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THE IMPACTS OF CO2 EMISSIONS FROM MARITIME TRANSPORT ON THE ENVIRONMENT AND CLIMATE CHANGE

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ABSTRACT

In the last decade, international climate policy has developed strongly and is nowadays one of the most important elements of national and international environmental policies. Maritime shipping is integral to the global economy. Over 80 per cent of traded goods travel by ship. Transport accounts for 24% of global CO_2 emissions and is one of the few industrial sectors where emissions are still growing. The present article looks at the relevant trends in international maritime transport and discusses both the greenhouse gas emissions from shipping and the possible repercussions of climate change on shipping.

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1. INTRODUCTION

Transport is the only sector where greenhouse gas (GHG) emissions have *increased* (+14%) between 1990 and 2012 in the EU-28, notably for road transport (+17%) and international aviation (+93%) [1]. Climate projections predict an increase in future climate variability. To ensure economically, socially and environmentally responsible transportation planning, it is necessary to consider future weather variations driven by climate change [2]. Urban areas are responsible for up to 70% of the production of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions causing global warming [3]. Ships emit both to air and sea, and the main source of these emissions is the exhaust gas from fuel combustion in the ships engines [4] the climate change and global warming, considerable attention has been given in recent years to improving the shipping efficiency in order to reduce the total greenhouse gas (GHG) (e.g. CO_2) emission [5]. Emissions from maritime transport account for 10–15% of global anthropogenic sulphur (SOx) and nitrogen oxide (NOx) emissions, and about 3% of global carbon dioxide (CO_2) emissions [6].

Current regulations provide emission limits for CO_2 for its climate change effects and for NO_x and SO_x for their health and environmental effects [7]. In addition, several studies have indicated that there is a higher probability of heat waves and air pollution episodes in the future due to increased stagnation [8].

Transport is an important contributor to overall GHG emissions and the second largest sector after electricity production. In 2009 transport represented approximately 24% of the CO2 emissions from fossil fuel combustion [9]. CO2 accounts for 93%-95% of the total GHG emissions from transport operations, the remaining 5%-7% consist of other gases such as nitrogen oxides (NOX), and different sulphur compounds [10]. Emissions from transport have grown globally by 45% from 1990 to 2007, and in contrast to other sectors the emissions are still growing. Within EU, emissions of CO2 from freight transport grew by 24% between 1990 and 2001 [11]. Globally, the yearly growth rate of transport emissions between 1990 and 2000 was 2,11%, but the rate is increasing and from 2000-2006 it was 2,26% annually. This is mainly driven by developing countries, many in Asia, since the annual growth rate in the western world has actually fallen in the last years [12]. With a business as usual approach, the global emissions are projected to grow by 38% from 2006 to 2030 [13]. The challenge is to reduce the dependence on oil without sacrificing the efficiency and mobility of the transport sector [14]. Transportation activity normally increases with economic development and increasing gross domestic product (GDP). This has been seen earlier in the western economics and is now seen in emerging markets, of which many in Asia. A growing transportation activity leads to increased emissions from transport, hence to reach a sustainable future, the increase must slow down and ultimately be reversed [15].

Two sectors produced two-thirds of global CO2 emissions from fuel combustion in 2015: electricity and heat generation, by far the largest, which accounted for 42%, and transport, accounting for 24% (Figure 1).

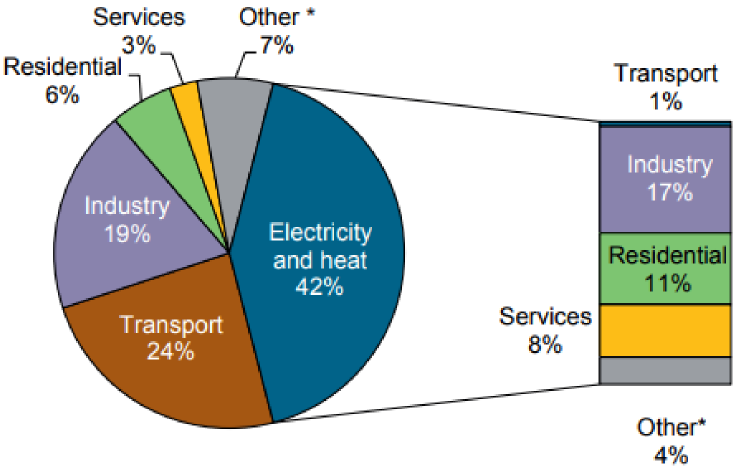

Figure 1. World CO2 emissions from fuel combustion by sector, 2015 [16]

Emissions from ships exhausts into the atmosphere can potentially be harmful to human health and cause acid rain and may also contribute to global warming.

To ensure that shipping is cleaner and greener, IMO is engaging in a two-pronged approach towards addressing GHG emissions from international shipping: through regulatory work, supported by capacity-building initiatives.

Firstly, IMO has adopted regulations to address the emission of air pollutants from ships and has adopted mandatory energy-efficiency measures to reduce emissions of greenhouse gases from international shipping, under Annex VI of IMO's pollution prevention treaty (MARPOL).

And secondly, IMO is engaging in global capacity-building projects to support the implementation of those regulations and encourage innovation and technology transfer.

The IMO has utilised these competences to regulate this GHG emissions issue within its Marine Environment Protection Committee (MEPC). The most significant achievement is the adopted technical and operational measures in the form of amendments to Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) in 2011 and 2014 [17]. To date three categories of measures have been discussed within the IMO to tackle GHG emissions from ships: technical measures, operational measures and market-based measures (MBMs) [21].

At the 62nd MEPC meeting in 2011, the IMO adopted amendments to Annex VI to MARPOL 73/78 which is regarded as the first global and legally binding regulation on the reduction of GHG emissions from ships [18]. By adding a new Chapter 4 to Annex VI on the regulation of energy efficiency for ships, the amendments make mandatory the energy efficiency design index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships.

The EEDI estimates ship CO2 emissions per ton-mile of goods transported relative to a reference average of similar ships. The full equation (detailed in MEPC.1/Circ.681) includes several adjustment and tailoring factors to suit specific classes of vessels and alternate configurations and operating conditions

Based on methodologies detailed in appendix A, and using IMO ranges for projected fleet growth, the ICCT estimates that if the EEDI is implemented according to the original schedule, with compliant ships deployed starting in 2015, the regulation would save 15–45 million metric tons (mmt) of CO2 annually by 2020 and between 141 and 263 mmt of CO2 annually by 2030. If implementation is delayed by 4 years for all ships, the potential CO2 reductions drop to between 2 and 6 mmt for 2020 and 80 and 143 mmt for 2030. ICCT estimates for both the on-time and deferred case, based on the IMO mid-range growth estimate (Scenario A2), are illustrated in Figure 2, along with estimates of corresponding fuel cost savings.

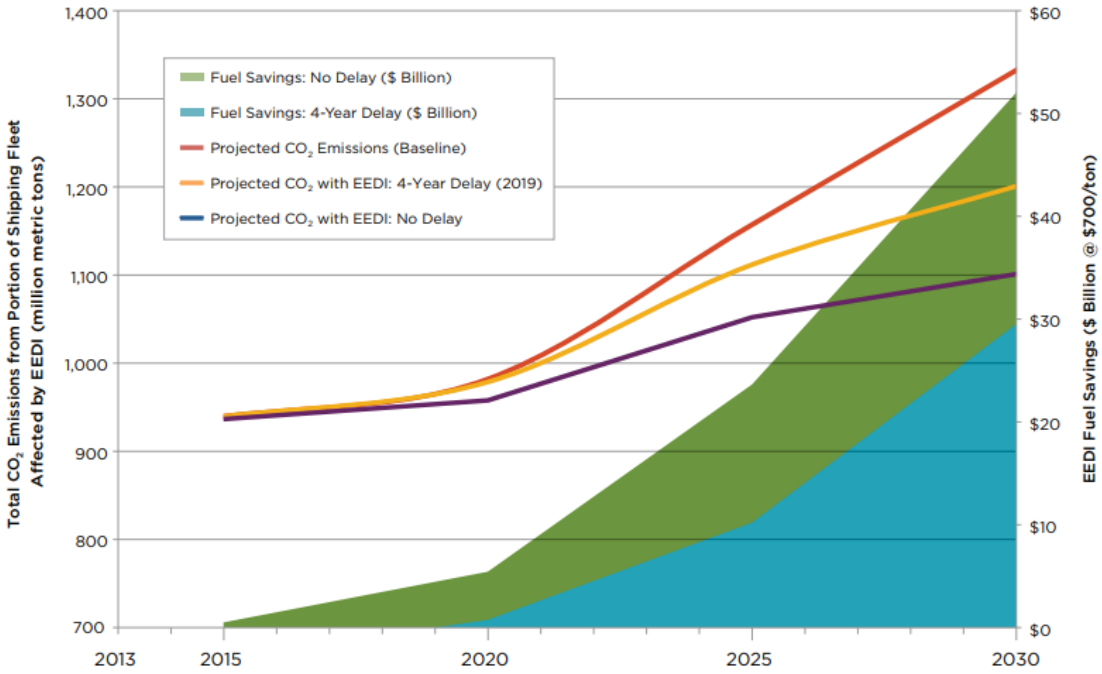

Figure 2. Projected CO2 emissions and cost savings through 2030 from the shipping fleet affected by EEDI Regulation. IMO Scenario A2, with and without proposed 4-year delay [19]

In 2013, the EU set out a strategy for progressively integrating maritime emissions into the EU's policy for reducing its domestic greenhouse gas emissions.

The strategy consists of 3 consecutive steps:

- Monitoring, reporting and verification of CO2 emissions from large ships using EU ports
- Greenhouse gas reduction targets for the maritime transport sector
- Further measures, including market-based measures, in the medium to long term.

2. IMPACT OF MARITIME TRANSPORT ON CLIMATE CHANGE

Maritime transport emits around 1000 million tonnes of CO_2 annually and is responsible for about 2.5% of global greenhouse gas emissions [20]. Shipping emissions are predicted to increase between 50% and 250% by 2050 – depending on future economic and energy developments. Emissions from maritime transport account for 3% of global greenhouse gas emissions today – equivalent to more than the total annual emissions of Germany – and this share is expected to rise to 5% by 2050. This is not compatible with the internationally agreed goal of keeping global warming below 2°C, which requires worldwide emissions to be at least halved from 1990 levels by 2050 Fig.3.

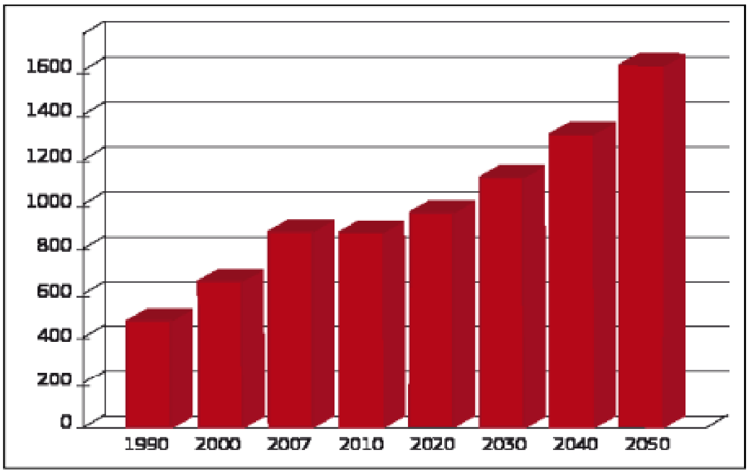

Figure 3. Rapid growth in CO2 emissions from international shipping[21]

The International Convention for the Prevention of Pollution from Ships (MARPOL) Treaty was agreed in 1973 to halt marine oil pollution from oil tankers. Since the 1950s, attempts had been made to restrict oil emissions into the marine environment by means of the International Convention for the Prevention of Pollution of the Sea by Oil (OILPOL) [22]. The Intergovernmental Panel on Climate Change (IPCC) National Greenhouse Gas Inventories Programme, at the invitation of the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the United Nations Framework Convention on Climate Change (UNFCCC), provides guidelines to assist countries to compile national inventories of greenhouse gases [23]. The 1997 Air Pollution Conference was a historical response by the IMO to address air emissions from ships and their contribution to air pollution and other environmental problems. Especially the control of emissions of nitrogen oxides (NOx) and sulphur oxides (SOx) were subject to extensive discussion at the IMO prior to and during the Air Pollution Conference [24]. In 2008, the IMO directed the first revision of the International Convention for the Prevention of Pollution from Ships (MARPOL Annex VI) which resulted in substantial measures for a gradual worldwide reduction in SOx and NOx.

A sustainable port is one in which the port authority together with port users, proactively and responsibly develops and operates, based on an economic green growth strategy, on the working with nature philosophy and on stakeholder articipation, starting from a long term vision on the area in which it is located and from its privileged position within the logistic chain, thus assuring development that anticipates on the needs of future generations, for their own benefit and the prosperity of the region that it serves [25]. Among various motivations for green activities, the rise of environmental awareness can be critical to the development of a firm's green strategies [26]. Table 1 presents the full time series of shipping CO2 emissions compared with global total CO2 emissions. All data are calculated using the bottom-up method and the results of this study are compared with the Second IMO GHG Study 2009 results in Figure 4 (all shipping).

Container ships accounted for the largest share (23%) of CO2 emissions from 2013–2015, as shown in Figure 5. Container ships, bulk carriers, and oil tankers together accounted for over half (55%) of the nearly 1 billion tonnes of CO2 emitted in 2013, 2014, and 2015. These three ship classes also accounted for 84% of total shipping transport supply, which contributes to their overall CO2 emissions compared to other ship classes. A full table of CO2 emissions and transport supply by ship class can be found in the supplemental information.

Solution	Relative CO_2 savings	Savings/Costs per tonne CO_2	Take-up 2007	Take-up 2011
Speed reduction	17-34%	- 280 €/t	0%	50%
Propeller & rudder upgrade	3-4%	- 150 €/t	0%	0%
Hull coating	2-5%	- 280 €/t	0%	50%
Waste heat recovery	2-6%	+ 60 €/t	0%	0%
Optimisation of trim & ballast	1-3%	- 200 €/t	0%	50%
Propeller polishing	1-3%	- 280 €/t	75%	75%
Hull cleaning	1-5%	- 200 €/t	75%	75%
Main engine tuning	1-3%	- 250 €/t	75%	75%
Autopilot upgrade	1-1.5%	- 280 €/t	75%	75%
Weather routing	1-4%	- 280 €/t	75%	75%

Figure 4. The relationship between energy demand, energy consumption, carbon emissions and climate change [21]

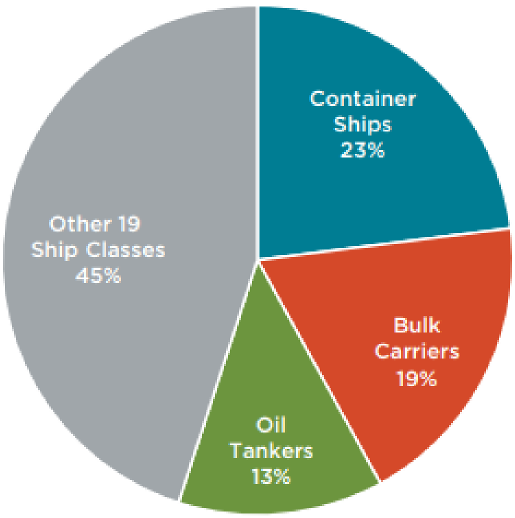

Figure 5. Average percent share of CO2 emissions by ship class, 2013–2015 [27]

As shown in Figure 6, out of the 223 flag states, most CO2 emissions can be attributed to ships flying seven flags: Panama (15%), China (11%), Liberia (9%), Marshall Islands (7%), Singapore (6%), and Malta (5%). These flags also have large numbers of ships registered to them and account for 66% of the global shipping fleet's dwt. Larger ships and the sheer number of vessels registered to these flags contributes to their overall CO_2 emissions relative to other flag states.

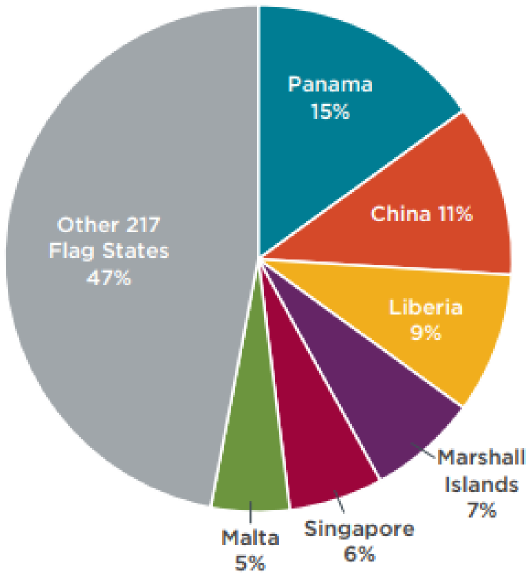

Figure 6. Average share of CO_2 emissions by flag state, 2013–2015 [27]

Ships emitted 932 million tonnes of CO_2 in 2015. Figure 7 shows the distribution of CO_2 emissions from total shipping (international + domestic + fishing) for 2015. Major shipping routes are clearly visible [27].

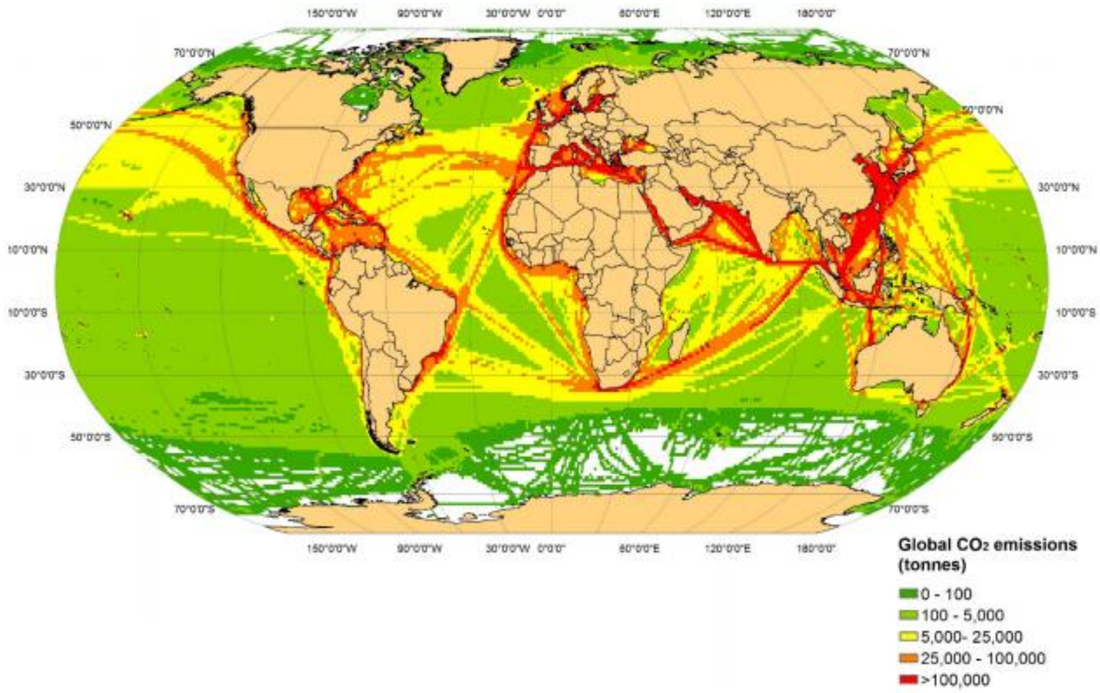

Figure 7. Global distribution of shipping CO_2 emissions, 1°x 1°, 2015

Total shipping CO_2 emissions increased from 910 million tonnes to 932 million tonnes (+2.4%) from 2013 to 2015 (Table 1). In 2015, global shipping accounted for approximately 2.6% of global CO_2 emissions, with the majority (87%) of shipping CO_2 emissions attributable to international shipping activity. Domestic shipping accounted for ~9% of total shipping CO_2 emissions and fishing accounted for ~4% in 2015. Although still below the 2008 peak, international shipping emissions may be rebounding from the 2010 minimum as the global economy recovers from the 2008 recession.

Figure 8 shows that IEA top-down estimates are consistently lower than bottom-up estimates of shipping fuel consumption. In general, the gap between IEA's top-down data and bottom-up estimates from IMO and ICCT is closing. For global (international, domestic, and fishing) shipping, the Third IMO GHG Study 2014 reported 12%–43% higher fuel consumption, and we report 12%–15% higher fuel consumption than IEA for 2013 to 2015.

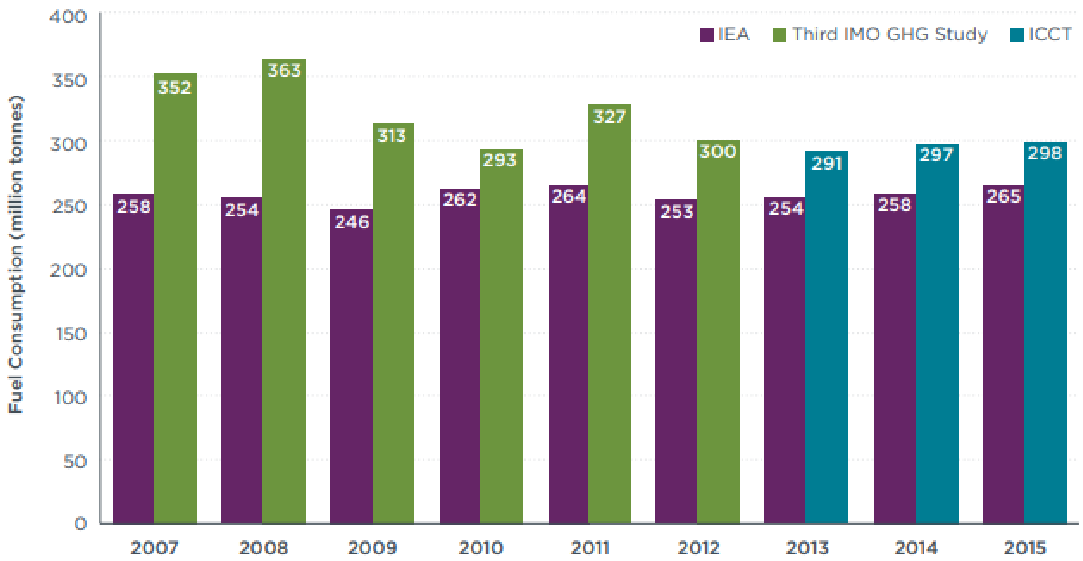

Figure 8. Fuel consumption estimates from IEA, IMO, and ICCT, 2007–2015 [28-29]

The gap for international shipping, partly imputable to a different methodological approach, is closing somewhat slower, from an average of 32% (20%–44%) in the Third IMO GHG Study down to 28% (24%–31%) in this work. It is likely that improving AIS data coverage over time has reduced the uncertainty in bottom-up estimates, in particular for domestic and fishing vessels, as seen by the smaller annual variability in emissions from these ships (see Table 1 below). Separately, IEA is working to improve the fuel sales data collected from its members for top-down analysis to avoid potential underreporting.

Table 1. Shipping CO2 emissions compared to global CO2 emissions, 2007–2015 [27]

Source	3rd IMO GHG Study (million tonnes)						ICCT (million tonnes)		
	2007	2008	2009	2010	2011	2012	2013	2014	2015
Global CO_2 emissions*	**31,959**	**32,133**	**31,822**	**33,661**	**34,726**	**34,968**	**35,672**	**36,084**	**36,062**
International shipping	881	916	858	773	853	805	801	813	812
Domestic shipping	133	139	75	83	110	87	73	78	78
Fishing	86	80	44	58	58	51	36	39	42
Total shipping	**1,100**	**1,135**	**977**	**914**	**1,021**	**942**	**910**	**930**	**932**
% of global	3.5%	3.5%	3.1%	2.7%	2.9%	2.6%	2.5%	2.6%	2.6%

CO2 emissions and climate change likely represents a loop, as presented in Fig. 9. If this is the case, this relationship implies that climate change may be self-reinforced by influencing energy demand, energy consumption and CO2 emissions, and accordingly, the process of global warming may be faster than is commonly expected [30]. However, the take-up of available cost-efficient technologies and operational solutions remains lower than expected due to a number of market barriers.

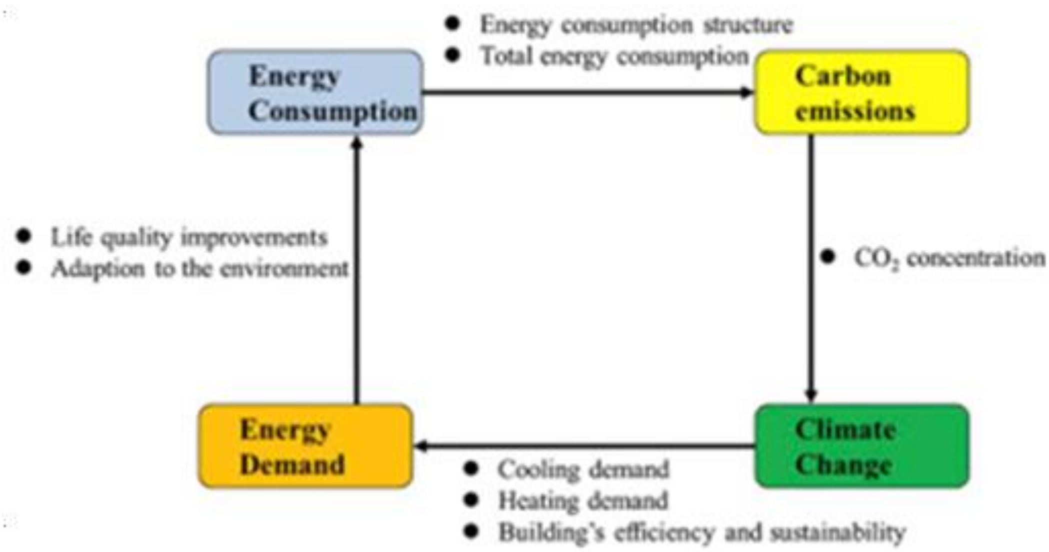

Figure 9. The 10 most effective CO2 emissions [21]

3. THE GLOBAL MARITIME ENERGY EFFICIENCY PARTNERSHIP (GloMEEP)

The aim of the Global Maritime Energy Efficiency Partnership (GloMEEP) Project is to contribute to a significant reduction of GHG emissions from international shipping via enabling 10 Lead Pilot Countries (LPCs) to take a lead in the respective developing regions to pursue relevant Legal, Policy and Institutional Reforms (LPIR), capacity building and enhance private-public partnerships for innovation and technology deployment.

While the long-term goal is the reduction of GHG emissions and mitigation of their impact on the oceans, the project is achieving its goals through the development of global guidance and methodology documents and templates, their national implementation, capacity building as well as information exchange platforms, and piloting these interventions with the assistance and involvement of the 10 selected LPCs.

The project contains a stream of work that aims to bring together like-minded maritime private industry champions and leverage the human, technological and financial resources of the industry to support an energy efficient and low carbon maritime transport system.

GloMEEP supports ten Lead Pilot Countries of the project to implement these measures, through:

1. Legal, policy and institutional reforms
2. Awareness raising and capacity-building activities
3. Establishment of public-private partnerships to encourage technology transfer

The Lead Pilot Countries (LPCs) of the GloMEEP project are:
Argentina, China, Georgia, India, Jamaica, Malaysia, Morocco, Panama, Philippines and South Africa.
The European Commission, the European Sea Ports Organisation (ESPO) promotes environmental management, policies and plans in European ports. In order to promote the ESPO Green Guide, in 1999 this institution established the EcoPorts Foundation, a network of European ports to identify the significant environmental aspects of port activities, products and services. Similarly, in the Americas, the American Association of Port Authorities (AAPA), with 150 members in North, Central and South America, has developed a guide for environmental management, the Environmental Management Handbook (EMH).

Green technologies offering support for more environmentally port and terminal operations are increasingly accessible and economically viable. Electric vehicles, gas-fuelled cranes, highly efficient LED lightings.

The MARPOL Convention was adopted on 2 November 1973 at IMO. The Protocol of 1978 was adopted in response to a spate of tanker accidents in 1976- 1977. As the 1973 MARPOL Convention had not yet entered into force, the 1978 MARPOL Protocol absorbed the parent Convention. The combined instrument entered into force on 2 October 1983. In 1997, a Protocol was adopted to amend the Convention and a new was added which entered into force on 19 May 2005. MARPOL has been updated by amendments through the years. It is reasonable to remind us all on the annexes which have been included in the MARPOL Consolidated Edition 2011, as follows [31]:

• **Annexes I and II** address, respectively, vessel-source oil pollution and pollution from the bulk carriage by sea of noxious liquid substances.

• **Annex III** is concerned with marine pollutants carried in packaged form and much work has been done to ensure consistency in the classification of marine pollutants through a harmonized approach with IMO's International Maritime Goods Code and also taking account of new scientific knowledge.

• **Annex IV** addresses sewage discharges into the sea. The latest amendments to this Annex has been set to enter into force on 1 January of 2013 and designate the Baltic Sea as the first Special Area to benefit from a general prohibition of sewage discharges, with strictly controlled exemptions for passenger and cruise ships.

• **Annex V** regulates the disposal of ship-generated garbage and has been completely revised. The amendments has been set to enter into force also on 1 January 2013 and introduce a general prohibition of the discharge of all garbage – under the currently applicable Annex the discharge of plastics has been subject to a total, globally applicable ban. The revised Annex does however permit exceptional discharges for food waste, cargo residues, animal carcasses and cleaning agents or additives, yet these will be subject to additional requirements being fulfilled and the discarded items not being harmful to the marine environment.

• **Annex VI** addresses global climate change concerns by prohibiting ships' emissions of ozone-depleting substances. Having been adopted by an IMO diplomatic conference in 1997, Annex VI did not enter into force until 2005. Further reductions of air pollutants were subsequently introduced in 2008 amendments and in 2011 a formidable milestone was reached with the adoption of new amendments pertaining to ships' energy efficiencies aimed at limiting and reducing greenhouse gas emissions through technical and operational measures. These concern the Energy Efficiency Design Index (EEDI), for mandatory application to newbuildings, and the Ship Energy Efficiency Management Plan (SEEMP), which is mandatory for both new and existing ships.

4. EEDI (ENERGY EFFICIENCY DESIGN INDEX)

Chapter 4 of MARPOL Annex VI introduces two mandatory mechanisms as energy efficiency standard for ships; with the main objective of reducing international shipping's GHG emissions via improved ship design and operations. The EEDI is an estimated measure of transport efficiency of a ship, which currently under the design stage. As such, it is important index for designers and builders of ships.
Goal of EEDI :

- Mitigate CO_2 emissions
- Increase cargo carrying capacity
- Enhance speed performance

The EEDI is an index that indicates the energy efficiency of a ship in terms of gCO2 (generated) / tonne.mile (cargo carried); calculated for a specific reference ship operational condition. The intention is that by imposing limits on this index, IMO will be able to drive ship technologies to more energy efficient ones over time. EEDI is thus a goal-based technical standard that is applicable to new ships. Ship designers and builders are free to choose the technologies to satisfy the EEDI requirements in a specific ship design. Overtime, the EEDI level will reduce; this gradually leading to more energy efficient ships [32].

As indicated, some ship types (e.g. fishing vessels) are not yet part of the EEDI regulations. Specifically, the following list provides the ship types that are currently required to comply with attained EEDI regulation.

- Bulk carrier
- Gas carrier (none LNG carriers)
- Tanker
- Container ship
- General cargo ship
- Refrigerated cargo ship
- Combination carrier
- Ro-Ro cargo ships (vehicle carrier)
- Ro-Ro cargo ships
- Ro-Ro Passenger ship
- LNG carrier
- Cruise passenger ships (having non-conventional propulsion)

Also, specific ship types such as those with turbine propulsion (with the exception of LNG ships) are also excluded.

4.1. *Regulation 21 – Required EEDI*

This regulation specifies the methodology for calculation of the Required EEDI and all relevant details. The Required EEDI is the regulatory limit for EEDI and its calculation involves use of “reference lines” and “reduction factors”.
The basic concepts included in this regulation are:

• **Reference line**: A baseline EEDI for each ship type, representing reference EEDI as a function of ship size.

• **Reduction factor**: This represents the percentage points for EEDI reduction relative to the reference line, as mandated by regulation for future years. This factor is used to tighten the EEDI regulations in phases over time by increasing its value.

• **Cut-off levels**: Smaller size vessels are excluded from having a Required EEDI for some technical reasons. Thus, the regulatory text specifies the size limits. This size limit is referred to as cut off levels.

• **Implementation phases**: the EEDI will be implemented in phases. Currently, it is in phase 1 that runs from year 2015 to 2019. Phase 2 will run from year 2020 to 2024 and phase 3 is from year 2025 onwards.
Figure 10 shows the above concepts in diagrammatic format.

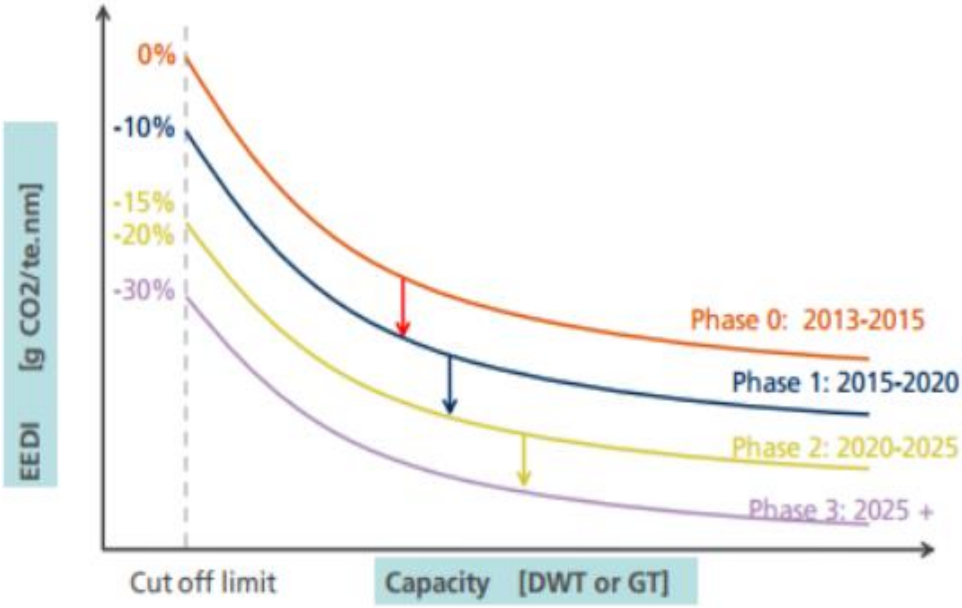

Figure 10. Concept of Required EEDI, reduction factor, cut off limits and EEDI phases [32]

4.2. ***EEDI Reference line***

This is a baseline EEDI for each ship type, representing reference EEDI as a function of ship size (see graph for Phase 0 in Figure 10). The reference lines are developed by the IMO using data from a large number of existing ships and analyzing these data as is shown in Figure 11.

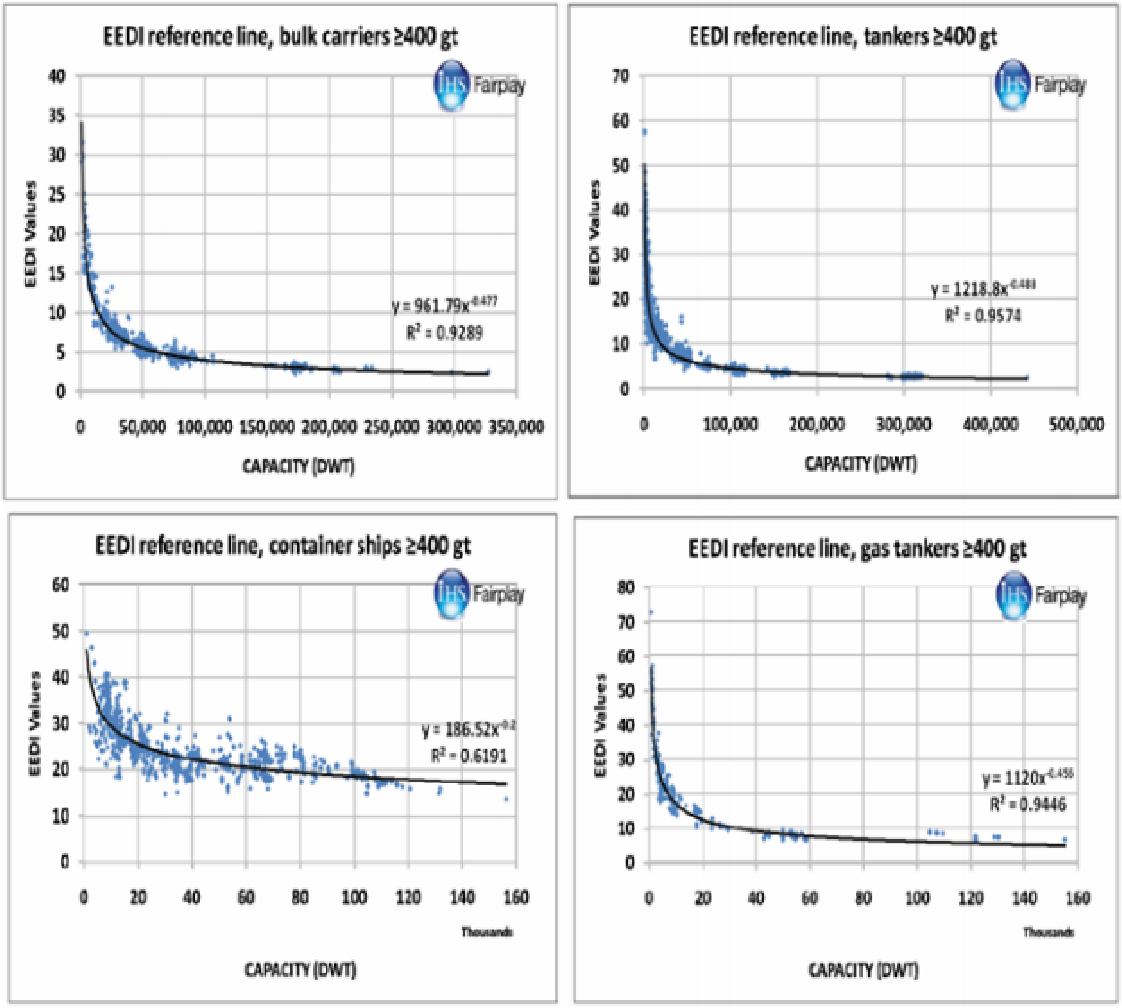

Figure 11. EEDI Reference Lines as developed by the IMO using techniques in Resolution MEPC.231(65) [32]

Full details of how reference lines are developed including sources of data, data quality checks, number of ships selected and year of build, ship sizes, etc. are fully described in relevant IMO guidelines [Resolution MEPC.231(65) and Resolution MEPC.233(65)]. As indicated, the above reference lines are produced through regression analysis of a large number of data and the resultant regression equation is shown on each diagram.

These regression equations are then embodied in Regulation 21 in the form of a formula:

$$\textbf{Reference EEDI} = a*b^{-c}$$

Parameters a, b and c for some of the ship types are given in Table 2.

Table 2. Parameters for determination of reference values for the different ship types

Ship type defined in regulation 2	a	b	c
2.25 Bulk carrier	961.79	DWT of the ship	0.477
2.26 Gas carrier	1120.00	DWT of the ship	0.456
2.27 Tanker	1218.80	DWT of the ship	0.488
2.28 Container ship	174.22	DWT of the ship	0.201
2.29 General cargo ship	107.48	DWT of the ship	0.216
2.30 Refrigerated cargo carrier	227.01	DWT of the ship	0.244
2.31 Combination carrier	1219.00	DWT of the ship	0.488

4.3. *EEDI reduction factor (X)*

This represents the percentage points for EEDI reduction relative to reference line, as mandated by regulation for future years. The value of "reduction factor" is decided by the IMO and is recorded in Regulation 21. This is shown in Table 3.

Table 3. EEDI reduction factors, cut off limits and implementation phases [Resolutions MEPC.203(62) and MEPC.251(66)] [32]

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 and onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000 – 10,000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000 – 15,000 DWT	n/a	0-10*	0-20*	0-30*
General Cargo ships	15,000 DWT and above	0	10	15	30
	3,000 – 15,000 DWT	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	5,000 DWT and above	0	10	15	30
	3,000 – 5,000 DWT	n/a	0-10*	0-15*	0-30*
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000 – 20,000 DWT	n/a	0-10*	0-20*	0-30*
LNG carrier***	10,000 DWT and above	n/a	10**	20	30
Ro-ro cargo ship (vehicle carrier)***	10,000 DWT and above	n/a	5**	15	30
Ro-ro cargo ship***	2,000 DWT and above	n/a	5**	20	30
	1,000 – 2,000 DWT	n/a	0-5*,**	0-20*	0-30*
Ro-ro passenger ship***	1000 DWT and above	n/a	5**	20	30
	250 – 1,000 DWT	n/a	0-5*,**	0-20*	0-30*
Cruise passenger ship*** having non-conventional propulsion	85,000 GT and above	n/a	5**	20	30
	25,000 – 85,000 GT	n/a	0-5*,**	0-20*	0-30*

Note: n/a means that no required EEDI applies.
* Reduction factor to be linearly interpolated between the two values dependent upon ship size. The lower value of the reduction factor is to be applied to the smaller ship size.
** Phase 1 commences for those ships on 1 September 2015.
*** Reduction factor applies to those ships delivered on or after 1 September 2019, as defined in paragraph 43 of regulation 2.

4.4. ***Required EEDI calculation formula***

Using the above concept, the following equations show the way Required EEDI is calculated for a ship. First, for each ship a "reference EEDI" is calculated using the below equation [32]:

$$\text{Reference EEDI} = a*b^{-c} \quad (1)$$

Where:
b: Ship capacity
a and c: Constants agreed for each ship type and included in the regulation.
Reference EEDI: Reference value for EEDI.

The next step is to establish the reduction factor (X) for the ship. This is dependent on year of ship built and is specified within the regulation (Table 3). Having established the Reference EEDI and X, the Required EEDI is calculated from the following equation [32]:

$$\text{Required EEDI} = (1-X/100)*\ (\text{Reference EEDI}) \quad (2)$$

Where:
X: Reduction rate; agreed and included in Regulation.
Required EEDI: The regulatory limit of the ship's EEDI, which the actual EEDI must not exceed.
The Required EEDI applies only to ships named in column 1 and the ship sizes specified in column 2 of Table 2. For these ships, regulation 22 stipulates that Attained EEDI must always be less than or equal to Required EEDI [32]:

$$\text{Attained EEDI} \leq \text{Required EEDI} \quad (3)$$

Where:
Attained EEDI: The actual EEDI of the ship, as calculated by the shipyard and verified by a recognized organization.

This regulation additionally stipulates the following:
- If the design of a ship allows it to fall into more than one of the above ship type definitions, the required EEDI for the ship shall be the most stringent (the lowest) required EEDI".
- For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the maneuverability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization".
- At the beginning of Phase 1 and at the midpoint of Phase 2, the IMO shall review the status of technological developments and, if proven necessary, amend the time periods, the EEDI reference line parameters for relevant ship types and reduction rates set out in this regulation". This review process is currently underway at the IMO.

5. CONCLUSION

Climate change policy needs to be able to promote collective actions while safeguarding flexibility and diversity. Due to uncertain future benefits and high present costs the issue faces the risk of time-inconsistency behavior, triggering policymakers to opt for unambitious environmental policies.

A CO2 design index has been in development within the IMO. The index is currently commonly known as the Energy Efficiency Design Index (EEDI). Once approved, it will in theory reduce CO2-emissions from new ships in the future. It will first apply to conventional vessels. The consensus of opinion within the global industry is that it will be possible for shipping to reduce CO2 emitted per tonne of cargo transported one kilometre (tonne/km) by 20% between 2005 and 2020, through a combination of technological and operational developments, as well as the introduction of new and bigger ships, designed to the new IMO Energy Efficiency Design Index.

A global maritime emission trading scheme that is open to other sectors and that allocates permits by means of auctioning is a valid option for the international maritime transport sector.

Carbon emissions from shipping can be reduced by five different means:

- Shifting to a fuel will low emissions of carbon (well-to-propeller).
- Supplementing fuels with wind-propulsion and/or solar power.
- Improving operations (maintenance of hull, engines and propellers, choice of operational speed, etc). ·
- Up-grading existing equipment by retrofitting (engines, propellers etc) · Ordering new, more fuel-efficient, tonnage.

The latest IPCC Synthesis Report (November 2014) suggests that all fossil fuels should be phased out by 2100. For the immediate future, shipping will probably remain dependent on fossil fuels. In the longer term, however, the shipping industry is exploring a number of alternative fuel sources to help reduce CO2 emissions. Liquid Natural Gas (LNG) produces lower CO2 emissions and could be an interim solution until a viable alternative to fossil fuels is eventually found, especially for shorter voyages provided that supply infrastructure can be developed. Third or fourth generation biofuels might conceivably provide a possible alternative although there is, of course, considerable public debate about the net environmental costs (and social effects) of the wider use of such fuels. Renewable energy sources, such as wind and solar power, may have a place in helping to meet some ancillary requirements, such as lighting on board ships. However, they are not practical for providing sufficient power to operate ships' main engines (the huge physical size of ships should not be underestimated). Fuel cells may be a possibility for new ships in the very long term, although they are currently too limited in range to offer a viable solution. Even nuclear propulsion for merchant ships is technically possible, although safety and security implications and support infrastructure costs would require serious consideration.

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