4. Climate change: The emission of gases by ships also contributes to affecting the climate of the earth. Certain mechanisms lead to higher atmospheric temperatures while others reflect the incoming solar light and cool the atmosphere. Other, more potent, climate gases are methane (CH_4) and nitrous oxide (N_2O), which are emitted in minor amounts (Cooper and Gustavsson, 2004). Emissions of particles and SO_2, which form sulfate-containing particles, contribute to cloud formation, which probably has a negative impact on the earth.

5. Eutrophication: Nitrogen oxides are also involved in eutrophication, which is a problem associated with elevated levels of plant nutrients such as nitrogen and phosphor in water and soil. Excess growth of certain nutrient-loving species occurs at the expense of others. In sea areas, algal blooms are typical examples related to eutrophication.

Conclusion

The industry of maritime transport as well as port activity cannot and must not be aggressive to the environment. It must be impelled to make use of clean technologies and respect the limits and space capacities where it operates. Despite the promising situation regarding the business-oriented volume achieved by the port of Santos, the information presented in this work demonstrates the presence of a critical problem concerning atmospheric emissions, rendering it vulnerable.

The work showed that there are still great gaps in the information on port activities and their environmental impacts, resulting from either a lack of concern about obtaining them, a lack of systemized procedures for data collection,or even a lack of the scientific knowledge that allows the creation of such procedures. It is necessary to emphasize that such a lack of data is not only a characteristic of the port of Santos, among the Brazilian ports.

The studies referring to the environmental impact caused by the port activities are very recent: a great part of them appeared at the end of the 1990s and at the beginning of the new millennium. It is certain that many other measures can be adopted and regardless of the type used they must necessarily lead to the consideration of what Gonzales (2003) emphasizes:

The problems of the modern world are basically environmental problems, defining them as resultant in the interaction between biophysical and a human population, expressed both in biophysical and in the manifestation of the culture built by this population. He still adds that the expression most visible of the progressive deterioration of the planet ecosystems, with effects in the interior of their social systems translate, into bigger difficulties to guarantee the sustainability of production and maintenance of the minimum level of life quality.

Emissions resulting from the combustion of fuels used for international transport activities, termed international bunker fuels under the UN Framework Convention on Climate Change (UNFCCC), are currently not included in national emission totals, but are to be reported separately. In general, the methodology in the *IPCC guidelines* recommends that emissions from navigation be estimated by multiplying the amount of fuel consumed by an appropriate emissions factor.

The accomplishment of work based on proposals certainly tends to enrich the small amount of literature existent on port environmental problems, as well as contributing to greater convergence between different methodological lines. The present work on the whole expects to represent a contribution, in great partoriginal, on port environmental management and more specifically on the problems of the atmospheric pollution in our ports.

In relation to future academic work, studies to complement the port knowledge are suggested. Research method that makes possible the establishment of parameters must be contemplated in the process of taking a decision regarding port environmental management, carrying out an in-depth study of environmental costs, efficiency, and operational productivity and conduct a studying on the recovery of port environmental liabilities, mainly in relation to the exploitation of idle installations, in order to revitalize the urban space.

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