An Open Online Calculator for Ship Air Emissions

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ABSTRACT:

The broader analysis of greenhouse gases such as CO_2, and of other, non-greenhouse gases, such as SO_2 and NOx is already very high on the International Maritime Organization's (IMO) agenda. Various analyses of many aspects of the problem have been and are being carried out and a spectrum of measures are being contemplated. The authors have developed a web-based tool that is freely available online for calculating the exhaust gas emissions (CO_2, SO_2 and NOx) of specific types of ships under a variety of operational scenarios. It can be used for example by ship owners who need to know both the amount of emissions that their ships produce, and, indirectly, the bunker consumption, in order to choose between alternative scenarios that are both economic and more environmental friendly. In this paper, the algorithm that is behind the web tool as well as the practical importance of this tool are presented. Actual scenarios based on data provided by shipping companies are used and possible ways to incorporate the webtool into actual decision-making are analyzed.

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1 INTRODUCTION

During the last decade there is a growing concern on the effects of emissions from commercial shipping. According to the Kyoto protocol to the United Nations Framework Convention on Climate Change - UNFCCC (1997), definite measures to reduce CO2 emissions are necessary in order to curb the projected growth of greenhouse gases (GHG) worldwide. Shipping has thus far escaped being included in the Kyoto global emissions reduction target for CO2 and other GHG, but it is clear that the time of non-regulation is rapidly approaching its end, and measures to curb future CO2 growth are being sought with a high sense of urgency. CO_2 is the most prevalent of these GHGs, and it is therefore clear that any set of measures to reduce the latter should primarily focus on CO_2..In parallel, the analysis of other greenhouse gases (such as CH_4 and N_2O) and other, non-greenhouse gases, such as SO_2, NO_x is already very high on the International Maritime Organization's (IMO) agenda.

IMO Assembly resolution A.963(23) on "IMO Policies and Practices Related to the Reduction of Greenhouse Gas Emissions from Ships" urged the Marine Environment Protection Committee (MEPC) to develop a methodology to describe the GHG efficiency of ships in terms of GHG emission index (see Section 8).

Furthermore, various analyses of many aspects of the problem have been and are being carried out and a spectrum of measures are being contemplated. It is clear that a reliable emissions inventory is essential for both scientists and policy-makers in order to formulate and evaluate the implementation of relevant regulations. There is also a clear need of tools that can perform the vast array of calculations that are necessary in that regard. Besides, tools that can estimate the GHG efficiency of such measures are valuable for ship operators during their decision- making progress of implementing these measures and for organizations to measure the effectiveness of their policies.

One of such tools that is not available in the public domain is a most rudimentary one, a simple emissions calculator. The main use of such a tool is to calculate various emissions-related statistics for a given ship, under some standard operational scenarios. This paper describes such a tool, which is web-based and freely accessible, and which was recently developed by the authors for the Hellenic Chamber of Shipping (HCS). The emissions web tool is available at the web address http://www.martrans.org/emis and is the analogue of what some airlines has available on their web sites.

The study that was conducted by the NTUA Laboratory for Maritime Transport for the Hellenic Chamber of Shipping (see Psaraftis and Kontovas (2008)) had originally two objectives, one of which was to develop a web-based tool for calculating the exhaust gas emissions (CO_2, SO_2 and NO_x) of specific types of ships under a variety of operational scenarios. The other objective, which is out of the scope of this paper, was an analysis of the world fleet database in order to estimate the carbon dioxide emissions of the world fleet (see Psaraftis and Kontovas (2008, 2009a) for more details).

Looking at the situation in other industries, carbon calculators promote public awareness of emissions from individual behavior. For this reason, many organizations and government agencies offer online calculators that calculate the 'carbon footprint' that an individual is responsible for, based on the individual's household activities and transportation. However, the use of such carbon calculators in transportation is only limited to automotive and air travel and most of these online calculators lack information about the method and emission factors that they use. See, for example, Padgett et al.(2008), who examine the similarities and differences among ten calculators.

Although various forms of carbon calculators have become prevalent on the internet, the authors are not aware of any such tool in the public domain that estimates emissions of sea-borne transport. The only tool we are aware of is the 'Maersk Carbon Footprint Calculator' which is, however, a non-public calculator developed by Maersk Line and Maersk Logistics and is only available to Maersk's clients. The only information we have on it is through its product sheet (Maersk, 2008). According to it 'the carbon footprint can be valuable for a variety of purposes, including environmental reporting and identification of "carbon hotspots" in the transportation supply chain'.

This means that to our knowledge, ours is the first publicly accessible emissions calculator for the shipping industry.

The purpose of this paper is to describe the web tool that has been developed and investigate its possible uses in decision making and policy evaluation. The rest of this paper is organized as follows. Section 2 refers to relevant literature. Section 3 describes the algorithm that is used in our calculations. Section 4 describes the running modes of the tool, and, finally, Section 6 presents the conclusion and some remarks including some possible extensions.

2 RELEVANT LİTERATURE

Looking at the literature on the broad area of this paper (including both scientific work and regulation-related documents), it is no surprise that the relevant material is immense. Still, we collected and studied a large number of such documents by focusing (a) on relations linking parameters such as bunker consumption, engine type and horsepower, to produced emissions of various exhaust types, (b) on data that can be used as inputs for our study (for instance, bunker consumption for various ship types) and (c) on various other reported statistics (for instance, bunker consumption).

An update of the IMO 2000 report which provides a consensus 2007 emissions inventory is presented in Buhaug et al (2008). Furthermore, there are some documents related to the concept of 'CO2 index'. IMO (2008b) proposes the development of a mandatory CO2 design index for new ships that reflects only the technical performance of the ship and its engine, and not operational or commercial aspects. IMO (2008d) contains a technical report prepared by Det Norske Veritas that presents information on the development of such an index. The discussions on the ship design index were continued at the 58th session of IMO's Marine Environment Protection Committee (MEPC 58). What are of particular interest are some submissions on the operational index. IMO(2008c) proposes amendments to MEPC/Circ. 471(see IMO(2005)) which contains the interim guidelines for voluntary ship emission indexing for use in trials. Furthermore, IMO(2008e) proposes a methodology for the recording and monitoring of the individual Ship's Efficiency Energy Management Tool.

Outside IMO documents, detailed methodologies for constructing fuel-based inventories of ship emissions have been published by Corbett and Köhler (2003), Endresen et al (2003, 2007), Eyring et al (2005), and in EMEP/CORINAIR (2002). Corbett and Köhler (2003) estimates global fuel consumption for ships greater than 100 GRT by using engine power and vessel activity data. Endresen at al (2003) did a similar work but improved the spatial representation of global ship air emissions by weighting ship reporting frequencies using the Automated Mutual-assistance Vessel Rescue system (AMVER) data set.

3 ALGORITHM

The approach for computing emissions per tonne-km is straightforward. The scenario on which the webtool is based on is the following:

A ship that carries a cargo payload of W (tonnes) is assumed to travel from point A to point B, which are L kilometers apart, going laden from A to B at speed V (km/day) and returning empty on ballast at speed v (km/day). W is a function of ship's deadweight and its capacity utilization, and the ship's deadweight is an upper bound to it. Ship spends time T (days) loading at port A and time t (days) discharging at port B.

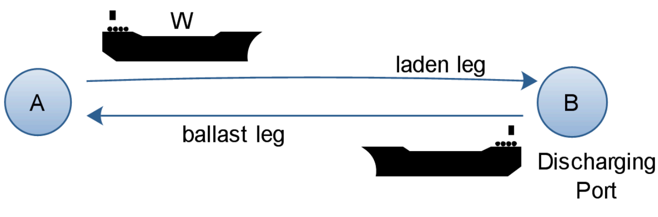

Figure 1: Ship Route

Also, assume that the fuel consumptions (all in tonnes per day) are known and are as follows:

At loading port, G
At sea, laden, F
At discharging port, g
At sea, on ballast, f.

In essence, both F and f are functions of speeds V and v respectively, a cube law applying in each case. That is, F is proportional to the cube of V and f is proportional to the cube of v. The coefficients of proportionality are not the same, as ship sails laden in the first case and on ballast in the second case. As all fuel consumptions are assumed known, the cube law will not be used here, as its use would only be if variations on fuel consumption versus speed were to be studied (which is not the case).

Based on the above, it is straightforward to compute the following:

Transit time from A to B (days): L/V
Transit time from B to A (days): L/v
Total fuel consumption per round-trip (tonnes): GT + FL/V + gt+ fL/v
Total tonne-km's carried per round-trip: WL
Total CO_2 produced in this round-trip: 3.17(GT + FL/V + gt+ fL/v)
CO_2 per tonne-km for this round-trip: 3.17(GT + FL/V + gt+ fL/v)/WL
= 3.17[(GT+gt)/L + F/V+ f/v]/W

The main output of the algorithm is the total emissions for three gases: CO_2, SO_2 and NOx, produced per roundtrip and per tonne-km. However, intermediate calculations include emissions per each leg (ballast and laden conditions) and at port. Tonne-km's for this scenario are computed by multiplying the amount of cargo carried on the laden part of the trip by the appropriate distance. Zero tonne-km's are registered in the ballast leg of the trip (although obviously this leg, plus times in port, do count as far as exhaust gases are concerned).

<u>Emission Factors</u>

The emissions factor for CO2 that we have used does not depend on type of fuel used or engine type. In fact, this is an approach widely used in the literature. According to it, one multiplies total bunker consumption (in tonnes per day) by the factor of 3.17 to compute CO2 emissions (in tonnes per day). The 3.17 CO_2 factor is the empirical mean value most commonly used in CO_2 emissions calculations based on fuel consumption (see EMEP/CORINAIR (2002) Table 8.1). However, we should note that in some reports separate emissions factors for Heavy Fuel Oil (HFO) and for Marine Diesel Oil (MDO) are being used. For example the update of the IMO 2000 study (Buhaug et al,2008), which has been presented at MEPC 58, uses slightly lower coefficients, namely 3.082 for Marine Diesel and Marine Gas Oils (MDO/MGO) and 3.021 for Heavy Fuel Oils (HFO).

According to the report of the IMO Working Group on Greenhouse Gas Emissions from Ships (IMO, 2008), the group agreed that the Carbon to CO2 conversion factors used by the IMO should correspond to the factors used by IPCC (2006 IPCC Guidelines) in order to ensure harmonization of the emissions factor used by parties under the UNFCCC and the Kyoto Protocol (see Table 1). Currently, we are in the process of updating our webtool in order to be able to use different emission factor for these two main types of oil.

Table 1: Comparison of Emission Factors kg CO_2/kg Fuel (MEPC 58/4/3)

FUEL TYPE	GHG-WG 1/3/1	IPCC 2006 Guidelines			Revised 1996 Guidelines
		Default	Lower[b]	Upper[b]	
Marine diesel and marine gas oils (MDO/MGO)	3.082	3.19	3.01	3.24	3.212[a]
Low Sulphur Fuel Oils (LSFO)	3.075	3.13	3.00	3.29	
High Sulphur Fuel Oils (HSFO)	3.021				

Turning to SO_2, emissions depend on the type of fuel and more specifically to the sulphur content of the fuel. One has to multiply total bunker consumption (in tonnes per day) by the percentage of sulphur present in the fuel (for instance, 4%, 1.5%, 0.5%, or other) and subsequently by a factor of 0.02 to compute SO_2 emissions (in tonnes per day). The 0.02 SO_2 factor is exact and comes from the chemical reaction of sulphur and oxygen to produce SO_2.

NO_x emissions, finally, depend on engine type. The ratio of NO_x emissions to fuel consumed (tonnes per day to tonnes per day) ranges from 0.087 for slow speed engines to 0.057 for medium speed engines. NO_x emissions factors are empirical (see EMEP/CORINAIR (2002) Table 8.2).

4 RUNNING MODES

The web tool can be run in two modes:

Mode A: run scenarios on pre-specified ships and routes, and
Mode B: run scenarios on user-defined ships and routes.

No data entry is necessary for mode A, except user selection as regards ship and route. By contrast, all necessary input should be entered in mode B.

4.1 Mode A – Prespecified scenarios

In this mode, the user can select scenarios based on actual ships and typical routes. For the purposes of developing the web tool, a set of representative routes for a variety of ships and operational scenarios were collected.

Thus, this web tool uses real data (including actual fuel consumption and not one derived by using engine's horsepower). Such data were solicited from shipping companies members of the Hellenic Chamber of Shipping (HCS). Solicited data include:

- Ship type
- Year of built
- DWT
- Average cargo payload per laden trip
- Engine type
- Horsepower
- Speed (laden, ballast)
- Time in port (loading, discharging)
- Fuel type (sea, port)
- Fuel consumption (sea/laden, sea/ballast)- by type of fuel
- Fuel consumption (port/loading, port/discharging)- by type of fuel

The web tool currently incorporates the most important categories of ships, each further broken down into size sub-categories and typical routes.

All ships used are actual ones but in order to protect the anonymity of data providers no information that could lead to the identification of the ship is given.

Furthermore, all routes (including those for containerships) are assumed laden on one leg and on ballast on the other. Although obviously for some categories of vessels (for instance, container vessels) this assumption is factually not valid, in the web tool it was made only for uniformity and comparison purposes. An extension of the web tool to cover cases of routes with multiple port stops and the ship being partially full in all legs or sailing triangular routes would be straightforward. Such extension would take as input the entire route sequence, the distance of each leg, the port time in each port stop and the ship's capacity utilization (from 0 to 100%) on each route leg.

Below is a sample output of one of the scenarios that were run and refers to a VLCC sailing from Ras Tanura to Rotterdam.

VESSEL DETAILS

SELECT SHIP TYPE	Crude Oil Carrier	SELECT SHIP SIZE	VLCC / Slow Speed Engine
ROUTE	Ras Tanura-Rotterdam	TRIP DISTANCE	11170 nm 20732 km
PAYLOAD (tonnes)	275000	DWT (tonnes)	300294

OPERATIONAL DETAILS

STATE	TIME (days)	SPEED (knots)	FUEL OIL S %	FUEL OIL Consumption (tonnes/day)	DIESEL OIL S %	DIESEL OIL Consumption (tonnes/day)
SEA LADEN	33.24	14	3.5	80	1.5	0
SEA BALLAST	33.24	14	3.5	80	1.5	0
PORT (loading,discharging)	4		3.5	72	1.5	0

EMISSIONS

	CO2	SO2	NOx
ROUNDTRIP EMISSIONS KG PER tonne TRANSPORTED	64.63	1.43	1.77
ROUNDTRIP EMISSIONS GRAMS PER LADEN tonne-MILE	5.79	0.13	0.16
ROUNDTRIP EMISSIONS GRAMS PER LADEN tonne-KM	3.12	0.07	0.09

DETAILED RESULTS

				EMISSIONS CO2	SO2	NOx
TOTAL BALLAST-LADEN DISTANCE		nm	22,340.00			
LADEN tonne-MILES		tonne*nm	3,071,750,000.00			
TIME IN PORT		days	4.00			
TRIP DURATION	SEA-LADEN	days	33.24			
TRIP DURATION	SEA-BALLAST	days	33.24			
TOTAL RTRIP DURATION		days	70.49	tonnes	tonnes	tonnes
CONSUMPTION FO	SEA LADEN	tonnes	2,659.52	8,430.69	186.17	231.38
CONSUMPTION DO		tonnes	0.00	0.00	0.00	0.00
CONSUMPTION FO	SEA BALLAST	tonnes	2,659.52	8,430.69	186.17	231.38
CONSUMPTION DO		tonnes	0.00	0.00	0.00	0.00
CONSUMPTION FO	PORT	tonnes	288.00	912.96	20.16	25.06
CONSUMPTION DO		tonnes	0.00	0.00	0.00	0.00
TOTAL FUEL CONSUMPTION	SEA	tonnes	5,319.05	16,861.38	372.33	462.76
TOTAL FUEL CONSUMPTION	PORT	tonnes	288.00	912.96	20.16	25.06
TOTAL FUEL CONSUMPTION	PER RTRIP	tonnes	5,607.05	17,774.34	392.49	487.81

Figure 2: Sample run of pre-specified scenario

4.2 Mode B – User Defined scenarios

In mode B, one can enter their own data and thus run their own scenario in 5 simple steps as follows:

1. First, select the "Enter your own data" option on the "Select Ship Type" drop-down menu to enter the mode.
2. Select the engine type (slow or medium speed).
3. Enter trip distance.
4. Enter payload of the laden leg.
5. Enter the operational details.

Then click on the "Calculate" button to get the results

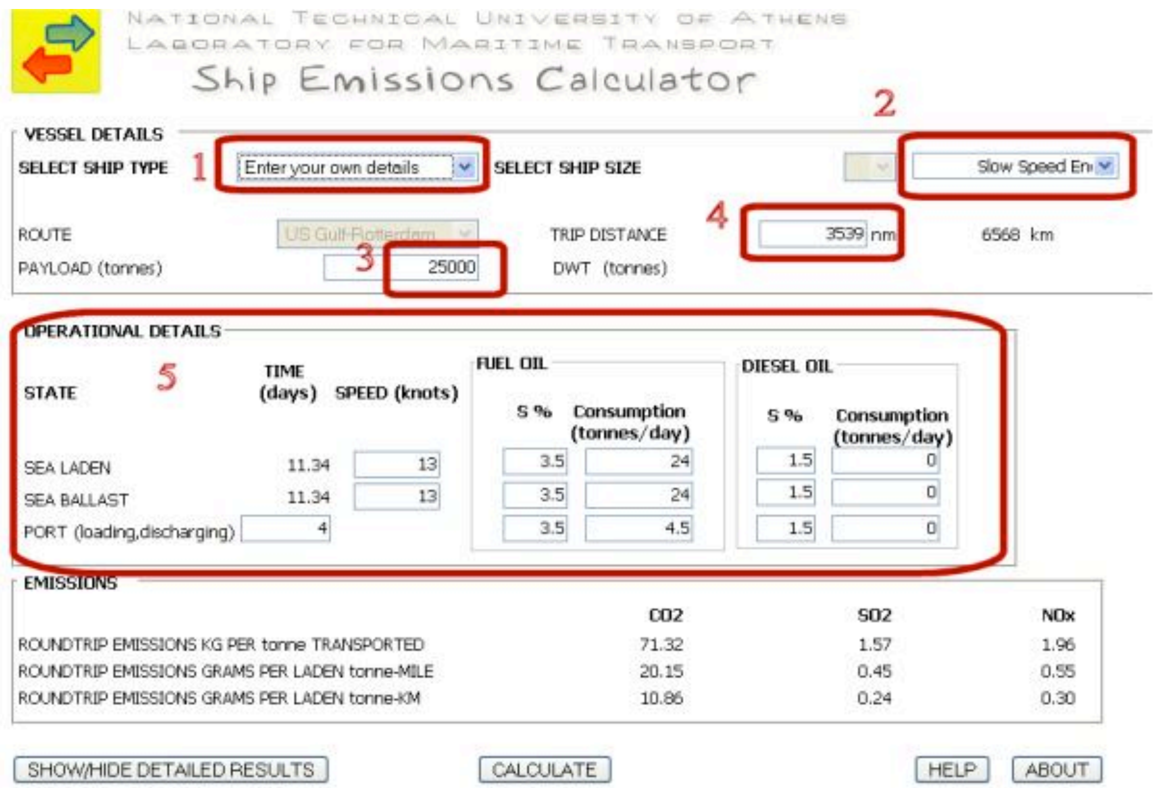

Figure 3: Sample run of user-defined scenario

The tool also includes a comprehensive 'help' section, with explanations on the methodology and detailed instructions on how to use it. In that sense, the tool does not function like a 'black box', but maximum transparency is provided to the user on how the results are reached.

5 USES OF THE WEBTOOL

Puclic awareness about climate change has been raised during the last years, but, in contrast, the understanding of the underlying science, for example the way to estimate personal carbon footprint, is limited. Obviously there are many individuals that would like to live in a more environmentally-friendly lifestyle but simply do not know how to do it. Nowadays, the internet is full of carbon calculators much of which are sponsored by governments and local authorities in order to help people calculate their footprint. People recognise that many transport modes have negative environmental effects and there is a strong belief that the results of a carbon calculation may act as an influential factor in people's journey planning. As briefly discussed in the introduction there is a lack of online calculators that include transport by sea. This paper is not intented to deal with the decision making of individuals, however, it should be mentioned that if carbon calculators did contain a comparison of travel modes that includes shipping, people could better understand the efficiency of shipping in comparison to the other modes. Thus, one use of our web tool is to raise the public awareness on this issue.

The main scope of this paper was to illustrate some uses of the web tool for shipping companies. Some shipping companies feel the pressure of the public's environmental awareness and try to improve their impact on the environment and the climate by introducing voluntary environmental strategies. Lately all of them had at least one strong reason to cut off emissions. This was the extremelly high fuel prices that had increased their fuel bills so much that in some voyages earnings were close to zero. So, regardless what the reason is, most companies are looking for ways to reduce emissions. The easiest measures to be implemented are the operational ones. These measures can be easily investigated using the webtool.

Thus, imagine a shipping company that wants to investigate the emissions reduction potential of a speed reduction. Speed reduction has attract much practical attention from shipping companies and has been recently investigated by the authors (see Psaraftis and Kontovas (2009c).

Using the webtool a company may enter the operational profile of the ship and estimate total emissions. With just one click the user can modify parameters such as the distance of the route, the ship speed and the fuel type and calculate the corresponding bunker consumption and exhaust gas emissions.

Last but not least, at a more macro level, the webtool can be expanded to calculate the Environmental Efficiency Design Index (EEDI) and the Environmental Efficiency Operational Indicator (EEOI), currently under discussion by the IMO (MEPC).

6 CONCLUSIONS AND REMARKS

We have presented a web tool that is publicly available and can be used to calculate emissions from shipping. To our knowledge, no other such tool has been developed. Interest for the tool since it was launched has been keen.

There have been, at least to our knowledge, two articles that referred to the tool, one in the Lloyd's List printed edition of June 23rd, 2008 under the title "Ship emissions formula helps policy makers" (Lloyd's List, 2008), and another in the TradeWinds magazine (TradeWinds, 2008) under the title "Online emissions tool set up". These articles were reproduced by many sites online. The web tool was also included in a list of 'Information Resources on Climate Change and the Maritime Industry', which is a resources document by the Maritime Knowledge Center of the International Maritime Organization. (IMO,2009)

Furthermore, according to web traffic statistics (from its launch, June,18th, 2008 until the end of January, 2009) the web tool has been used 2,472 times by users from 49 countries (218 cities) all over the world.

Possible extensions of the tool can be carried out in the future. These include the explicit computing of an appropriately defined emissions index (per the discussion at the IMO) and other indicators (KPIs) such as those discussed , extending the tool to cover not just the sea leg but the entire intermodal chain, and embedding optimization algorithms to optimize that chain according to some criteria that also take into account emissions.

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ANDRIAKI SHIPPING CO LTD
AEOLOS MANAGEMENT SA
ATLANTIC BULK CARRIER MANAGEMENT LTD
ALPHA TANKER
BLUE STAR FERRIES
ANANGEL SHIP. ENTERPRISES SA
CARRAS HELLAS SA
CELEBRITY CRUISES
CENTROFIN MANAGEMENT INC
CHANDRIS HELLAS INC
COSTAMARE
DANAOS SHIPPING CO LTD
EASTERN MEDITERRANEAN MARITIME
EASY CRUISE
ELETSON CORP.
EUROPEAN PRODUCT CARRIERS
FAFALIOS SHIPPING
HALKIDON SHIPPING COPR
HELLENIC SEAWAYS
KRISTEN NAVIGATION
MINERVA MARINE INC
NEDA MARITIME
NEPTUNE LINES
NEREUS SHIPPING SA
SKYROS SHIPPING
SPRINGFIELD SHIPPING CO
SUPERFAST FERRIES
TSAGARIS PROS
TSAKOS HELLAS
VASSILIOS SHIPPING CO

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