

Climate changes and maritime transportation: a state of the art

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Abstract. In the next years, the worldwide fleet will be called to adopt drastic measures to reduce their emissions of pollutants. In order to comply with the Paris Agreement and keep the average increase in the earth's temperature below 2°C, anthropogenic emissions will have to drop significantly from 2020 onwards. Maritime transportation plays an important role in these policies. At the end of 2018, the *United Nations Framework Convention on Climate Change* (UNFCCC) expects the IMO to communicate its intentions regarding the Paris Agreement. During the last session of MEPC71 guidelines have been set for the purpose. While waiting for regulatory updates in the maritime world, the study aims at interpreting the present position of IMO on the subject within the framework set by the IPCC's last Assessment Report, AR5. The Third IMO study on GHG (3⁰ IMO-GHG's) is analyzed in details, covering the inventory for the period 2007 to 2012 of GHG and of non-GHG emissions in the world's fleet and the forecast scenario for years 2012 to 2050. A last part of the work will concern the effects of these pollutants, with reference to the impact on human health and on environment.

Keywords. Climate change, maritime sector, Green House Gases, CO₂ and CO_{2eq} emissions

1. Introduction

Human activities play a fundamental role in climate changes. The production of carbon dioxide by anthropogenic activities is one of the main factors influencing climate variations on the Earth. The so-called greenhouse effect is the natural phenomenon by which a layer of *greenhouse gases* (GHG) placed in the upper atmosphere of the Earth prevents a part of the heat of the earth from being radiated into space. The heat balance between the incoming solar radiation (which is not affected by the GHG layer) and the outgoing radiation has been altered by the introduction into the atmosphere of pollutants related to human activities. Agriculture, industry, energy production and transportation are just some activities intrinsically determining pollution, contamination and alteration of the natural habitat and influencing the energy balance of the climate system. Economic development and population growth imply important increases in anthropogenic greenhouse gas emission. The concentration of carbon dioxide, methane and nitrous oxide in the atmosphere are at the highest level in the last 800.000 years, although man is among the most recent causes of these climatic changes [1]. The continuous emission of GHG will only increase the several and negative effects, with changes that could be irreversible in the long term for people and for the terrestrial ecosystem. As Anderson et al. [2] report, the global emission of CO₂ in 2011, year of economic crisis for many industrialized nations, has increased by 3.2% compared to 2010. In the context of climate

changes, Greenhouse gases are those emissions that contribute together, although in a different way, to climate change. The following updated list of the main GHG gases has been published in an amendment to the Kyoto Protocol [3]: Carbon dioxide (CO₂), Methane (CH₄), Nitrous oxide (N₂O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur Hexafluoride (SF₆) and Nitrogen Trifluoride (NF₃), carbon dioxide being certainly the main contributor among these. The so-called CO_{2eq} is used to weight the impact of all these seven gases on global warming, this quantity converting the emissions in terms of various other gases into an amount of carbon dioxide producing an equivalent GH effect in the time unit. Other non-GHG emissions are relevant from the viewpoint of environmental impact, especially in the transport sector, in addition to the GHG: oxides of Nitrogen and Sulphur, Particulate Matter (PM) and Volatile Organic Compound (VOC), produce a different effect at a local level on the air quality and a negative impact on human health. Almost 70% of ship emissions, in fact, are generated within 400 km of coastlines, leading to reduced air quality in coastal areas and harbors [4].

2. The Paris agreement

The Paris Climate conference, COP21, gave a strong impulse to global policies aimed at reducing GHG emissions into the atmosphere. Result of this was the first universal and legally binding agreement of the world on the subject, known as “Paris Agreement”. The ratification began on 22 April 2016 and the same will enter into force from 2020, only after at least 55 countries, responsible for more than 55% of global emission, will have signed it. The agreement includes [5]:

- Long-term objectives aimed at maintaining the average increase in global temperature below 2°C compared to pre-industrial level
- Strategic plans: aimed at maintaining these values preferably close to 1.5°C
- Attention to developing countries: more benefits for this countries and a general willingness to reach the maximum values of global emission as soon as possible
- Research and innovation: in order to continue with rapid successive reductions, after reaching this maximum value, using the most advanced scientific and technological solutions
- Cooperation: obligation for richer countries to subsidize poor ones with a “green climate fund” of \$100 billion a year, starting in 2020, to help them reduce emission
- Monitoring five-year checks starting from 2023.

3. Climate changes: transport sector and actions by IMO

The effects of the Paris agreement will influence all sectors of human activity, in particular that of transports. Indeed, this sector, will not be exempt in the next few years by the need to develop policies aimed to contain emissions in the next years [6]. Given the latest [1] *Intergovernmental Panel on Climate Change* (IPCC) report- AR5- in 2010 about 23% of CO₂ emission is due to transports; the estimated quantities are as large as 6.7 Gt of CO₂ and 7.0 Gt of CO_{2eq}. This percentage is stable compared to the data of 2004 when, however, the emissions related to transports were of 6.3 Gt CO₂. It is

therefore evident, simply by comparing this two data, that the policies adopted on a global scale and the improvement of vehicle efficiency did not achieve great results.

The perception of the severity of these increases is amplified by comparing the quantities of 1970 with these of 2010: direct emission related to transport increased by 250%, going from 2.8 to 7.0 Gt CO_{2eq}. In fact, the General Secretariat of the United Nations expects by both the *International Maritime Organization* (IMO) and the *International Civil Aviation Organization* (ICAO) incisive, pragmatic and urgent actions. With particular focus on maritime sector, on the upcoming IMO decisions in this respect, are in the spotlight. That is clearly reflected in the “Negotiating text” for the Paris agreement, (UNFCCC, Geneva Climate Change Conference, February 2015) which states [7]:

“In meeting the 2°C objective, Parties agree on the need for global sectorial emission reduction targets for international aviation and maritime transport and on the need for all Parties to work through the International Civil FCCC/ADP/2015/1 19 Aviation Organization and the *International Maritime Organization* to develop global policy frameworks to achieve these targets”.

The *Commission for the Protection of the Marine Environment* (MEPC) continues to work on the MEPC70 roadmap developing medium and long-term strategies. The seventy-first session of the MEPC, held on 3 to 7 July 2017, was preceded by meetings of the working group ISWG-GHG (Intersession Meeting of the Working Group on reduction of the Green House Gases emission from ships). At the end of these meetings, the regulatory principles to be developed and a list of short/medium/long-term prevention measures to be applied were set. These strategies will need to be approved by MEPC72 in April 2018. The following are the recent IMO decisions in this respect [8] [9]:

- Amendment to Annex VI of MARPOL 73/78 at the MEPC66 (2014); the amendments make mandatory the *Energy Efficiency Design Index* (EEDI) for new ships and the *Ship Energy Efficiency Management Plan* (SEEMP) for all ships
- Amendment to Annex VI of MARPOL 73/78 at the MEPC66 (2014); the amendments were adopted to extend the application scope of the EEDI to other five types of ships (LNG, Ro-Ro passenger/cargo, cruise passenger having non-conventional propulsion and vehicle carriers) [10].
- The MPEC70 (2016) ended with the following results: was formally adopted a mandatory data collection system for fuel consumption of ships; was agreed that an initial but comprehensive IMO strategy on reduction of GHG emission from ships should be adopted in 2018. Fixed first of January 2020 as entry-into-force date of the 0.5% sulphur in marine fuel as allowed limit. Under global data collection scheme to ships of 5000 gross tonnage and above will be required to collect consumption data for each type of fuel use as well as data relevant to energy efficiency. The aggregated annual data will be reported to the flag state that subsequently transfer this data to an IMO ship fuel consumption database. IMO will be required to produce annual report where individual ship data will not be recognizable.

4. Fifth IPCC Assessment Report

Approximately 90% of the goods traded in the world are transported by sea and for many countries such as Brazil, Chile or Peru maritime transport is the main source of imports and exports. In latest years the economic growth of the countries of the far-east has favored the increase in the amount of maritime traffic. In the chapter on transport of the last IPCC report (AR5: [11]) base year is 2010.

As shown in Table 1, the maritime sector is responsible for the global emission of CO_{2eq} for relatively low percentages compared to the other transportation modes (72% of the same emission is caused by traffic road). Of the total contribution from shipping the share between domestic and international is also available in the dedicated documents. Domestic shipping has been defined by the IMO as “shipping between ports of the same country in opposed to international shipping” [12]. This is consistent with the 2006 IPCC Guidelines.

Table 1. Emissions of CO_{2eq} due to maritime transport (subdivided into domestic waterborne and international shipping) referred to 2011 according to the latest IPCC report (AR5).[11]

Type of transport	% referring to global	Gt CO _{2eq}
Domestic Waterborne	1.91	0.14
International Shipping	9.26	0.64

The values in the table, referred to year 2011 can be compared with those of 1990, indicating a decrease of 0.18% for “Domestic Waterborne” and an increase of 1.6% for the “International Navigation”. In the IPCC AR5 ranges of emission values for each category of ships are provided, see Table 2. For passenger’s traffic values are expressed in grams of CO₂ emitted per passenger per km, while for the freight’s traffic units are the grams of CO₂ emitted per tons of freight's per km. These ranges, when compared to air traffic (95 to 250 g CO₂/p-km for passengers’ traffic) are very low.

Table 2. Emission of CO₂ due to the maritime sector divided by type of ship referred to 2011 according to the latest IPCC report (AR5: [11]).

Ship category	Emission:
Passenger ferry	25-150 g CO ₂ /p-km
Barge	28-55 g CO ₂ /t-km
Roll-on-off ferry	30-85 g CO ₂ /t-km
Container ship	10-47 g CO ₂ /t-km
Bulk	1-13 g CO ₂ /t-km
Tanker	5-15 g CO ₂ /t-km

5. Third IMO GHG Study [9]

Another study providing quite an updated picture of the emissions from shipping was the 3^o IMO-GHG’s [12] containing data up to 2012. According to this report, in 2012, the maritime transport produced about 938 million tons of CO₂ (0.938 Gt CO₂) and 961 million tons of CO_{2eq} (0.961 Gt CO_{2eq}). If these quotas are compared with the global emissions of CO₂ and CO_{2eq}, they amount to 2.2% and 2.1% respectively. Figure 1 shows the emissions related to the maritime traffic for the period running from 2007 to 2012.

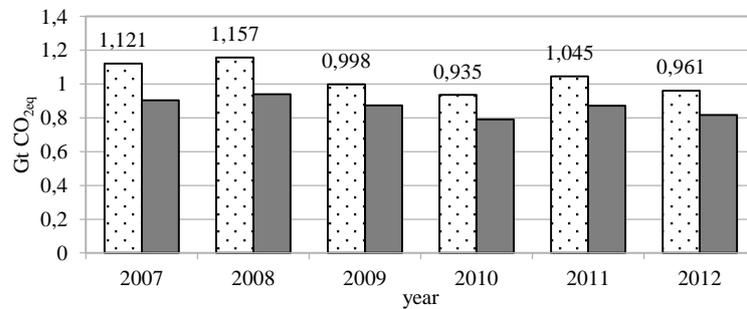


Figure 1. Emission of CO_{2eq} for total shipping (left) and international shipping (right) (3^o IMO-GHG's) [12]

Turning to the details of the various types of ships, the study provides a breakdown of the emissions referred to 2012 obtained through a “bottom-up” methodology. In Figure 2 the results are presented, appropriately converted to be compared with the results of the IPCC report.

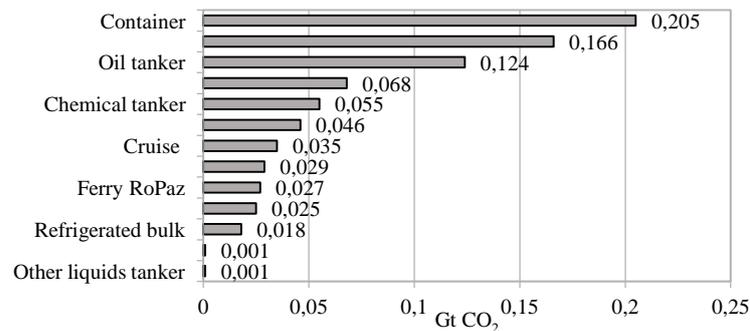


Figure 2. CO₂ emissions from international shipping (year 2012)-3^o IMO-GHG's [12].

By comparing the two reports, the emissions values indicated in the two reports are different because of the different procedures adopted for the estimation of the annual global emissions; however, an increase in annual emissions seems confirmed. In Table 3 and in Figure 4 the possible comparisons.

Table 3. Comparison between the IMO (3^o IMO-GHG's) [12] and IPCC (AR5) [11] inventory. The percentages refer to the comparison between the two IMO studies. [Gt CO_{2eq}]

Report	AR5 (2010)	IMO (2010)	IMO (2012)	Increase [%] IMO 2012 vs 2010
Total shipping	0.785	0.935	0.938	0.30
International shipping	0.648	0.790	0.796	0.8

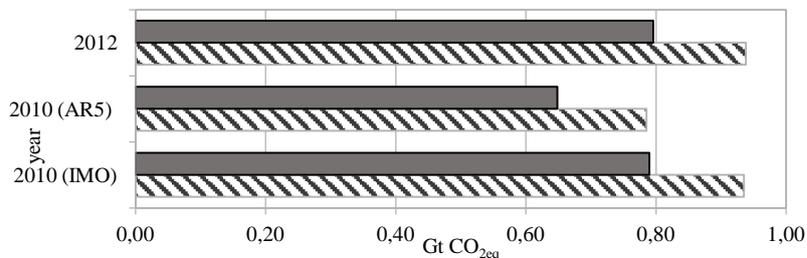


Figure 4. Emission linked to maritime transport (International: full bar; total shipping: dotted bar). (From 3^o IMO-GHG's [12] and IPCC 2014 inventory [11]).

The CO₂ is not the only GHG emitted by ships. In 2012, the emissions of CH₄ and N₂O were respectively: 9.8 and 12.71 ktons. These pollutants, together with CO₂, contribute to the total of GHG emissions [12].

Data updated to 2012 can be compared with a prediction of the annual emission of the maritime sector realized for 2015 through AIS data and the STEAM3 model [13].

According to this study, about 8.3 Gt CO₂ were produced in that year by ships, of which 7.5 from IMO-registered ships, with the most significant contributions coming from container ships, carriers and tankers. Following the same study, the four largest fleets (Panama, China, Liberia and Marshall Islands) were responsible for almost 50% of these emissions.

5.1. Future scenarios

Dealing with predictions about future emissions of GHG in the shipping field, development scenarios are to be hypothesized. In the second last IPCC report [14] quite worrying increases in emissions were expected: assuming a “*business as usual*” (BAU) economic growth and the absence of strong precautionary measures, from 2002 to 2030 a increase in emissions of about 80% was expected [1] [12]. This increase, according to the study, could occur, in the absence of precautionary measures, with an average increase of 2.1% per year (with peaks of 3.65% per year for developing countries). At the same time, the potential impact of possible countermeasures was estimated. These potential effects were roughly confirmed by the last available IPCC report. Below are the possible reduction scenarios:

- From 5% to 30% of emission reduction on new ships with the optimization of engines, transmissions, hull forms, the use of alternative fuels (LNG, biofuels), reduction of weight, use of renewable energy from the wind or the sun, and optimization of the speed of ships [15]
- 4% to 20% of improvement with retrofit actions capable of providing additional efficiency
- Peak emission reductions are reported to be possibly achieved for all types of ocean-going ships, for which a wider range of technological solutions would allow reductions up to 50%.

Data updated to 2010 report emissions ranging from 10 to 40 g CO₂/t-km; these values could potentially decrease by 43% in 2020 and by 63% in 2050.

The *United Nations Conference on Trade and Development* (UNCTAD) [16], on the other hand, stated in 2017 that there is a possibility of reducing emissions by up to 75% by implementing appropriate technical and operational measures in the maritime sector. Also the IMO hypothesized scenarios of development covering the period from 2012 to 2050. These IMO scenarios [12] are composed by the combination of two different paths:

- RCPs “Representative Concentration Pathways” for future demand of coal and oil in transport
- SSPs “Shared Socioeconomic Pathways” for future economic growth.

Both scenarios assume that the present policies on energy efficiency and emission of ships remain in force and that no restrictions or additional policies will be introduced (BAU scenarios). In addition, for each of the BAU scenarios, the IMO developed three policy scenarios having an increased action on either energy efficiency or emission or both. In total, projections of emissions are made for 16 scenarios. There are four main

RCPs in use: RCP 2.6/4.5/6.0/8.5; the number associated with the RCP refer to resultant, in W/m^2 , of radiative forcing by 2100. The envisaged scenarios foresee increases in the average global temperature ranging from 1.5 to 4.9 degrees. For SSPs there are five different possible scenarios ranging from sustainability to conventional development (1-5). The possible combinations are shown in the table 4; those considered by the IMO were RCP8.5-SSP5; RCP6-SSP1; RCP4.5-SSP3; RCP2.6-SSP4. In this paper, as example of all the possible scenarios projected, the extreme ones (3 [continuous line] and 13 [dashed lines]) are reported in Figure 5.

Table 4. Overview of assumptions per scenarios (From 3^o IMO-GHG's) [12].

Scenario	RCP scenario	SSP	Efficiency improvement 2050	Fuel mix (LNG, ECA)
1	RCP8.5	SSP5	High	High LNG –
2	RCP6.0	SSP1	High	extra ECA
3	RCP4.5	SSP3	High	-
4	RCP2.6	SSP4	High	-
5	RCP8.5	SSP5	Low	-
6	RCP6.0	SSP1	Low	-
7	RCP4.5	SSP3	Low	-
8	RCP2.6	SSP4	Low	-
9	RCP8.5	SSP5	High	Low LNG – no
10	RCP6.0	SSP1	High	ECA
11	RCP4.5	SSP3	High	-
12	RCP2.6	SSP4	High	-
13 (BAU)	RCP8.5	SSP5	Low	-
14 (BAU)	RCP6.0	SSP1	Low	-
15 (BAU)	RCP4.5	SSP3	Low	-
16 (BAU)	RCP2.6	SSP4	Low	-

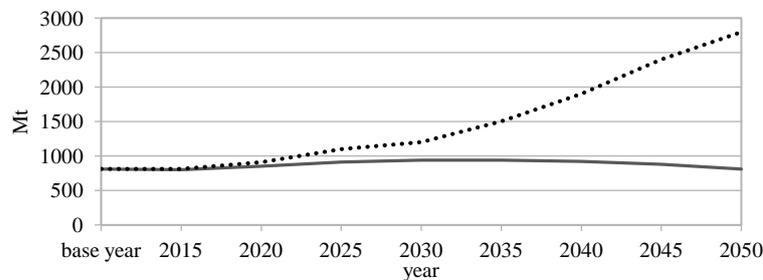


Figure 5. CO₂ emission (from 3^o IMO-GHG's) [12].

6. Overview of effects on humans and on the environment

Anthropogenic emissions produce local effects in terms of pollution of air, water, soil and consequently of the food chain, in the areas of the globe directly affected by the emissions. The major impact however is on a global scale, with climate changes of the Earth affecting millions of people. Global temperature rises, increase of ultraviolet radiation, extreme weather phenomena, melting of glaciers and rising levels of the sea are just some of the various effects of such changes on the ecosystems [17]. These changes imply a direct impact on humans and the other elements of the ecosystem: desertification of zones previously featuring a temperate climate will damage agriculture:

the difficulties in the supply of drinking water and food will lead to malnutrition and disease. The increase in temperatures favors the spread of diseases carried by vectors (insects, rodents) and invasive species; spatial distribution, seasonality, incidence and severity of communicable diseases could be strongly influenced by climatic variations. The World Health Organization (WHO) estimates that between 2030 and 2050 the deaths due to these effects will increase significantly (with an order of 250,000 deaths per year more). Latest statistics indicate that the number of natural disasters and catastrophic events has tripled in the world compared to 1960s, with an increased impact on the human society (as well as on other the life forms). The increase in the production of CO₂ will lead to an acidification of the oceans with damage to the marine ecosystems.

Because of all the examples cited above and many other types of negative implications, the increase of GHG content in the Earth's atmosphere does have a social cost, which the Human Kind is called to pay in the next and far future. In an attempt of establishing a balance between those areas of the Society that actually contribute to emissions, generally experiencing an advantage, and those areas who instead bear mainly the cost of consequences, the concept of cost for ton of CO₂ emitted was introduced. The underlying idea is internalization, i.e. making the economic accounting of the GHG active emitters reflect explicitly the damage caused to the environment, that otherwise will be bore by entities external to their interest. The implication of the concept is also quite evidently to provide this way economical means for the Society for trying to re-establish the balance disrupted.

Many institutions and groups around the world have provided a monetary evaluation of the cost of a ton of CO₂ or CO_{2eq} emitted: f.i. the *US Environmental Protection Agency* (EPA) in 2015, proposed a cost of \$37 per ton of CO₂ [18][18]. Another research, carried out by the University of Stanford, estimates that this cost may reach as much as \$220 [19]. According to the IPCC AR-5, impact estimates are in general incomplete and depend on a large number of assumptions, many of which are disputable. Many estimates, indeed, do not account for the possibility of large-scale singular events and irreversibility, especially those that are difficult to monetize, such as loss of biodiversity [20]. Independently from the debate about numbers, which are definitely beyond the scope of the present paragraph, the range of figures indicates that a huge amount of resources will be employed in the future to control the climate changes due to human pollution on Earth.

7. Conclusions

Anthropogenic activities generated an increase in the amount of greenhouse gases present in the atmosphere thus causing, among other effects, an increase in the average temperature of the globe. The whole world is called to take actions to protect the ecosystem of our planet by reducing GHG emissions. The shipping world, like all sectors, must play a role, despite the fact that the weight of marine traffic on the global emissions is comparatively low (less than 3%) and that marine transportation is a comparatively efficient way for transporting large amounts of goods. The main trend for the reduction of emissions is represented by an increase in the efficiency of the transportation process and in the use of cleaner fuels.

Investments, mitigation projects and appropriate environmental policies therefore seem increasingly urgent, in view of controlling the GHG emission process (that at the moment seems out of control).

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