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LIFE CYCLE ASSESSMENT OF THE ALTERNATIVE FUELS IN THE LIGHT OF THE INTERNATIONAL MARITIME ORGANIZATION INITIAL GHG REDUCTION STRATEGY

Abstract

The article aims to increase knowledge on methods for assessing Greenhouse Gases (GHG) emissions throughout the life cycle of marine alternative fuels. The life cycle of new marine alternative fuels and the assessment of GHG emissions resulting not only from their combustion is one of the new topics that are currently being discussed by the IMO, under the 'Initial IMO GHG Reduction Strategy' announced by the Organization in 2018. The IMO Marine Environment Protection Committee (IMO MEPC) is currently working on the development of Guidelines for Life-Cycle Assessment of GHG emissions for marine fuels from their extraction, through transport, processing, bunkering on board and end use in vessels propulsion systems, what is often called 'from Cradle-to-Grave'. The use of fossil hydrocarbon fuels is common throughout the shipping industry, but in recent years ships with alternative energy sources have begun to be successfully introduced. Alternative fuels, although they may have low, zero or zero net GHG emissions in use (Tank to Wake or TtW), GHG emissions during their production, processing and distribution (Well-to-Tank or WtT) can vary widely. While a range of low-carbon and zero-carbon energy sources are potentially available for shipping, currently there is no clear decarbonization path or paths, and is likely that in the future a range of solutions will be adopted according to different vessel and operational requirements.

Keywords: LCA – Life Cycle Assessment, GHG – Greenhouse gas, GWP – Global warming potential, CO_2 – Carbon dioxide, CO_{2eq} – Carbon dioxide equivalent, WtW – Well-to-Wake, TtW – Tank-to-Wake, WtT – Well-to-Tank

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INTRODUCTION

The long-term viability and success of a transportation fuel depends on both economic and environmental sustainability. These include, but are not limited to, the environmental impacts on global climate and air quality, the efficient usage of water and land resources, technical feasibility and the economic cost of fuel production. This article focuses on aspects of environmental sustainability, with an emphasis on life cycle greenhouse gas emissions as they relate to impacts on global climate. Through a life cycle accounting of the GHG emissions starting with the well, field, or mine where the fuel feedstock is extracted, and extending to the wake behind the vessel, one can ascertain the change in GHG emissions that result from the use of an alternative fuel.

1. FUEL LIFE CYCLE AND GHG EMISSIONS

From the feedstock extraction or production to the final use in an engine, the fuel goes through multiple steps constituting its life cycle. At each of these steps, GHG emissions are likely to be produced. The total carbon foot print of the fuel is obtained by adding all these emissions together in a life cycle assessment (LCA) approach.

For fossil fuels, in addition to combustion, emissions are associated with crude oil extraction and refining, as well as final fuel transport and distribution. In the case of biofuels, combustion emissions can be considered as neutral, but there are emissions associated to the cultivation, harvesting, transport and conversion of the feedstock. In particular, depending on the feedstock and agricultural practices, the cultivation of the feedstock can represent a significant part of the emissions.

Thus, to assess the emissions reductions from using alternative fuels, a comprehensive accounting process must be completed for all emissions across all steps of the fuel's life cycle, from the field to the tank of the vessel. If there are lower emissions from the full life cycle of the alternative fuel, in comparison to the full life cycle of fossil fuels, then there is an environmental benefit for climate change.

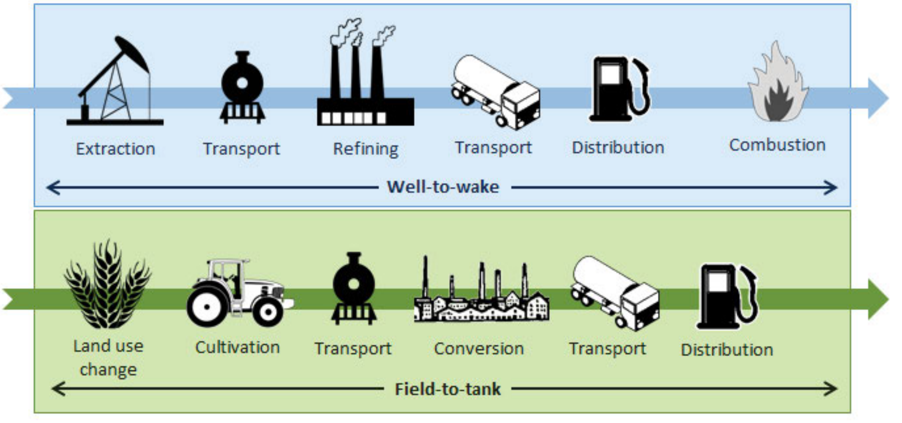

Figure 1. Life cycle process considered for an LCA for fossil fuel (upside) and for biofuels (downside). Source: ICAO, 2022[1].

2. INTERNATIONAL MARITIME ORGANISATION'S GREENHOUSE GAS REDUCTION STRATEGY

In the IMO, legislative work to reduce GHG from ships has been carried out continuously since 1997. In September 1997, the IMO *International Conference on Air Pollution* adopted Resolution 8 of the Conference on 'CO_2 Emissions from Ships', which recognized that CO_2 emissions, the main greenhouse gas (GHG), have adverse effects on the environment. This resolution reaffirmed also the IMO's mandate to control greenhouse gas emissions. Carbon dioxide emissions of around 75-80% are the main source of EU and global GHG emissions as shown in Figures 2 and 3 below.

In April 2018, the 72nd session of the IMO Marine Environment Protection Committee (IMO MEPC) adopted the 'Initial IMO Strategy on reduction of GHG emissions from ships[2] (Strategy). In line with the IMO Initial GHG Strategy, a 50% reduction in GHG emissions from international shipping is planned by 2050, compared to 2008, while striving towards a complete cessation of GHG emissions[3].

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[1] *Fuel Life Cycle and GHG emissions*, International Civil Aviation Organization (ICAO), 2022, https://www.icao.int/environmental-protection/Pages/AltFuels_LifeCycle-Box.aspx (accessed: 10.10.2022).

[2] *Initial IMO Strategy on reduction of GHG emissions from ships*, Res.MEPC.304(72), https://wwwcdn. imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.304(72).pdf (accessed: 10.10. 2022).

[3] D. Pyć, *Techniczne i operacyjne środki efektywności energetycznej dla statków morskich*, Prawo Morskie, 2019, t. XXXVII, pp. 112-113.

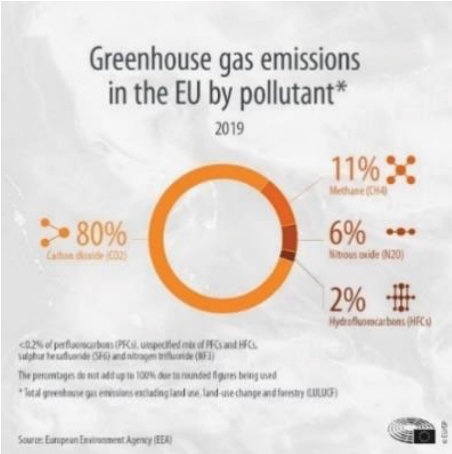

Figure 2. Share of individual greenhouse gases in total EU GHG emissions. Source: EEA 2019[4].

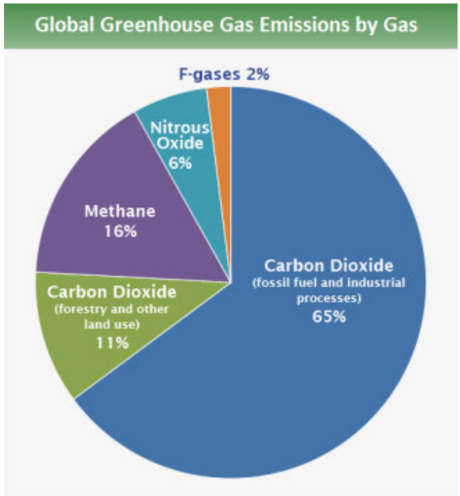

Figure 3. Global GHG Emissions by Gas. Source: IPCC 2014[5].

The Strategy provides a framework for further action, sets out a future vision for international shipping, the so-called IMO ambition levels for reducing GHG emissions and guiding principles for action (non-discrimination, prohibition of more favourable treatment, and the principle of common but differentiated responsibility), and includes further measures[6]. The strategy also identifies barriers and support measures for its implementation through capacity building, technical cooperation and research and development. In addition, the Strategy contains a specific reference to the 'CO_2 emission reduction pathways in line with temperature targets' set out in the framework of the United Nations Framework Convention on Climate Change (UNFCCC)[7] and its 2015 Paris Agreement[8].

This Strategy is the first milestone set out in the Roadmap for developing a comprehensive IMO Strategy on reduction of GHG emissions from ships (the

[4] *Amount of greenhouse gas emissions per year in the EU*, European Environment Agency (EEA), 2019, https://www.europarl.europa.eu/news/en/headlines/society/20180301STO98928/greenhouse-gas-emissions-by-country-and-sector-infographic (accessed: 10.10. 2022).

[5] *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, Intergovernmental Panel on Climate Change, 2014 (accessed: 10.10. 2022).

[6] D. Pyć, *Ship Energy Efficiency Measures and Climate Protection*, International Community Law Review, 2021, 23(2-3), pp. 241-251.

[7] The consolidated versions of the UNFCCC text: https://unfccc.int/sites/default/files/convention_text_with _annexes_english_for_posting.pdf (accessed: 10.10. 2022).

[8] Paris Agreement: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed: 10.10. 2022).

Roadmap) approved at 70th session of the IMO MEPC. The Roadmap identifies that a revised Strategy is to be adopted in 2023.

The vision contained in the Strategy presents a gradual but as soon as possible reduction of GHG emissions from international shipping in this century. The measures to reduce GHG emissions from ships specified in the Strategy are: improving the energy efficiency of ships, increasing their energy efficiency at the operational level, implementing MBM (Market Based Instruments) market tools and the global transition to the so-called alternative fuels with low and zero carbon content[9].

The Strategy sets out three levels of IMO GHG ambition:

1) the carbon intensity of the ship will be reduced by implementing the successive phases of the Energy Efficiency Design Index (EEDI) for new ships (review to increase the design energy efficiency requirements for ships with a percentage improvement for each phase to be determined for each type of ship, as appropriate);
2) the carbon intensity of international shipping will be reduced (to reduce CO_2 emissions in relation to the effect of transport work, by an average of at least 40% by 2030, aiming at 70% by 2050 compared to 2008); and
3) GHG emissions from international shipping will peak and fall (peak GHG emissions from international shipping as quickly as possible and reduce total annual GHG emissions by at least 50% by 2050 compared to 2008, while aiming to phase them out – IMO vision – as a point on the pathway to reducing CO_2 emissions).

3. IMO GHG STRATEGY CANDIDATE MEASURES

The Strategy also includes a list of additional measures to further reduce CO_2, the so-called ‘candidate measures’ (short-, medium- and long-term) with a proposed timetable and an indication of their impact on countries. These measures can be classified as having the effect of directly limiting greenhouse gas emissions from ships and those that support actions to reduce greenhouse gas emissions from ships.

In the mid-term measures, an implementation programme for low- and zero-carbon fuels is required. To enhance IMO’s contribution to global efforts by addressing GHG emissions from international shipping, it is important that future low- and zero-carbon marine fuels actually produce low emissions throughout their entire production process to achieve the desired effect for the

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[9] D. Lost-Siemińska, *Obowiązek stosowania najlepszej dostępnej technologii w ochronie środowiska morskiego*, Prawo Morskie, 2021, t. XL, pp. 135-137.

goals of the Paris Agreement. In this sense, a widely used tool to assess the sustainability of activities is the Life Cycle Assessment (LCA) of products, processes and services. Life Cycle Assessment is an especially important methodology that has constantly evolved in recent decades. It considers the whole life of the product – from its raw material to its final disposal – to assess its environmental sustainability.

4. LIFE CYCLE ASSESSMENT (LCA)

LCA is a widespread tool in the world. The various standards, guides, books, methodologies and databases related to the issue show that this tool is well developed and has a robustness that makes it highly qualified to express the environmental impact of products/processes/services[10].

In the case of shipping fuels, the LCA is indispensable because a simple analysis of the final use of the fuel ('tank-to-wake') would bring a short-sighted view about total emissions[11]. In addition to the ship's direct emissions, a complete LCA for fuel also considers emissions associated with fuel extraction, production, transportation, processing, conversion and distribution. The inclusion of emissions associated with all the stages through the fuel lifecycle provides a more comprehensive description of the sectoral emissions and helps to avoid misunderstandings arising from the isolated examination of operational emissions[12].

5. IMO LCA GUIDELINES

IMO is currently working on Lifecycle GHG and Carbon Intensity Guidelines for Marine Fuels[13]. In accordance with the Term of Reference given by IMO MEPC the scope of these guidelines is to address WtW and TtW GHG emissions and sustainability criteria related to all fuels used for combustion and energy conversion (e.g. fuel cells) as well as electricity, for propulsion and

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[10] S. Bengtsson, *Life cycle assessment of present and future fuels Gothenburg,* Chalmers University of Technology, 2011, p. 3.

[11] SWAFEA Formal Report D.6.2 (SW_WP6_D.6.2_Onera_28Mar2011), *Environmental Impact Analysis Report*, 2011, pp. 65-72.

[12] R.W. Stratton et al., *Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels,* PARTNER Project 28 Report, 2010, pp. 5-7.

[13] Document MEPC/76/INF.69, *Life Cycle Assessment: an essential tool to evaluate the sustainability of fuels,* IMO MEPC, 76th Session, 2021.

operation on board a ship[14]. The GHGs included are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These guidelines are not intended to provide guidance for a complete IMO GHG inventory for international shipping and does not cover, for example, emissions from cargo (e.g. VOC), or use of refrigerants. Other short-lived climate forcers and precursors such as NMVOC, SO_x, CO, PM and Black Carbon are also not included in the scope.

The GHG emissions are calculated as CO_2-equivalents (CO_{2eq}) using the Global Warming Potential over a 100-year horizon (GWP100), as given in the *IPCC Sixth Assessment Report*, for CO_2, CH_4 and N_2O.

These guidelines provide:

1) WtW GHG emission factors based on a full lifecycle analytical (attributional) methodology, which enables the evaluation of fuels on Global Warming Potential (GWP) and can be used for reporting all relevant GHG emissions;
2) TtW CO_2, CH_4 and N_2O emission factors in line with the IPCC Guidelines for National Greenhouse Gas Inventories, which enables accounting of GHG emissions while avoiding double counting across sectors; and
3) sustainability criteria for fuels capturing both the WtW GHG emissions and other sustainability aspects.

These guidelines defines also a Fuel Lifecycle Label (FLL) that characterizes fuels per type, feedstock, production pathway, and relevant sustainability criteria. The FLL enables documentation and sharing of necessary information about the fuel when delivered to the ship and further when reporting fuel consumption through the IMO Data Collection System (DCS).

The Figure 4 below, taken from document ISWG-GHG 11/2/3, shows a generic WtW supply chain for a fuel. The fuel bunkering marks the step between the Well-to-Tank (WtT) and the TtW phases.

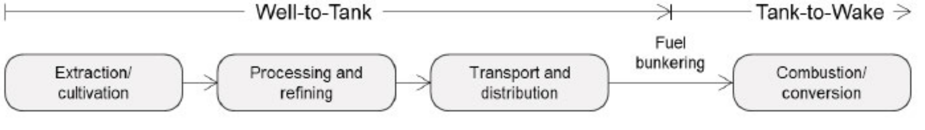

Figure 4. Generic Well-to-Wake supply chain.[15]

[14] Document ISWG-GHG 11/2/3, *Development of Draft Lifecycle GHG and Carbon Intensity Guidelines for Maritime Fuels (Draft LCA Guidelines)*, IMO Marine Environment Protection Committee, 11th Session of the ISWG-GHG, 2022.

[15] Ibidem.

6. LIFECYCLE PRINCIPLES, WELL-TO-WAKE METHODOLOGY

A Lifecycle Assessment (LCA) offers a holistic examination for the product/service/system from cradle to grave based on data in relation to the specific activity. LCA or the WtW (Well to Wake) GHG emissions estimation approach is applicable across all geographical regions where emissions are released and estimates the actual GHG emissions over the entire supply chain. LCA is relevant to assess the overall GHG impact of shipping fuels given that shipping activity accounts for emissions in the fuel combustion but not from the fuel production. WtT GHG emissions calculated using the LCA methodology aim to assess the total emissions of growing or extracting raw materials, producing, and transporting the fuel to the point of use. The TtW emissions, however, represent the total emissions from combustion or conversion (including leakage). The WtW emissions are the sum of the WtT and TtW emissions, and estimate the full lifecycle GHG emissions for a given fuel. WtW methodology satisfies the IPCC principle of reporting all relevant emissions for information purposes[16].

7. IPCC ACCOUNTING PRINCIPLES, TANK-TO-WAKE METHODOLOGY

IMO GHG inventory for international shipping should follow the principles laid out in the *IPCC Guidelines for National Greenhouse Gas Inventories* in order to avoid double-counting of the same emissions between the IMO GHG inventory and national GHG inventories[17]. International water-borne navigation (international bunkers) is grouped under Mobile combustion under the Energy sector, but emission from fuel used by ships in international transport is not included in national totals in national GHG inventories and has to be covered by the IMO GHG inventory.

In accordance with the IPCC guidelines, any non-combustion emissions including fugitive emissions should be accounted for in the sector(s) where the fuel is explored, produced, processed, refined, transported and distributed. The IMO GHG inventory for international shipping should only be concerned with GHG emissions from fuel used by ships, as the GHG emissions from exploring,

[16] *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* Chapter III Vol.2.1.1, Choice of Method – Mobile Combustion, https://www.ipcc-nggip.iges.or.jp/public/2006gl/ (accessed: 10.10. 2022).

[17] *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html (accessed: 10.10. 2022)

producing, processing, refining, transporting and distributing the fuel they use should be accounted for in national GHG inventories.

The IMO GHG inventory for international shipping should estimate and report all emissions from fuel used by ships regardless of the source of the carbon to prevent any emissions from not being captured and not being counted, however, to comply with IPCC guidelines, any carbon in the fuel derived from biomass should be reported as an information item and not included in the sectoral or national totals to avoid double counting as the net emissions from biomass are already accounted for in the Agriculture Forestry and Other Land Use (AFOLU) sector.

In accordance with a TtW approach, zero-carbon energy carriers such as hydrogen and ammonia have a carbon content of zero. This is still the case regardless of whether it comes from electrolysis with renewable electricity or from reformed natural gas, with or without CCS. This also applies to electricity from onshore, used either directly by a shore connection or store in batteries. For energy carriers that contain carbon, such as diesel, methane and methanol, the source of the carbon is critical to the accounting.

It is important that when calculating the TtW GHG emissions according to the IPCC accounting principles a Carbon Source Factor (S_F) should be applied. The factor determines if the TtW CO_2 emissions should be accounted for in the IMO GHG inventory for international shipping (S_F = 1) or not (S_F = 0) and should be multiplied with the CO_2 Emission Factor (C_F) for the specific fuel. CH_4 and N_2O emissions should be reported regardless of carbon source and are not affected by S_F. In this respect, S_F does not affect the WtT emissions and a fuel with $S_F = 0$ does not imply that the GHG WtT emissions are zero. For fuel blends, for example of bio and fossil methane, the S_F is the weighted average of the blended feedstock.

8. FUEL LIFECYCLE LABEL

To enable the application of the WtW and TtW methodologies and the sustainability criteria in these guidelines, it is proposed that a fuel delivered on board a ship should include a Fuel Lifecycle Label (FLL) which categorizes the fuel per feedstock, production pathway and other sustainability aspects. Such proposal is currently under development.

The FLL provides the necessary information (by a standardized approach conveying the relevant information of the production pathway for a fuel product or fuel batch) for cross-checking and transparency and should be verified according to the criteria defined in the IMO LCA guidelines. It is proposed that the FLL could be documented in the Bunker Delivery Note and reported through the IMO Data Collection System.

The FLL should be based on a certification of the supplier and/or fuel according to internationally recognized standards or certification schemes. The accepted certification bodies are determined by the individual certification scheme. In case the FLL is not certified, the highest default WtT emissions factor for the given fuel type should be used and the carbon source factor (S_F) should be 1.

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The FLL may consist of four parts concerning:

- Carbon content of the fuel;
- Feedstock Nature or Primary energy source for production;
- Production pathway and
- Fuel type.

9. GHG EMISSIONS FACTORS BASED ON GWP100

The methods and general principles for calculating WtW and TtW emissions are outlined below.

WELL–TO–WAKE EMISSIONS CALCULATING

When calculating WtW emissions according to the principles (i.e.: according to Equation (1)), the carbon source factor (S_F) should always be 1 for the purpose of calculating GHG_{TtW} in Equation (3), as the TtW CO_2 emission is balanced in the WtT calculation method.

The WtW GHG emissions factor (gCO_{2eq}/MJ fuel or electricity) is calculated according to Equation 1 below:

$$GHG_{WtW}\left[gCO_{2eq}/MJ\right] = GHG_{WtT} + GHG_{TtW} \tag{1}$$

where:

Term	Units	Explanation
GHG_{WtW}	gCO_{2eq}/MJ	Total well-to-wake GHG emissions per energy unit from the use of the fuel or electricity in a consumer on board the ship
GHG_{WtT}	gCO_{2eq}/MJ	Total well-to-tank GHG upstream emissions per energy unit of the fuel provided to the ship
GHG_{TtW}	gCO_{2eq}/MJ	Total tank-to-wake GHG downstream emissions per energy unit from the use of the fuel or electricity in a consumer on board the ship

WELL–TO–TANK EMISSIONS GUIDANCE AND METHODOLOGY

The WtT GHG emissions factor (gCO_{2eq}/MJ fuel or electricity) is calculated according to Equation 2. Further specification of the methodology is given in the Guidelines subpart *Well–To–Tank Emissions*.

$$GHG_{WtT}\left[\frac{gCO_{2eq}}{MJ}\right] = e_{ec} + e_l + e_p + e_{td} - e_c - e_{sca} - e_{ccs} - e_{ccu} \qquad (2)$$

where:

Term	Units	Explanation
e_{ec}	gCO_{2eq}/MJ	Emissions from the extraction or from the cultivation of raw materials
e_l	gCO_{2eq}/MJ	Annualized emissions from carbon stock changes caused by land-use change (over 20 years)
e_p	gCO_{2eq}/MJ	Emissions from processing, including electricity generation
e_{td}	gCO_{2eq}/MJ	Emissions from transport and distribution
e_c	gCO_{2eq}/MJ	Emissions credits generated by biomass growth
e_{sca}	gCO_{2eq}/MJ	Emission savings from soil carbon accumulation via improved agricultural management
e_{ccs}	gCO_{2eq}/MJ	Emission savings from CO_2 capture and geological storage
e_{ccu}	gCO_{2eq}/MJ	Emission savings from CO_2 capture and utilization

The aim of the WtT methodology is to evaluate the amount of upstream GHG emissions for the fuel. The WtT emissions should be calculated using Equation (2) as stated above and reported.

The carbon feedstock and production pathway of a fuel should be identified in order to apply the WtW methodology and included as part of the FLL. The production steps to be included are:
– Feedstock extraction/cultivation;
– Feedstock (early) processing/ transformation at source Feedstock transport;
– Feedstock conversion to product fuel;
– Product fuel transport;

– Product fuel storage Local delivery;
– Retail storage and dispensing.

The WtT emissions in Equation 2 include emissions associated with raw materials extraction or cultivation, primary energy sources used for production of goods and utilities such as energy carriers (fuels and electricity), transport and distribution, land use change and changes in carbon stocks.

For carbon-based fuels, changes in carbon feedstock can be either from a fossil origin, i.e. energy carriers produced from crude oil, coal or natural gas; or from a biological origin (crops and residues). Biogenic sources include energy carriers like biogas, bio-ethanol, biodiesel, hydro-treated vegetable oils (HVO). For non-carbon fuels, such as electricity, the origin can also be renewables other than bioenergy, e.g. wind or solar energy, sometimes in combination with fossil fuels.

Emission saving from carbon capture (either of fossil or biological origin) and geological storage e_{ccs}, that have not already been accounted for in ep (emissions from processing), should be limited to emissions avoided through the capture and sequestration of emitted CO_2 directly related to the extraction, transport, processing and distribution of fuel.

Emissions savings from carbon capture and utilization e_{ccu}, should be limited to emissions avoided through the capture of CO_2 of which the carbon originates from biomass and which is used to replace fossil-derived CO_2 used in commercial products and services.

The proposed methodology includes the use of default values for fossils fuels for the WtT established in such way to incorporate the overall uncertainties stemming from the averaging at global scale. Such default values for fossil fuels WtT can be used without any certification scheme (while still complying with certain sustainability criteria and be reviewed after the sustainability criteria are finalized), as opposed to the actual values that for all other types of fuels can be subject to certification. Performers who believe to do better than default values should be given the opportunity to demonstrate their real performances through the application of a certification scheme.

BLENDING OF FUELS

A fuel batch may be a mix of various sources (e.g. by blending 20% biodiesel into MGO). The S_F should be calculated as the weighted average of the mass of the various blended stocks. Each blended stock should be accompanied with a FLL.

TANK–TO–WAKE EMISSIONS GUIDANCE AND METHODOLOGY

The TtW GHG emission factors (gCO_{2eq}/MJ fuel) is calculated according to Equation 3. Further specification of the methodology is given in the Guidelines subpart *Tank–To– Wake Emissions.*

$$GHG_{TtW} = [(1 - C_{slip}) \times \\ \times (S_F \times C_{fCO_2} + C_{fCH_4} \times GWP_{CH_4} + C_{fNO_2} \times GWP_{NO_2}) + \\ + (C_{slip} \times GWP_{CH_4}) - e_{occs}]/LCV \tag{3}$$

where:

Term	Units	Explanation
S_F	0 or 1	Carbon source factor
C_{slip}	% of fuel mass	Coefficient accounting for fuel (methane) slip (share of the total fuel in use)
C_{fCO_2}	gCO_2/gfuel	CO_2 emission conversion factor (g CO_2/g fuel)
C_{fCH_4}	gCH_4/gfuel	CH_4 emission conversion factor (g CH_4/g fuel)
C_{fNO_2}	gN_2O/gfuel	N_2O emission conversion factor (g N_2O/ g fuel)
GWP_{CH_4}	gCO_{2eq}/gCH_4	Global Warming Potential of methane over 100 set at 29.8 for fossil and at 27.5 for non-fossil methane (IPPC AR 6)
GWP_{NO_2}	gCO_{2eq}/gN_2O	Global Warming Potential of N_2O over 100 set at 273 (IPCC AR 6)
e_{occs}	gCO_{2eq}/MJ	Emission savings from on-board CO_2 capture and geological storage
LCV	MJ/g fuel	Lower Calorific Value of the fuel (MJ/g fuel)

When calculating TtW emissions according to the principles (i.e.: according to Equation (3)), the carbon source factor (S_F) assumes the values given in the Table 1 for the relevant Fuel Lifecycle Label. Equations (1) and (2) are not used in the TtW methodology.

The aim of the TtW methodology is to evaluate the amount of CO_2, CH_4 and N_2O emitted including combustion/conversion and fugitive emissions. The TtW emissions should be calculated using Equation (3) as stated above and reported

Table 1. Well to Tank default Emission Factors and Carbon Source Factors (ISWG-GHG 11/2/3[14])

Part I: Carbon content*	Part II: Feed stock Nature	Part III: Production pathway	Part IV: Fuel type	Region of the world (*)	GHG CO_{2eq}	S_F	Source
Carbon	Fossil	Default	MDO/MGO	Global	14.9	1	
Carbon	Fossil	Default	LFO	Global	13.2	1	
Carbon	Fossil	Default	HFO	Global	[9.6]/[14.1]	1	
Carbon	Fossil	Default	LPG	Global		1	
Carbon	Fossil	Default	LNG/ methane	Global	18.5	1	
Carbon	Fossil	Default	Butane	Global	7.8	1	
Carbon	Fossil	Natural gas	Methanol	Global	31.3	1	RED II
Carbon	Biogenic	Main products / wastes / feedstock mix /rapeseed incl. LUC	Diesel		115.1(**)	0	Rapeseed incl. LUC
Carbon	Biogenic	Main products / wastes / feedstock mix /palm incl. LUC	Diesel		306.7	0	Palm incl. LUC
Carbon	Biogenic	Main products / wastes / Feedstock mix	Diesel	Region 1,2,3,4,5	-26.1	0	RED II
Carbon	Biogenic	Main products / wastes / Feedstock mix	HVO		-20.7	0	RED II
Carbon	Biogenic	Main products / wastes / Feedstock mix	LNG/ methane		-38.9	0	RED II
Carbon	Biogenic	Main products / wastes / Feedstock mix	Hydrogen			N/A	

Part I: Carbon content*	Part II: Feed stock Nature	Part III: Production pathway	Part IV: Fuel type	Region of the world (*)	GHG CO_{2eq}	S_F	Source
Carbon	Captu-red car-bon	Captured carbon/ Elec-trolysis/ elec-tricity mix	Diesel		-47.6 (***)	0	RED RESD1 (from-RES)
Carbon	Captu-red car-bon	Captured carbon/ Elec-trolysis/ elec-tricity mix	Methanol		-67.1	0	RED REME1a (from-RES)
Carbon	Captu-red car-bon	Capt.carbon/ biomass gasi-fication/ electricity mix	LNG/ methane		-26.6	0	RED WFLG2
Carbon	Captu-red car-bon	Captured carbon (****)	LNG/ methane		97	0	
Zero C	Fossil	Natural gas	Hydrogen		132	N/A	JEC
Zero C	Fossil	Natural gas	Ammonia		121	N/A	
Zero C	Biogenic	Sugarbeet	Ethanol		-33.2	0	RED su-garbeet
Zero C	Fossil /rene-wable	Electrolysis/ electricity mix	Hydrogen		3.6		JEC
Zero C	Fossil /rene-wable	Electrolysis/ electricity mix	Ammonia		0		SINTEF 2020
Zero C	Fossil /rene-wable	Electricity mix	Electricity		106.3		EU MIX 2020

Note: all values are preliminary and not all relevant pathways and feedstock are mapped
(*) The geographical scope can be applicable to each fuel. It is shown only on one entry for simplicity purpose.
(**) Note that the WtT emission factor for biogenic sources include negative emissions generated by biomass growth (e_c) which is calculated based on the theoretical TtW emissions.
(***) Note that WtT emission factor of the group labelled as captured carbon may include negative emissions from the carbon capture process which is calculated based on TtW emissions. These emissions are added in the TtW phase for the calculation of WtW emissions
(****) Only if the captured CO_2 is to be accounted in national GHG inventories of any UNFCCC member countries, in alignment with the IPCC guidelines. If not, S_F=1.
N/A stands for Not Available

Default values for the relevant emissions and slip factors are provided in Table 2 (except for on board CCS).

Table 2. Tank to Wake default emission factors (ISWG-GHG 11/2/3[14])

Fuel type	Energy Converter	LCV	C_{fCO_2}	C_{fCH_4}	C_{fNO_2}	C_{slip}
		MJ/g fuel	$[gCO_2/g\text{Fuel}]$	$[gCH_4/g\text{Fuel}]$	$[gN_2O/g\text{Fuel}]$	% of fuel mass
HFO ISO 8217 Grades RME to RMK	ALL ICEs	0.0402	3.114	0.00005	0.00018	-
	Gas Turbine					
	Steam Turbines and Boilers					
	Aux Engines					
LSFO [better HFO>0,5]	ALL ICEs	0.0412	3.114	0.00005	0.00018	-
	Gas Turbine					
	Steam Turbines and Boilers					
	Aux Engines					
LFO ISO 8217 Grades RMA to RMD	ALL ICEs	0.0412	3.151	0.00005	0.00018	-
MDO MGO ISO 8217 Grades DMX to DMB	ALL ICEs	0.0427	3.206	0.00005	0.00018	-
LNG	LNG Otto (dual fuel medium speed)	0.0480	2.75	0	0.00011	Built before 200X 3,1 Built after 200X *
	LNG Otto (dual fuel slow speed)					Built before 200X 1,7 Built after 200X *
	LNG Diesel (dual fuel slow speed)					Built before 200X 0.2 Built after 200X *
	LBSI					N/A

Fuel type	Energy Converter	LCV	C_{fCO_2}	C_{fCH_4}	C_{fNO_2}	C_{slip}
		MJ/g fuel	$[gCO_2/g\text{Fuel}]$	$[gCH_4/g\text{Fuel}]$	$[gN_2O/g\text{Fuel}]$	% of fuel mass
LPG	All ICEs	0.0463 Buthane 0.0457 Propane	3.03 Buthane 3.00 Propane	TBM	TBM	
HYDROGEN	Fuel Cells	0.120	0	0	-	-
	ICE		0	0	TBM	
Methanol	All ICEs	0.0199	1.375	TBM	TBM	
Ammonia	No engine	0.0186	0	0	TBM	-
Ethanol E100	All ICEs	0.0268	1.913	TBM	TBM	-
FAME						
Bio-diesel	ALL ICEs	0.0270 – 0.0372	2.834	0.00005	0.00018	-
HVO	ALL ICEs	0.044	3.115	0.00005	0.00018	-
Electricity	OPS	-	-	-	-	-

* Stands to be specified

N/A stands for Not Available , TBM stands for To Be Measured , ICE stands for Internal Combustion Engine

The actual emissions depend both on the properties of the fuel and on the efficiency of the energy conversion. For CO_2, the emission factors are based on the molar ratio of carbon to oxygen multiplied with the carbon mass of the fuel, assuming that all the carbon in the fuel is oxidized. The CH_4 and N_2O emissions factors are dependent on the combustion or conversion process in the energy converter.

C_{fCO2} (gCO_2/g fuel) is a non-dimensional conversion factor between fuel consumption measured in grams and CO2 emissions also measured in grams based on carbon content. C_{fCH4} and C_{fNO2} are engine and fuel specific emission factors. Newer generations of engines are expected to reduce certain emissions and there may be a need to distinguish on the engine build year. For fuels and engines that are not developed yet, the default factors need to be developed at a later stage and also kept under review.

Fugitive emissions (such as those from methane) come from fuel that does not reach the combustion chamber and from fuel that is not burned in the combustion chamber (e.g. methane slip) and which are lost, leaked, vented, boiled-off in the system. The slip factor C_{slip} is expressed as share of fuel mass. The fuel slip should also be deducted before the emission conversion factors are applied, as this fuel is not combusted or converted. The values of C_{slip} should be calculated at 50% of the engine load (E2/E3 test cycle can also be considered as method of reference in the certification guidelines).

10. USE OF DEFAULT VALUES AND CERTIFIED ACTUAL VALUES

Default emission and slip factors per fuel type, engine/converter type and generation are given in the tables below. However, performers who claim to do better than default values should be given the opportunity to demonstrate their real performance through the application of certified actual values. Criteria for certification of the various factors will be given in the Guidelines Part IV. No default values are given for the use of on-board CCS (e_{occs}), and the amount of captured carbon per unit of energy should be specifically certified according to criteria in the Guidelines Part IV.

CONLUSION

Stakeholders in the shipping industry are demanding a holistic, fact-based approach to climate and sustainability. Life-cycle accountability and being able to understand and quantify business-related emissions are key. A credible life cycle assessment (LCA) or carbon footprint calculation can provide valuable insights and documentation of emissions associated with all life cycle phases of an asset or product. In accordance with the international standards ISO 14040 and 14044 for conducting LCA research, combined with LCA's recognized state-of-the-art software, maritime industry insights and deep technical expertise, it is possible to provide shipping industry stakeholders with a better understanding of the environmental impact from cradle to grave.

OCENA CYKLU ŻYCIA PALIW ALTERNATYWNYCH W ŚWIETLE WSTĘPNEJ STRATEGII REDUKCJI GHG MIĘDZYNARODOWEJ ORGANIZACJI MORSKIEJ

Słowa kluczowe: LCA – Ocena cyklu życia, GHG – Gaz cieplarniany, GWP – Współczynnik globalnego ocieplenia, CO_2 – Dwutlenek węgla, CO_{2eq} – Ekwiwalent dwutlenku węgla, WtW – od źródła do wykorzystania, TtW – od zbiornika do wykorzystania, WtT – od źródła do zbiornika

Abstrakt

Artykuł ma na celu zwiększenie wiedzy na temat metod oceny emisji gazów cieplarnianych w całym cyklu życia morskich paliw alternatywnych. Cykl życia nowych morskich paliw alternatywnych oraz ocena emisji gazów cieplarnianych wynikających nie tylko z ich spalania to jeden z nowych tematów, które są obecnie omawiane przez IMO, w ramach Wstępnej Strategii Redukcji Gazów Cieplarnianych ogłoszonej przez Organizację w 2018 r. Komitet Ochrony Środowiska IMO (IMO MEPC) pracuje obecnie nad opracowaniem wytycznych dotyczących oceny cyklu życia emisji gazów cieplarnianych dla paliw żeglugowych z ich wydobycia, poprzez transport, przetwarzanie, bunkrowanie na pokładzie i końcowe wykorzystanie w systemach napędowych statków, co często nazywa się „od kołyski do grobu". Stosowanie kopalnych paliw węglowodorowych jest powszechne w całym przemyśle żeglugowym, ale w ostatnich latach statki z alternatywnymi źródłami energii zaczęły być z powodzeniem wprowadzane. Paliwa alternatywne, chociaż mogą mieć niską, zerową lub zerową emisję gazów cieplarnianych netto w użyciu (*Tank to Wake* lub TtW), to emisje gazów cieplarnianych podczas ich produkcji, przetwarzania i dystrybucji (*Well-to-Tank* lub WtT) mogą się znacznie różnić. Chociaż wiele niskoemisyjnych i bez emisyjnych źródeł energii jest potencjalnie dostępnych dla żeglugi, obecnie nie ma jasnej ścieżki lub ścieżek dekarbonizacji i jest prawdopodobne, że w przyszłości zostanie przyjęty wiele rozwiązań zgodnie z różnymi wymogami dotyczącymi statków i eksploatacji.

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