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Implementation of impact mitigation measures for maritime transport: an analysis of alternative waste management practices, air emissions monitoring and GHG reduction

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IMPLEMENTATION OF IMPACT MITIGATION MEASURES FOR MARITIME TRANSPORT: AN ANALYSIS OF ALTERNATIVE WASTE MANAGEMENT PRACTICES, AIR EMISSIONS MONITORING AND GHG REDUCTION

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Abstract

The problem of waste management and waste generation in the shipbuilding sector is crucial in the context of sustainability, in which context the concept of a circular economy system for both re-use and recycling of waste should also be included. For these considerations, the proposed study examines a combined system for optimising ship waste management and evaluates its possible use for energy purposes. In addition, this work aims to develop indicators to monitor and assess the instantaneous environmental impact in the air from different types of ships. With regard to the first point, a number of systems were analysed in relation to their potential to reduce greenhouse gas emissions, regardless of the routes and ports of destination. As a result of this analysis, the case studies of particular interest were identified: the thermochemical treatment of waste oils and sludges to obtain fuel oils, the installation of a waste-to-energy plant and subsequent energy recovery on board, a potential innovative pattern of recycling food waste from cruise ships for use as feed in aquaculture and potential green practices with particular attention to paper input and output flows in a waste minimization perspective. UNFCCC (United Nations Framework Convention on Climate Change) methodologies were applied to two of these case studies to calculate the reduction in greenhouse gas emissions resulting from their implementation. The results obtained are presented with the aim of supporting sustainable on-board waste management strategies in a carbon circular economy perspective. With regard to the second point, the main objective was to make an objective assessment of the ship's environmental impact in real time to allow for possible adjustments and improve energy efficiency. The definition of these new indicators can be used as a decision support system for shipboard personnel. Environmental performance indicators are developed following the evaluation of data collected on board by specific instrumentation, marine exhaust cleaning systems, existing legislation. Different ship types, characterised by different propulsion system configurations, are considered using real experimental data provided by

CETENA, a Fincantieri Group company. The indicators allow to compare the performance of the ship and the efficiency of the exhaust cleaning systems under different operating conditions. They can be used as new tools, added to existing instrumentation that can be implemented to minimize the ship's environmental footprint.

Dedicata ai miei Amori, che illuminano la mia vita

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Chapter 1

Introduction

Climate change and greenhouse gas (GHG) emissions reduction represent the main challenges for the sustainability of any action and sector. The awareness of the issue-which over the past 30 years has been strengthening in converging opinions within the scientific community-is now moving towards the public decision makers, influencing the future leanings of the global economy and subsequently the individual behaviours.

As regards the emissions of greenhouse gases, the European Union has defined a series of goals to reduce them by 2050 through the Climate and Energy 20-20-20 Package [1] and the 2030 Climate and Energy framework [2]. In particular, by 2030, GHG emissions must be reduced by at least 40% compared to 1990. The maritime transport sector is also involved in achieving these goals and the GHG emissions generated by this sector are progressively integrated into the Commission's strategy and in the policy of the Union. It has been evaluated that the International maritime shipping has emitted 870 million tons of CO2e in 2007 alone, which corresponds to about 2.7% of the global GHG emissions [3].

Although the percentage contribution may still appear to be low, by the progressive containment of GHG emissions in other civil (e.g., air transport sector) and industrial sectors (e.g., steelworks, chemical industry) the international maritime industry is expected in future to weigh about 19% of global emissions in case of not taking appropriate reduction measures.

For this reason, the contribution of the naval sector to the reduction in GHG emissions is nowadays greatly taken into account, as highlighted in several international offices. In this context, EU Regulation 2015/757 [4] was issued on monitoring, reporting and verification of carbon dioxide emissions generated by maritime transport (known as EU MRV Regulation). The MRV Regulation is a mandatory system of monitoring, reporting and verification established by the European Commission for ships over 5000 gross tonnages travelling one or more commercial routes-both freight and passenger transport-to and from European Union ports, regardless of their flag.

Subsequently, during the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) held in 2016 in Marrakech (COP22), the International Maritime Organization (IMO) presented its mitigation actions to support the Sustainable Development Goals of the United Nations. In the same year, in the context of 70th session of the Marine Environment Protection Commission (MEPC 70) a mandatory system of data collection on the fuel consumption of ships was adopted and the roadmap for the development of an “IMO global strategy on the reduction in greenhouse gases emissions from ships” was defined. During the subsequent COP23 held in Bonn in November 2017, which consolidates the targets and the ambitions of the Paris agreement, an action plan for the decarbonisation of the maritime sector was created. At the summit, it was agreed that the international maritime industry has the technological tools needed for the decarbonisation of the sector itself, through the application of different strategies including: cruise speed reduction, further technological development to increase energy efficiency in the design phase, the use of renewable energy sources (e.g., wind), the use of alternative fuels.

With these premises, the IMO published in 2018 an initial plan for reducing GHG emissions and it was planned to agree on a definitive strategy by 2023 [5]. Recently at the European level, the Parliament and the Council reached an agreement on the CO2 emissions of ships, in order to align any EU action with the targets set by the IMO, with the support of the European Sea Ports Organization (ESPO) [6]. This compromise falls within the application of EU Directive 2003/87 [7]. Otherwise, if the IMO negotiations on a strategy for CO2 reduction measures have not achieved sufficient progress, the naval sector will be included in the application of EU Directive 2003/87 [8] on the Emissions Trading System (ETS) from 2023.

COP26, held in Glasgow in November 2021, concluded with the Glasgow Climate Pact, which has been agreed by all the 197 participating countries. The Pact aims to keep limiting global warming to 1.5C above pre-industrial levels, but recognises that limiting global warming to this target requires rapid, deep and sustained reductions in global greenhouse gas emissions (GHG). Concerning maritime sector, even though the industry as a whole is already under great pressure to comply with the International Maritime Organization (IMO)’s progressively tightening emission standards, there is a consensus in the sector that the current targets of reducing annual GHG by at least 50% compared to 2008, by 2050, are inadequate.

In the lead-up to COP26 a Call to Action for Shipping Decarbonization had been signed by more than 200 companies and organizations. The Call to Action includes a request for the IMO to set a target for zero emission shipping by 2050. A similar Declaration on Zero Emission Shipping by 2050 has been signed by 14 countries during COP26.

The Secretary General of the IMO has acknowledged at COP26 that shipping must raise its environmental targets, but whether the 174 IMO member states will be persuaded to agree to a revision is yet to be seen. The current revision of the GHG targets is due in 2023, but there is increasing pressure for this to be addressed during the forthcoming IMO Marine Environment Protection Committee (MEPC) meeting scheduled in London next week, between 22 and 26 November 2021. The Glasgow Climate Pact further provides that, to keep the 1.5C target achievable, emission reduction plans are to be revised yearly.

During COP 26, in terms of alternative sources of energy, the technical experts operating in the maritime sector agree that there is no single solution. Different energy sources are likely to be used on ships depending on the needs, such as hydrogen, batteries, wind, methanol, and clean technology retrofits may be installed on existing vessels during the transition.

From leading companies to start-ups, some shipowners are already moving in this direction, by developing innovative new builds or by re-fitting their existing fleet. A.P. Møller - Mærsk announced they will introduce a series of 8 large ocean-going container vessels capable of being operated on carbon neutral methanol by 2024. However, the adoption of new zero-emission technologies on a larger scale will require infrastructure, the adoption of new systems by the market, sufficient investments and a clear regulatory framework.

Over 20 countries signed the Clydebank Declaration during COP26, pursuant to which the signatories have pledged to create emission-free corridors that will encourage the development of alternative fuels. The plan is for at least six green shipping corridors to be launched by 2025, and to see many more corridors in operation by 2030.

IMO was be present at COP 27, the United Nations climate conference which takes place in Egypt from 6-18 November 2022. IMO was highlighted that international shipping is indispensable to the world and is a vital industry to support the UN Sustainable Development Goals and the global energy transition.

Amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI enter into force on 1 November 2022. Developed under the framework of the Initial IMO Strategy on Reduction of GHG Emissions from Ships agreed in 2018, these technical and operational amendments require ships to improve their energy efficiency in the short term and thereby reduce their greenhouse gas emissions.

From 1 January 2023 it will be mandatory for all ships to calculate their attained Energy Efficiency Existing Ship Index (EEXI) to measure their energy efficiency and to initiate the collection of data for the reporting of their annual operational carbon intensity indicator (CII) and CII rating. This means that the first annual reporting will be completed in 2023, with initial CII ratings given in 2024.

Beside contributing to global warming, maritime sector is a significant cause of harmful air pollution. The main pollutant gases emitted by ships are nitrogen oxides (NO_x) and sulphur dioxide (SO2) [9]. NO_x gases produced during combustion, react to form smog, acid rain and contribute to the formation of particulate matter. NOx causes health issues like respiratory inflammation and increase the response to allergens. Fuel oils used on board ships contain sulphur which, following combustion in the engine, ends up in SOx emissions. It is harmful to human health and it can lead to acid rain contributing to the acidification of the oceans. A study submitted to Marine Environment Pro-tection Committee (MEPC) in 2016 by Finland, estimated that not reducing the SOx limit for ships from 2020, the air pollution from ships would contribute to hundreds of thousands of premature deaths worldwide between 2020-2025. So, a reduction in the limit of fuel oil sulphur content will have tangible health benefits and protects the environment. Moreover, it is necessary to consider not only the fuel oils, essential for the activity of ships, but also all the products of common and daily use that on board any type of boat is used in large quantities (cleaning products, maintenance of small and large plants). These represent a minimum percentage of environmental pollution compared to the per-centages of pollution generated by propulsion systems but must be taken into considera-tion when you want to carry out an in-depth investigation of the subject.

In addition to GHG and pollutant emissions due to fuel consumption for propulsion, the assessment of GHG emissions due to onboard waste management systems could be of great importance [8].

Management and production of waste in the context of the naval sector is indeed an issue of interesting relevance: a cruise ship, with its capacity to host about 5000 people, a length often in excess of 300 metres, and a gross tonnage of over 100000 tons, is like a small floating city which, also considering the logistical and management peculiarities, can produce a huge quantity of waste-about 70 times more than a typical cargo ship. Ship cruises represent less than 1% of the global merchant fleet, but it has been estimated that they are responsible for 25% of all the waste produced by the entirety of merchant ships [10]. Onboard waste is distinguished in two main categories: "garbage", that is the kind of waste listed and regulated in the International Marpol Convention (e.g., paper and cardboard, plastic, food, ashes of incinerator, metals, glass); and "not Marpol" or "special" (as defined in Italian laws applicable to this kind of waste) which can be-depending on their features-hazardous or non-hazardous. Waste must be differentiated on board by type and unloaded separately in order to join the recovery and recycling programs in the ports that carry out this activity. More specifically, waste can be divided as follows: oil-ballast water; oil-oily bilge water; black water (sewage); grey water (wastewater generated in households or office buildings from streams without faecal contamination); solid waste (garbage); hazardous waste. An interesting aspect to explore could be the evaluation of the criteria to be met to access the possibility of converting potential GHG emission reductions-generated by the strategies and methods of waste management implemented in negotiable carbon credits that can be subjected to the subsequent certification and registration process [11].

The goal of this study is to analyze the feasibility of the implementation of impact mitigation measures for maritime transport. UNFCCC methodologies and Life Cycle Assessment are followed to calculate the overall impact of the alternatives analyzed in the research.

First, different waste management systems and strategies that can be implemented on-board, in relation to their potential to reduce GHG emissions, is assessed. In particular, the study identify, among the different methods of waste management, either those for which the reduction in GHG emissions is significant or those for which waste becomes a resource, according to a model of circular economy, which overcomes the concept of end of life for waste, in accordance with the guidelines of the European Union. Then environmental performance indicators for maritime transport for different types of ships are developed in order to monitor and evaluate the instantaneous environmental impact in air. In particular, the main goal of this activity is to make an objective assessment of the environmental impact of the ship in real time to allow possible adjustments and improve energy efficiency.

Chapter 2

Scientific and regulation background

2.1 Global impact of maritime sector

In the following, specific issues related to the global impact of maritime sector are presented concerning the following aspects: greenhouse gas emissions, pollutants emissions and waste production.

2.1.1 GHG emissions

The shipping sector is one of the major emitters of greenhouse gas emissions (GHG) and it is a significant cause of harmful air pollution such as nitrogen oxides (NO_x) and sulphur dioxide (SO_2).

Concerning greenhouse gas emissions (GHG), maritime transport emits around 1000 million tonnes of CO_2 annually and hence contribute to global greenhouse gas emissions.

The greenhouse gas (GHG) emissions - including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), expressed in CO_{2e} (Carbon Dioxide equivalent)- of total shipping (international, domestic and fishing) have increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018 (9.6% increase). In 2012, 962 million tonnes were CO_2 emissions, while in 2018 this amount grew 9.3% to 1,056 million tonnes of CO_2 emissions.

The share of shipping emissions in global anthropogenic emissions has increased from 2.76% in 2012 to 2.89% in 2018. Under a new voyage-based allocation of international shipping, CO_2 emissions have also increased over this same period from 701 million tonnes in 2012 to 740 million tonnes in 2018 (5.6% increase), but to a lower growth rate than total shipping emissions and represent an approximately constant share of global CO_2 emissions over this period (approximately 2%), as shown in Table 2.1.

Using the vessel-based allocation of international shipping taken from the Third IMO GHG Study, CO_2 emissions have increased over the period from 848 million tonnes in 2012 to 919 million tonnes in 2018 (8.4% increase). Due to developments in data and inventory methods, this study is the first IMO GHG Study able to produce greenhouse gas inventories that distinguish domestic shipping from international emissions on a voyage basis in a way which, according to the consortium, is exactly consistent with the IPCC guidelines and definitions. Projecting the same method to 2008 emissions, this study estimates that 2008 international shipping GHG emissions (in CO_{2e}) were 794 million tonnes (employing the method used in the Third IMO GHG Study, the emissions were 940 million tonnes CO_{2e}).

Carbon intensity 2008, 2012 - 2018

Year	Global antropogenic CO_2 emissions	Total shipping CO_2	Total shipping as a percentage of global	Vojage-based International shipping CO_2	Vojage-based International shipping as a percentage of global	Vassel-based International shipping CO_2	Vassel-based International shipping as a percentage of global
2012	34793	962	2,76%	701	2,01%	848	2,44%
2013	34959	957	2,74%	684	1,96%	837	2,39%
2014	35255	964	2,74%	681	1,93%	846	2,37%
2015	35239	991	2,81%	700	1,99%	859	2,44%
2016	35380	1026	2,90%	727	2,05%	894	2,53%
2017	35810	1064	2,97%	746	2,08%	929	2,59%
2018	36573	1056	2,89%	740	2,02%	919	2,51%

Table 2.1: Total shipping and voyage-based and vassel-based international shipping CO_2 emissions 2012-2018 (million tonnes)

Year	EEOI (gCO2/t/nm)				AER (gCo2/dwt/nm)				DIST (kgCO2/nm)				TIME (tCO2/hr)			
	Vassel-based		Voyage-based		Vassel-based		Voyage-based		Vassel-based		Voyage-based		Vassel-based		Voyage-based	
	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change
2008	17,10	-	15,16	-	8,08	-	7,40	-	306,46	-	350,36	-	3,64	-	4,38	-
2012	13,16	-23,1%	12,19	-19,6%	7,06	-12,7%	6,61	-10,7%	362,65	18,3%	387,01	10,5%	4,32	18,6%	4,74	8,1%
2013	12,87	-24,7%	11,83	-22,0%	6,89	-14,8%	6,40	-13,5%	357,73	16,7%	380,68	8,7%	4,18	14,6%	4,57	4,1%
2014	12,34	-27,9%	11,29	-25,6%	6,71	-16,9%	6,20	-16,1%	360,44	17,6%	382,09	9,1%	4,17	14,4%	4,54	3,5%
2015	12,33	-27,9%	11,30	-25,5%	6,64	-17,8%	6,15	-16,9%	366,56	19,6%	388,62	10,9%	4,25	16,6%	4,64	5,7%
2016	12,22	-28,6%	11,21	-26,1%	6,58	-18,6%	6,09	-17,7%	373,46	21,9%	397,05	13,3%	4,35	19,3%	4,77	8,7%
2017	11,87	-30,6%	10,88	-28,2%	6,43	-20,4%	5,96	-19,5%	370,97	21,0%	399,38	14,0%	4,31	18,2%	4,79	9,2%
2018	11,67	-31,8%	10,70	-29,4%	6,31	-22,0%	5,84	-21,0%	376,81	23,0%	401,91	14,7%	4,34	19,1%	4,79	9,2%

Table 2.2: Estimates on carbon intensity of international shipping and percentage changes compared to 2008 vallues

- Carbon intensity has improved between 2012 and 2018 for international shipping as a whole, as well as for most ship types. The overall carbon intensity, as an average across international shipping, was 21 and 29% better than in 2008, measured in AER and EEOI respectively in the voyage-based allocation; while it was 22 respectively 32% better in the vessel-based allocation (Table 2.2). Improvements in carbon intensity of international shipping have not followed a linear pathway and more than half have been achieved before 2012. The pace of carbon intensity reduction has slowed since 2015, with average annual percentage changes ranging from 1 to 2%.

- Annual carbon intensity performance of individual ships fluctuated over years. The upper and lower quartiles of fluctuation rates in EEOI of oil tankers, bulk carriers and container ships were around ±20%, ±15% and ±10% respectively. Quartiles of fluctuation rates in other metrics were relatively modest, yet still generally reaching beyond ±5%. Due to certain static assumptions on weather and hull fouling conditions, as well as the non-timely updated AIS entries on draught, actual fluctuations were possibly more scattered than estimated, especially for container ships.

- Emissions are projected to increase from about 90% of 2008 emissions in 2018 to 90-130% of 2008 emissions by 2050 for a range of plausible long-term economic and energy scenarios (Figure 2.1).

- Emissions could be higher (lower) than projected when economic growth rates are higher (lower) than assumed here or when the reduction in GHG emissions from land-based sectors is less (more) than would be required to limit the global temperature increase to well below 2 degrees centigrade.

- Although it is too early to assess the impact of COVID-19 on emission projections quantitatively, it is clear that emissions in 2020 and 2021 will be significantly lower. Depending on the recovery trajectory, emissions over the next decades maybe a few percent lower than projected, at most. In all, the impact of COVID-19 is likely to be smaller than the uncertainty range of the presented scenarios.

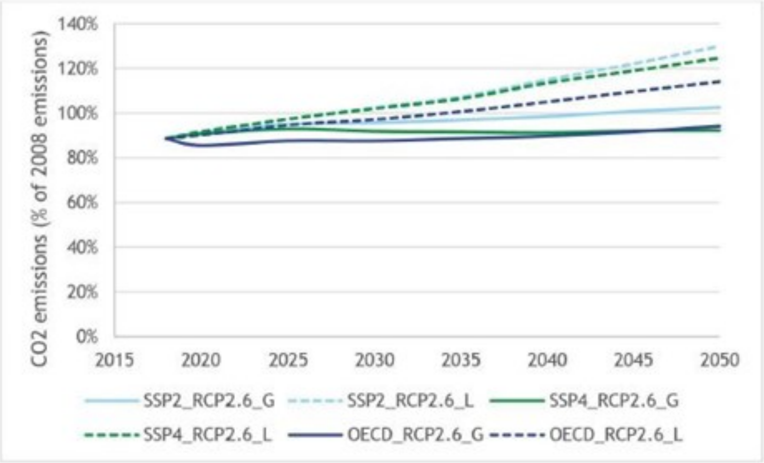


Figure 2.1: Projections of maritime ship emissions as a percentage of 2008 emissions

2.1.2 Pollutant emissions

In 1997, a new annex was added to the International Convention for the Prevention of Pollution from Ships (MARPOL). The regulations for the Prevention of Air Pollution from Ships (Annex VI) seek to minimize airborne emissions from ships (SO_x, NO_x, ODS, VOC shipboard incineration) and their contribution to local and global ai r pollution and environmental problems. Annex VI entered into force on 19 May 2005 and a revised Annex VI with significantly tightened emissions limits was adopted in October 2008 which entered into force on 1 July 2010.

NO_x gases produced during combustion, react to form smog, acid rain and contribute to the formation of particulate matter. NO_x causes health issues like respiratory inflammation and increase the response to allergens.

Fuel oils used on board ships contain Sulphur which, following combustion in the engine, ends up in SO_x emissions. It is harmful to human health and it can lead to acid rain contributing to the acidification of the oceans. A study submitted to Marine Environment Protection Committee (MEPC) in 2016 by Finland, estimated that not reducing the SO_x limit for ships from 2020, the air pollution from ships would contribute to hundreds of thousands of premature deaths worldwide between 2020-2025. So, a reduction in the limit of fuel oil Sulphur content will have tangible health benefits and protects the environment.

Third IMO Greenhouse Gas Study 2014 [12] presents emissions scenarios for GHGs and for other relevant substances (No_x, SO_x). These socioeconomic and energy scenarios present possible ways in which emissions could develop and can inform policymakers and scientists about the development of the environmental impact of shipping. Maritime emissions projections show an increase in fuel use and GHG emissions in the period up to 2050, due to an increase in demand for maritime transport. The rise in emissions is most pronounced in scenarios that combine the use of fossil fuels with high economic growth and it is lower in scenarios that involve a transition to renewable energy sources. It is necessary to mitigate emissions growth through actions on efficiency and regulatory work.

Maritime emissions projections show an increase in fuel use and GHG emissions in the period up to 2050, despite significant regulatory and market-driven improvements in efficiency. Depending on future economic and energy developments, BaU scenarios project an increase of 50%-250% in the period up to 2050. Further action on efficiency and emissions can mitigate emissions growth, although all scenarios but one project emissions in 2050 to be higher than in 2012. The main driver of the emissions increase is the projected rise in demand for maritime transport. This rise is most pronounced in scenarios that combine the sustained use of fossil fuels with high economic growth and is lower in scenarios that involve a transition to renewable energy sources or a more moderate growth pattern.

Among the different cargo categories, demand for transport of unitized cargoes is projected to increase most rapidly in all scenarios (Table 2.3 and Figure 2.2). The emissions projections show that improvements in efficiency are important in mitigating emissions growth, but even the most significant improvements modelled do not result in a downward trend. Compared to regulatory or market-driven improvements in efficiency, changes in the fuel mix have a limited impact on gHg emissions, assuming that fossil fuels remain dominant. The projections are sensitive to the assumption that the productivity of the fleet, which is currently low, will revert to its long-term average by taking more cargo on board. If productivity does remain at its current level, or if it increases by increasing the number of days at sea or ship speed, emissions are likely to increase to a higher level.

		Scenario	**2012**	**2020**	**2050**
			index (2012 = 100)	**index (2012 = 100)**	**index (2012 = 100)**
Greenhouse gases	CO_2	Low LNG	100	108 (107-112)	183 (105-347)
		High LNG	100	106 (105-109)	173 (99-328)
	CH_4	Low LNG	100	1,600 (1,600-1,700)	10,500 (6,000-20,000)
		High LNG	100	7,550 (7,500-7,900)	32,000 (19,000-61,000)
	N_2O	Low LNG	100	108 (107-112)	181 (104-345)
		High LNG	100	105 (104-109)	168 (97-319)
	HFC		100	106 (105-108)	173 (109-302)
	PFC		-	-	-
	SF_6		-	-	-
Other relevan substances	NO_x	Constant ECA	100	107 (106-110)	161 (93-306)
		More ECAs	100	99 (98-103)	130 (75-247)
	SO_x	Constant ECA	100	64 (63-66)	30 (17-56)
		More ECAs	100	55 (54-57)	19 (11-37)
	PM	Constant ECA	100	77 (76-79)	84 (48-159)
		More ECAs	100	65 (64-67)	56 (32-107)
	NMVOC	Constant ECA	100	108 (107-112)	183 (105-348)
		More ECAs	100	106 (105-110)	175 (101-333)
	CO	Constant ECA	100	112 (111-115)	206 (119-392)
		More ECAs	100	123 (122-127)	246 (142-468)

Table 2.3: Emissions of CO_2 and other substances in 2012, 2020 and 2050 (million tonnes)

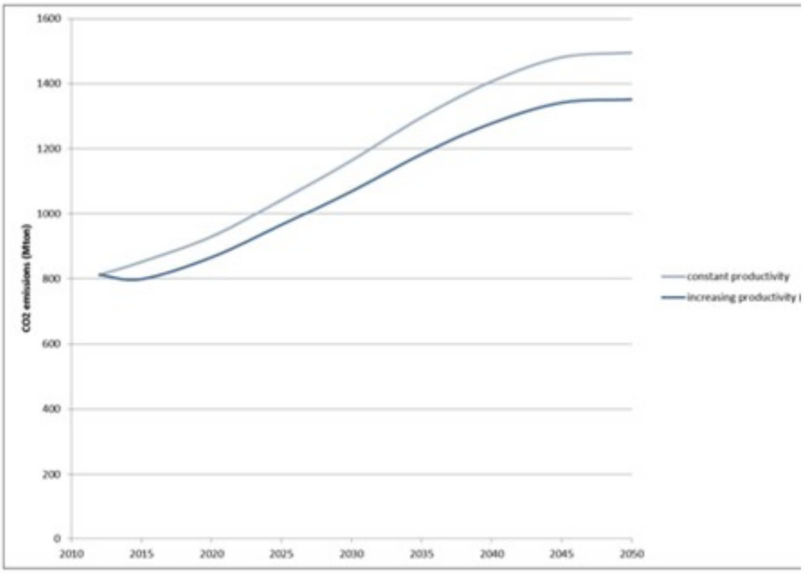


Figure 2.2: Impact of productivity assumptions on emissions projections

2.1.3 Waste production

Management and production of waste in the context of the naval sector is indeed an issue of interesting relevance: a cruise ship, with its capacity of hosting about 5000 people, a length often passing 300 metres and a gross tonnage of over 100000 tons, is like a small floating city which, also considering the logistical and management peculiarities, can produce a huge quantity of waste, about 70 times more than a typical cargo ship. Ship cruises represent less than 1% of the global merchant fleet, but it has been estimated that they are responsible for 25% of all the waste produced by the entirety of merchant ships [10].

Onboard waste is distinguished in two main categories: “garbage”, that is the kind of waste listed and regulated in the International Marpol Convention (e.g. paper and cardboard, plastic, food, ashes of incinerator, metals, glass); and “not Marpol” or “special” (as defined in Italian laws applicable to this kind of waste) which can be - depending on their features - hazardous or non-hazardous. Waste must be differentiated on board by type and unloaded separately in order to join the recovery and recycling programs in the ports that carry out this activity. More specifically, waste can be divided as follows: oil - ballast water; oil - oily bilge water; black water (sewage); grey water; solid waste (garbage); hazardous waste. An interesting aspect to explore could be the evaluation of the criteria to be met to access the possibility of converting potential GHG emission reductions - generated by the strategies and methods of waste management implemented - in negotiable carbon credits that can be subjected to the subsequent certification and registration process [11]. With the aim of evaluating waste management alternatives in a circular economy perspective, the study examines a combined system for the optimisation of ship waste management and assesses its possible use for energy purposes [13].

2.2 Regulation

Shipowners have to comply with regulations on protection of the environment. The main international convention covering prevention of pollution of the marine environment by ships is the International Convention for the Prevention of Pollution from Ships (MARPOL). It was adopted in 1973 by IMO. IMO is the acronym of International Maritime Organization, the United Nation agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. Committee of IMO empowered to consider prevention and control of pollution of ships is the Marine Environment Protection Committee (MEPC). In particular, it concerns the adoption and amendments of conventions and other regulations. This committee updates MAR-

POL by amendments through the years.

In this thesis the following regulations are taken into account:

- Regulation (EU) 2015/757 on the monitoring, reporting and verification (MRV) of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC [14]
- Regulation 4 & Equivalents of revised MARPOL Annex VI (MEPC.176(58)) [15]
- Nitrogen oxides (NO_x) of revised MARPOL Annex VI (MEPC.176(58))

2.2.1 Regulation on CO_2 emissions

At the present time, there are regulated limits of NO_x and SO_2 emissions, while there are no national or regional restrictions on CO_2 emissions from maritime shipping. Nevertheless, in July 2011 IMO adopted technical and operational measures to reduce emissions of greenhouse gases and increase the ship energy efficiency. These measures include the following steps:

- Design the energy efficient ships through the Energy Efficiency Design Index (EEDI). EEDI is the tool that is used during the design of construction stage of the vessel and it is the amount of CO2 emitted by the ship (in grams) per tonne-mile of work. To consider a ship energy-efficient, the attained EEDI need to be less than the required EEDI.
- Plan to operate and improve the energy efficiency of the ships through the Ship Energy Efficiency Management Plan (SEEMP). It is a ship specific plan that provides a mechanism to improve the energy efficiency of a ship in a cost- effective manner.
- Monitor energy efficiency and collect data for further improvements through Energy Efficiency Operation Index (EEOI), that is a voluntary tool for measuring the operational energy efficiency.

At European Level, in 2013 the European Commission sets out a strategy for reducing maritime greenhouse gas emissions. The strategy consists of three steps:

- The first is a system of monitoring, reporting and verification (MRV) of carbon dioxide emissions from ships over five thousand gross tonnage calling at European ports.

- The second is setting targets for greenhouse gas reduction, while the last step provides for market-based measures.
- The last step is verification. Verifiers responsibilities include ensuring that monitoring plans and emissions reports are correct and in compliance with the requirements. Assurance is to be provided by assessing the reliability, credibility and accuracy of the monitoring systems and of the reported data. Verification of emissions reports starts in January 2019.

At the moment it is going through the first step governed by the 2015 (757) Regulation of the European Union, that lists the requirements on the monitoring, reporting and verification of carbon dioxide emissions from the maritime transport. Data collection started on first January 2018.

Companies shall monitor emissions for each ship on a per-voyage or annual basis depending on ship type and schedule. The aggregated ship emissions and efficiency data will be published by the European Commission by thirtieth June 2019 and then every consecutive year.

Shipping emissions represent around 13% of the overall EU greenhouse gas emissions from the transport sector, so the Commission set out a strategy towards reducing GHG emissions from the shipping industry.

The strategy consists of 3 consecutive steps:

- Monitoring, reporting and verification of CO_2 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.

The contribution of the shipping sector to emission reductions consistent with the temperature goals of the Paris Agreement remains an important issue in the EU.

The recent amendment to the EU Emissions Trading System (ETS) Directive, by Directive (EU) 2018/410 of the European Parliament and the Council, emphasises the need to act on shipping emissions as well as all other sectors of the economy.

The Directive also states that the Commission should regularly review IMO action and calls for action to address shipping emissions from the IMO or the EU to start from 2023, including preparatory work and stakeholder consultation.

On 14 July 2021, the European Commission adopted a series of legislative proposals setting out how it intends to achieve climate neutrality in the EU by 2050, including the intermediate target of an at least 55% net reduction in greenhouse gas emissions by 2030. The package proposes to revise several pieces of EU climate legislation, including the EU ETS, Effort Sharing Regulation, transport and land use legislation, setting out in real terms the ways in which the Commission intends to reach EU climate targets under the European Green Deal [16].

Fit for 55' package [17], which contributes to reaching the EU objectives - set in the European Climate Law - to reduce greenhouse gas (GHG) emissions by at least 55% by 2030 (compared to 1990) and to achieve climate neutrality (net zero GHG emissions) by 2050. It presents three partially cumulative policy options against the baseline, and explains the methodology for selecting the measures and policy options.

The measures have been grouped in each policy option in three intervention areas:

- improvement of the penetration rate of RLF;
- stimulation of the introduction of zero-emissions energy solutions;
- certification, reporting and enforcement.

The documents explains that the initiative would concern vessels beyond 5000 gross tonnes, as they are responsible for 90% of CO_2 emissions in the maritime sector.

The Baseline (no EU action) builds on the EU reference baseline scenario 2020 (a common baseline for the 'fit for 55' proposals), but also takes into account the impacts of the coronavirus pandemic and the EU Member States' national energy and climate plans. According to the baseline projections, tank-to-wake CO_2 emissions would grow by 14% by 2030 and by more than 30% by 2050 (relative to 2015). In addition, it is expected that the uptake of biofuels (1.3% of the fuel mix by 2050) and the electricity use at berth (0.1% of the fuel mix by 2050) would remain limited. On the other hand, the share of LNG in the fuel mix is expected to grow (19% by 2050). It explains that the baseline scenario does not consider the other 'fit for 55' proposals in order to ensure 'a consistent approach with the IAs accompanying the other 'Fit for 55' initiatives'.

Option 1 (Prescriptive approach on the choice of technologies) would improve the penetration rate of RLF by establishing a volume-based minimum share of RLF (blending mandate) for ships in navigation calling at EU ports (measure M1) from 2025 onwards. In this option, the technology would be chosen by the regulator. In addition, Option 1 would provide a mandate from 2030 onwards, for using on-shore power supply (OPS) or corresponding alternatives (e.g. hydrogen, batteries) for the most polluting ships (three categories identified on the basis of MRV data 2018: containerships, passenger ships, ro-pax ships) in ports (M3). Option 1 would also provide guidance to facilitate the uptake of technology (M4). This option would reflect the advance in technological development and regularly update the list of selected fuels. As a measure to stimulate the introduction of zero-emissions energy solutions, this option would increase awareness-raising, exchange of experience, and encourage industry-led programmes in support of the uptake of alternative fuels (M6). In terms of certification, reporting and enforcement, Option 1 would establish an EU-wide methodology to certify the well-to-wake performance of fuels (M7), and introduce requirements for certification and acceptance of bunkering supplied in third countries (M8). This option would also provide a set of rules to follow for monitoring, reporting and verification - based on the EU MRV Regulation - of consumption of alternative fuels (M9), and port state control procedures for the use of RLF (M10).

Option 2 (Goal-based approach on technologies) would - contrary to the volume-based blending mandate in Option 1 (M1) - set maximum targets on the GHG intensity of the energy used by vessels in navigation and at berth (M2) from 2025 onwards in order to improve the uptake of RLF. Maritime operators would be free to choose fuels and technologies. Otherwise, Option 2 proposes the same measures as Option 1.

Option 3 (Goal-based approach on technology and reward mechanisms for over-achievers) (preferred option) contains the same measures as Option 2, but additionally proposes incentives to stimulate the introduction of zero-emission energy solutions and to reward over-achievers (M5). This option would attribute greater weight to zero-emission solutions when considering ships' performance in terms of achieving the defined annual target ('multipliers for zero-emission options'). It would also provide a mechanism for voluntary transfers and compensation of balances between operators (from over-achievers to under-achievers) (e.g. pool compliance at company level), which would be included in the MRV system.

As required in the Better Regulation Guidelines, the document presents a sufficiently broad range of options. It clearly indicates the links between the specific objectives and policy measures of the policy options, and explains the differences and similarities of the three options.

However, some elements 'Fit for 55' package: Fuel EU Maritime could have been explained in more detail, for example, the measure concerning requirements for certification and acceptance of bunkering supplied in third countries (M8). Moreover, stakeholders' views on the policy options are not indicated in the description of options.

2.2.2 Regulation on limits and emissions of NO_x and SO_2

The main international convention covering prevention of pollution of the marine environment by ships is the International Convention for the Prevention of Pollution from Ships (MARPOL). It was adopted in 1973 by International Maritime Organization, the United Nation agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships.

Committee of IMO empowered to consider prevention and control of pollution of ships is the Marine Environment Protection Committee (MEPC). In particular, it concerns the adoption and amendments of conventions and other regulations. This committee updates MARPOL by amendments through the years. In this study the following regulations are taken into account:

- Regulation (EU) 2015/757 on the monitoring, reporting and verification (MRV) of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC (Regulation (EU) 2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC, 2015);
- Regulation 4 Equivalents of revised MARPOL Annex VI (MEPC.176(58)) (International Maritime Organization (IMO), Resolution MEPC.176(58), Amendments to the Annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 1973, as modifed by the protocol of 1978, relating thereto, 2008);
- Regulation 13 Nitrogen oxides (NO_x) of revised MARPOL Annex VI (MEPC.176(58)) (International Maritime Organization (IMO);
- Resolution MEPC.176(58), Amendments to the Annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 1973, as modifed by the protocol of 1978, relating thereto, 2008);
- Regulation 14 Sulphur oxides (SO_x) and particulate matter of revised MARPOL Annex VI (MEPC.176(58)) (International Maritime Organization (IMO);
- Resolution MEPC.176(58), Amendments to the Annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 1973, as modifed by the protocol of 1978 relating thereto, 2008);
- Resolution MEPC.259;

- 2015 Guidelines for exhaust gas cleaning systems (International Maritime Organization (IMO);
- Resolution MEPC.259, 2015 Guidelines for exhaust gas cleaning systems, 2015.

The MARPOL conventions includes Annex VI titled Regulations for the prevention of air pollution from ships that sets, among others, limits on NO_x and SOx emissions from ship exhausts. Annex VI defines two requirement types of emission and fuel quality:

- global requirements;
- more stringent requirements applicable to ships in Emission Control Areas (ECAs).

ECAs are sea areas in which stricter controls were set up to limit airborne emissions from the vessels sailing in them. These strict rules come into effect under Regulation 13, which covers NO_x emissions (NO_x Emission Control Area NECA) and under Regulation 14, which covers SOx emissions (SOx Emission Control Area SECA).

ECA zones apply to the North American area (including most of the US and Canadian coast and the area surrounding US Caribbean territory), the Baltic Sea and the North Sea (Figure 2.3).

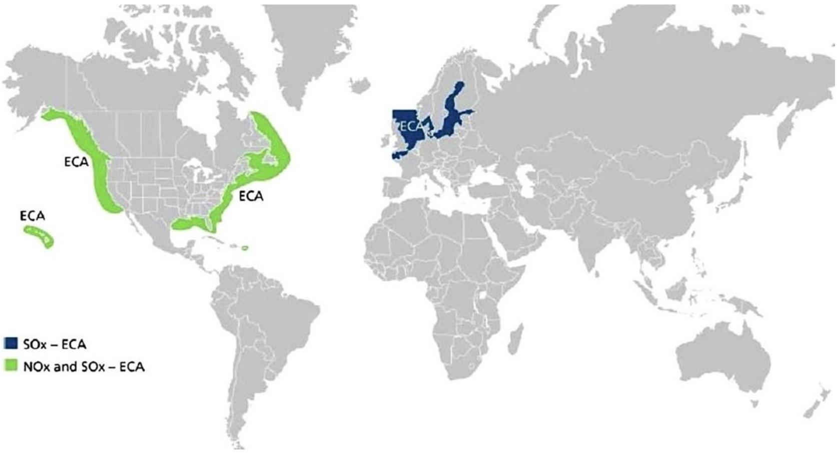


Figure 2.3: Map of Emission Control Areas in Europe and North America [18]

The NO_x emission limits of Regulation 13 of MARPOL Annex VI apply to each marine diesel engine with a power output of more than 130 kW installed on the ship. NO_x emission limits are set for diesel engines depending on the engine maximum operating speed (n [rpm]) and on the date of construction of the ship. The requirements of these emission levels are divided into three tiers: Tier I and Tier II limits are global, while the Tier III standards apply only in NECAs (Table 2.4).

Tier	**Date of built**	**NO_x emission limit [g/kWh]**		
		$n < 130$	$130 \leq n < 2000$	$n \geq 2000$
I	1 January 2000	$17,0$	$45 \cdot n^{(-0,2)}$	$9,8$
II	1 January 2011	$14,4$	$44 \cdot n^{(-0,23)}$	$7,7$
III	1 January 2016	$3,4$	$9 \cdot n^{(-0,2)}$	$2,0$

Table 2.4: MARPOL Annex VI NO_x emission limits

Regulation 14 of MARPOL Annex VI includes caps on fuel oil sulphur content as a measure to control SOx emissions, depending on the navigation area (Table 2.5).

Year	**Fuel oil sulphur content [% m/m]**	
	SECA	**Outside SECA**
Prior to 1 July 2010	1,50	4,50
1 July 2010	1,00	
1 January 2012		3,50
1 January 2015	0,10	
1 January 2020		0,50

Table 2.5: MARPOL Annex VI fuel oil sulphur content limits

European Union and Italy transposed into legislation the fuel oil sulphur content limits respectively through the Directive 2012/33/EC and the Legislative Decree No 112 of 16 July 2014 that amending the Legislative Decree No 152 of 3 April 2006.

2.2.3 Regulation on waste management

Regulations for the prevention of pollution by garbage from ships are contained in Annex V of MARPOL. Garbage from ships can be just as deadly to marine life as oil or chemicals.

The greatest danger comes from plastic, which can float for years. Fish and marine mammals can in some cases mistake plastics for food and they can also become trapped in plastic ropes, nets, bags and other items - even such innocuous items as the plastic rings used to hold cans of beer and drinks together.

It is clear that a good deal of the garbage washed up on beaches comes from people on shore - holiday-makers who leave their rubbish on the beach, fishermen who simply throw unwanted refuse over the side - or from towns and cities that dump rubbish into rivers or the sea. But in some areas most of the rubbish found comes from passing ships which find it convenient to throw rubbish overboard rather than dispose of it in ports.

For a long while, many people believed that the oceans could absorb anything that was thrown into them, but this attitude has changed along with greater awareness of the environment. Many items can be degraded by the seas - but this process can take months or years.

Persuading people not to use the oceans as a rubbish tip is a matter of education - the old idea that the sea can cope with anything still prevails to some extent but it also involves much more vigorous enforcement of regulations such as MARPOL Annex V.

MARPOL Annex V seeks to eliminate and reduce the amount of garbage being discharged into the sea from ships. Unless expressly provided otherwise, Annex V applies to all ships, which means all ships of any type whatsoever operating in the marine environment, from merchant ships to fixed or floating platforms to non-commercial ships like pleasure crafts and yachts.

Although the Annex is optional1, it did receive a sufficient number of ratifications to enable entry into force on 31 December 1988. Today, more than 150 Countries have signed up to MARPOL Annex V.

MARPOL Annex V generally prohibits the discharge of all garbage into the sea, except as provided otherwise in regulations 4, 5, and 6 of the Annex, which are related to food waste, cargo residues, cleaning agents and additives and animal carcasses. An overview of the MARPOL Annex V discharge provisions can be accessed here. Exceptions with respect to the safety of a ship and those on board and accidental loss are contained in regulation 7 of Annex V.

Under MARPOL Annex V, garbage includes all kinds of food, domestic and operational waste, all plastics, cargo residues, incinerator ashes, cooking oil, fishing gear, and animal carcasses generated during the normal operation of the ship and liable to be disposed of continuously or periodically. Garbage does not include fresh fish and parts thereof generated as a result of fishing activities undertaken during the voyage, or as a result of aquaculture activities.

To assist Governments, ships and port operators in implementing relevant requirements under MAPROL Annex V, MEPC has developed and adopted the Guidelines for the implementation of MARPOL Annex V, known as a living document, the latest of which is resolution MEPC.295 [19].

Port reception facilities

The effectiveness of ships to comply with the discharge requirements of MARPOL depends largely upon the availability of adequate port reception facilities, especially within special areas. Hence, MARPOL Annex V also obliges Governments to ensure the provision of adequate reception facilities at ports and terminals for the reception of garbage without causing undue delay to ships, and according to the needs of the ships using them.

As provided in regulation 8.3, Small Island Developing States (SIDS) could satisfy the requirements for providing adequate port reception facilities through regional arrangements when, because of those States' unique circumstances, such arrangements are the only practical means to satisfy these requirements. Parties participating in a regional arrangement must develop a Regional Reception Facility Plan, taking into account the guidelines developed by IMO2.

Special areas

The special areas established under Annex V are:

- the Mediterranean Sea area;
- the Baltic Sea area;
- the Black Sea area;
- the Red Sea area;
- the Gulfs area;
- the North Sea area;
- the Wider Caribbean Region;
- the Antarctic area.

These are sea areas where for recognized technical reasons relating to their oceanographic and ecological condition and the particular character of traffic, such as heavy maritime traffic, low water exchange, extreme ice states, endangered marine species, etc., the adoption of special mandatory methods for the prevention of marine pollution by garbage is required.

Port state control

Provisions to extend port State control to cover operational requirements as regards prevention of marine pollution were adopted in 1994 and entered into force on 3 March 1996. Like similar amendments to the other MARPOL Annexes, regulation 9 of Annex V makes it clear that port State control officers can inspect a foreign-flagged ship at a port or an offshore terminal of its State ”where there are clear grounds for believing that the master or crew are not familiar with essential shipboard procedures relating to the prevention of pollution by garbage.

Placard

Regulation 10.1 also requires every ship of 12 metres in length or over and every fixed or floating platform to display placards notifying passengers and crew of the disposal requirements of the Annex; these placards should be written in the working language of the ship’s crew and also in English, French or Spanish for ships travelling to other States’ ports or offshore terminals.

Garbage management plan

All ships of 100 gross tonnage and above, every ship certified to carry 15 persons or more, and every fixed or floating platform must carry a garbage management plan on board, which includes written procedures for minimizing, collecting, storing, processing and disposing of garbage, including the use of the equipment on board (regulation 10.2). The garbage management plan must designate the person responsible for the plan and be written in the working language of the crew. Resolution MEPC.220 [20] provides the 2012 Guidelines for the development of garbage management plans.

Garbage record book

Implementation and enforcement is also the focus of regulation 10.3, which requires all ships of 400 gross tonnage and above and every ship which is certified to carry 15 persons or more engaged in voyages to ports and offshore terminals under the jurisdiction of another Party to the Convention and every fixed or floating platform to provide a Garbage Record Book and to record all disposal and incineration operations. The date, time, position of the ship, description of the garbage and the estimated amount incinerated or discharged must be logged and signed. The Garbage Record Book must be kept for a period of two years after the date of the last entry. This regulation does not in itself impose stricter requirements - but it makes it easier to check that the regulations on garbage are being adhered to as it means ship personnel must keep track of the garbage and what happens to it. It could also prove an advantage to a ship when local officials are checking the origin of discharged garbage - if ship personnel can adequately account for all their garbage, they are unlikely to be wrongly penalised for discharging garbage when they have not done so. Appendix 2 of MARPOL Annex V provides a standard form for a Garbage Record Book.

Cargo residues

Cargo residues are defined as the remnants of any cargo which are not covered by other Annexes to the present Convention and which remain on deck or in holds following loading or unloading. They include loading and unloading excess or spillage, whether in wet or dry condition or entrained in wash water, but do not include cargo dust remaining on deck after sweeping or dust on the external surfaces of the ship (regulation 1.2 of Annex V). In addition to this definition, MARPOL Annex V also stipulates that only those cargo residues that cannot be recovered using commonly available methods for unloading could be considered for discharge.

A simplified overview of the regulations regarding the discharge of cargo residues under MARPOL Annex V can be accessed here. As a general rule, cargo residues which contain substances classified as harmful to the marine environment (HME) must not be discharged at sea, but have to be taken to port reception facilities. Regarding the discharge of cargo residues which do not contain any HME substances, the Annex establishes different requirements depending on whether they are contained in wash water or not.

Solid bulk cargoes must be classified and declared by the shipper as to whether or not they are harmful to the marine environment, in accordance with the criteria set out in appendix 1 of MARPOL Annex V.

Shipboard incinerator

The Standard Specification for Shipboard Incinerators (resolution MEPC.244 [21]) covers the design, manufacture, performance, operation and testing of incinerators designed to incinerate garbage and other shipboard waste.

Verification of compliance

Chapter 2 of MARPOL Annex V provides that Parties must use the provisions of the Code for Implementation in execution of their obligations and responsibilities, and be subject to the IMO Member State Audit Scheme (IMSAS) in accordance with the audit standard to verify compliance with and implementation of the Annex. The mandatory IMSAS commenced from 1 January 2016.

Polar regions

Chapter 3 of MARPOL Annex V makes use of the environment-related provisions of the Polar Code mandatory, and requires that ships trading the Polar Regions must comply with strict environmental provisions specific to the harsh conditions in Polar waters - the Arctic waters and the Antarctic area.

2.3 Mitigation strategies

The mitigation strategy is made up of three main required components: mitigation goals, mitigation actions, and an action plan for implementation. These provide the framework to identify, prioritize and implement actions to reduce risk to hazards.

2.3.1 GHG emissions

International Maritime Organization, IMO, as a specialized agency of the United Nations, is the main organization contributing contribute to the global fight against climate change, in support of the UN Sustainable Development Goal 13, to take urgent action to combat climate change and its impacts adopting mitigation strategies in the maritime sector. In particular, it has adopted mandatory measures to reduce emissions of greenhouse gases from international shipping, under IMO's pollution prevention treaty (MARPOL) - the Energy Efficiency Design Index (EEDI) mandatory for new ships, and the Ship Energy Efficiency Management Plan (SEEMP).

IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. Its main role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented.

Through IMO, the Organization's Member States, civil society and the shipping industry are already working together to ensure a continued and strengthened contribution towards a green economy and growth in a sustainable manner. The promotion of sustainable shipping and sustainable maritime development is one of the major priorities of IMO in the coming years.

As part of the United Nations family, IMO is actively working towards the 2030 Agenda for Sustainable Development and the associated Sustainable Development Goals (SDGs) . Indeed, most of the elements of the 2030 Agenda will only be realized with a sustainable transport sector supporting world trade and facilitating global economy. IMO's Technical Cooperation Committee has formally approved between the Organization's technical assistance work and the SDGs. While the oceans goal,SDG 14, is central to IMO, aspects of the Organization's work can be linked to all individual SDGs.

Energy efficiency, new technology and innovation, maritime education and training, maritime security, maritime traffic management and the development of the maritime infrastructure: the development and implementation, through IMO, of global standards covering these and other issues will underpin IMO's commitment to provide the institutional framework necessary for a green and sustainable global maritime transportation system.

2.3.1.1 Ships

In 2018, IMO adopted an initial strategy on the reduction of GHG emissions from ships, setting out a vision which confirms IMO's commitment to reducing GHG emissions from international shipping and to phasing them out as soon as possible. The initial strategy is described in the following.

IMO remains committed to reducing GHG emissions from international shipping and, as a matter of urgency, aims to phase them out as soon as possible in this century. The Initial Strategy identifies levels of ambition for the international shipping sector noting that technological innovation and the global introduction of alternative fuels and/or energy sources for international shipping will be integral to achieve the overall ambition. Reviews should take into account updated emission estimates, emissions reduction options for international shipping, and the reports of the Intergovernmental Panel on Climate Change (IPCC). Levels of ambition directing the Initial Strategy are as follows:

- carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships to review with the aim to strengthen the energy efficiency design requirements for ships with the percentage improvement for each phase to be determined for each ship type, as appropriate;

- carbon intensity of international shipping to decline to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008.

GHG emissions from international shipping to peak and decline to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO_2 emissions reduction consistent with the Paris Agreement temperature goals. IMO is also executing global technical cooperation projects to support the capacity of States, particularly developing States, to implement and support energy efficiency in the shipping sector.

GHG emissions from ships are mainly related to energy consumption during their us phase. The Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI. This was the first legally binding climate change treaty to be adopted since the Kyoto Protocol.

The EEDI for new ships is the most important technical measure and aims at promoting the use of more energy efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments. Since 1 January 2013, following an initial two years phase zero, new ship design needs to meet the reference level for their ship type. The level is to be tightened incrementally every five years, and so the EEDI is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase.

The EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions for the ship to comply with the regulations. The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO_2) per ship's capacity-mile (the smaller the EEDI the more energy efficient ship design) and is calculated by a formula based on the technical design parameters for a given ship. The CO_2 reduction level (grams of CO_2 per tonne mile) for the first phase is set to 10% and will be tightened every five years to keep pace with technological developments of new efficiency and reduction measures. Reduction rates have been established until the period 2025 and onwards when a 30% reduction is mandated for applicable ship types calculated from a reference line representing the average efficiency for ships built between 2000 and 2010.

The EEDI is developed for the largest and most energy intensive segments of the world merchant fleet and embraces emissions from new ships covering the following ship types: tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers and combination carriers. In 2014, MEPC adopted amendments to the EEDI regulations to extend the scope of EEDI to: LNG carriers, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships; ro-ro passenger ships and cruise passenger ships having non-conventional propulsion. These amendments mean that ship types responsible for approximately 85% of the CO_2 emissions from international shipping are incorporated under the international regulatory regime. The Ship Energy Efficiency Management Plan (SEEMP) is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner.

The SEEMP also provides an approach for shipping companies to manage ship and fleet efficiency performance over time using, for example, the Energy Efficiency Operational Indicator (EEOI) as a monitoring tool. The guidance on the development of the SEEMP for new and existing ships incorporates best practices for fuel efficient ship operation, as well as guidelines for voluntary use of the EEOI for new and existing ships (MEPC.1/Circ.684). The EEOI enables operators to measure the fuel efficiency of a ship in operation and to gauge the effect of any changes in operation, e.g. improved voyage planning or more frequent propeller cleaning, or introduction of technical measures such as waste heat recovery systems or a new propeller. The SEEMP urges the ship owner and operator at each stage of the plan to consider new technologies and practices when seeking to optimise the performance of a ship.

2.3.1.2 Harbour

International efforts to address GHG emissions include the Paris Agreement and its goals, and the United Nations 2030 Agenda for Sustainable Development and its SDG 13: “Take urgent action to combat climate change and its impacts”. With a view to contributing to global emission reduction efforts, IMO in April 2018 adopted resolution MEPC .304(72) on the Initial IMO Strategy on reduction of GHG emissions from ships, setting out a vision to reduce GHG emissions from international shipping and phase them out as soon as possible in this century.

The Strategy includes a list of candidate short, mid and long-term measures which IMO could further develop with a view to achieving the ambitious targets as set out in the strategy. As part of the list of candidate short- term measures, the Strategy calls for the encouragement of port developments and activities globally to facilitate reduction of GHG emissions from shipping, including provision of ship and shoreside/onshore power supply from renewable sources, infrastructure to support supply of alternative low-carbon and zero-carbon fuels, and to further optimize the logistics chain and its planning, including ports.

Furthermore, the important role of ports in the wider supply chain and the action that ports can take to facilitate the reduction of GHG emissions from shipping has been recognized through the adoption of resolution MEPC .323(74) in May 2019 on Invitation to member states to encourage voluntary cooperation between the port and shipping sectors to contribute to reducing GHG emissions from ships.

With a view to supporting the maritime industry in achieving IMO's emission reduction goals and contributing to greener shipping, a guide has been reported. It is a Call for Action to port and shipping sectors to facilitate the reduction of GHG emissions in the ship-port interface. This guide is a particularly useful document for shipowners, ship operators, charterers, ship agents, shipbrokers, port authorities, terminals and nautical services providers, and other relevant stakeholders, who ultimately play a key role in implementing the necessary changes and facilitating the uptake of emission reduction measures in the ship-port interface.

This guide presents several practical measures that:

- can be applied today with limited or low capital and operational investments;
- are relatively easy and quick to implement;
- have the potential to contribute to GHG emission reduction with additional benefits.

With the average economic lifetime of a ship of approximately 25 years1 and the prospect of zero emission ships entering the market from 2030 onwards, measures that have relatively short payback times with additional benefits for safety and security can be considered low-risk investments.

With this in mind, this guide presents eight practical measures that can be implemented with limited capital. The measures have not been ranked in terms of emission reduction potential, but have been ordered into measures related to port operations, administrative data, nautical data and speed optimization as follows:

- Measure 1: Facilitate immobilization in ports: implementation of this measure would allow for maintenance and repairs of the main engine (ME) to occur simultaneously with cargo operations . This would contribute to a reduction in GHG emissions as it would optimize the time spent in port, and eliminate the need for the ship to transit to another location for work to be undertaken;
- Measure 2: Facilitate hull and propeller cleaning in ports: implementation of this measure would allow hull and propeller cleaning to take place in port, ideally simultaneously with cargo operations . This would contribute to a reduction in

GHG emissions as it would optimize the time spent in port and eliminate the need for the ship to transit to another location for hull and propeller cleaning to be performed, as well as the reduced GHG emissions as a result of the hull and propeller cleaning itself;

- Measure 3: Facilitate simultaneous operations (simops) in ports: implementation of this measure would allow operations to occur simultaneously (e.g. cargo, bunkering, provisioning, tank cleaning etc.). This would contribute to a reduction in GHG emissions as it would optimize the time spent in port, as operations can be concluded in parallel rather than in sequence;

- Measure 4: Optimize port stay by pre-clearance: This measure optimizes the port call and aims to eliminate unnecessary waiting time by facilitating all required clearances in advance, thereby contributing to a reduction in GHG emissions through the optimized port stay. Ships may experience operational delays on arrival, during port operations or at departure due to clearance processes in ports. The delays may need to be recovered in transit, often resulting in higher transit speeds, and thereby increased fuel consumption and emissions. Port stay optimization can be supported by introducing pre-clearance of e.g. customs, immigration, port health or port authority formalities, avoiding waiting time to arrive, during operations alongside or to depart;

- Measure 5: improve planning of ships calling at multiple berths in one port: This measure aims to improve the planning of ships calling at multiple berths in one port, as is often the case with container feeder ships, chemical and parcel tankers. This measure aims to ensure:

  - Just in Time shifting of ships between berths;
  - Optimization of cargo operations.

  Addressing the planning would result in lower GHG emissions as the ship's time under engine in port, the terminal operations as well as all services ordered (e.g. nautical service providers) are aligned which result in improved port turnaround times and present an opportunity for bunker savings in subsequent voyage to the next port of call, thereby contributing to a reduction of GHG emissions.

- Measure 6: Improve ship/berth compatibility through improved Port Master Data: this measure involves improving Port Master Data to ensure that the right ship size is utilized, by:

  - reliable identification of the terminal and berth;
  - reliable maximum length and beam per berth.

Having the right ship size utilized results in lower GHG emissions per carried ton of cargo;

- Measure 7: enable ship deadweight optimization through improved Port Master Data: This measure involves improving Port Master Data (depths, water density, tidal heights) to enable optimization of the draught of the ship, eliminating unnecessary allowances and additional buffers in the Under Keel Clearance (UKC). Improved access to reliable and up to date Port Master Data allows for better optimization of the deadweight capacity and therefore contributes to a reduction in GHG emissions per cargo ton transported;

- Measure 8: Optimize speed between ports: this measure would allow for ships to optimize speed between ports, to arrive “Just In Time” when the berth, fairway and nautical services are all available . This “Just In Time Arrival” concept (JIT Arrival) will improve the port call process and ultimately reduce GHG emissions .Through the application of JIT Arrival, GHG emissions and air pollutants can be reduced in a twofold manner:
    - for the ship voyage through the optimization of the sailing speed and hence more optimal engine efficiency resulting in lower fuel consumption;
    - for the port area as the amount of time ships manoeuvring in the approaches or waiting at anchorage is reduced.

The guide presents an explanation of each of these measures and identifies how their implementation can lead to GHG emission reductions and further benefits for the maritime sector (e.g. for the safety and security of shipping). Barriers to the global implementation of each measure are identified and preliminary potential solutions and next steps are suggested which could be taken to progress implementation further.

The annex of this Guide provides an idea of the potential fuel savings which can be achieved through implementation of some of the measures presented in this guide. Data used in this Guide is based on real fuel consumption data and was provided and analysed in-kind by two GIA members (A.P. Møller-Mærsk A/S and the Port of Rotterdam).

It should be noted that while the Guide in general refers to GHG emissions, the calculations presented in the annex show the differences in potential fuel consumption. The calculations therefore provide only an indication of the potential CO_2 savings, under the specified conditions, and further deeper analysis of the fuel and emission reduction potential of each measure is required.

The eight measures presented in this guide have been selected for their potential application on a global scale. Measures can be implemented individually as well as collectively, which would maximize the emission reduction benefit. Some of the measures would be applicable each time a ship calls a port (e.g. simultaneous operations, pre-clearance), while others may be applicable less frequently but can have a large impact on fuel consumption (e.g. immobilization, hull and propeller in-water cleaning). Measures such as Onshore Power Supply (OPS) fall outside the scope of this Guide, given the higher capex.

The list of presented measures is non-exhaustive and should serve to raise awareness of preliminary ideas which the maritime community could potentially implement. Recognizing that every port is different and has its unique challenges and characteristics, readers are encouraged to use this guide as a starting point for discussions and explore these opportunities further within their own port community. Furthermore, the cost of implementation of each of these measures is difficult to assess given the variety of stakeholders involved in their implementation and therefore, the applicability of each measure should be individually assessed for each port and, if needed, explored to see how their uptake could be incentivized.

It should be noted that in all cases, measures to reduce GHG emissions in the ship-port interface will require a triangular collaboration (between ships, ports and terminals) and that none of these measures can be implemented by one stakeholder alone. Furthermore, the speed of implementation will largely depend on the strength of that collaboration and the willingness of all stakeholders to play a part, even if they may not be the direct beneficiaries.

This guide has been developed by the Global Industry Alliance to Support Low Carbon Shipping (Low Carbon GIA), a public-private partnership originally established under the framework of the GEF-UNDP-IMO Global Maritime Energy Efficiency Partnerships Project (GloMEEP Project). The Low Carbon GIA was launched with the aim to identify and develop innovative solutions to address common barriers to the uptake and implementation of energy efficiency technologies and operational measures. Since January 2020, the Low Carbon GIA has been operating under the GreenVoyage2050 Project, a joint IMO-Norway initiative to support implementation of the Initial IMO GHG Strategy.

This guide, based on research and discussions undertaken by members of the Low Carbon GIA and other subject matter experts in this field, does not intend to showcase fully developed measures. Instead, this Guide presents initial ideas which require further work and deeper assessment.

Looking into the near future, Low Carbon GIA Members will, based on this guide and bringing together ports, shipping lines and terminal operators, encourage implementation of these practical measures . With a view to contributing to scaling-up and increasing the uptake of these ship-port interface measures, experiences and best practices will be shared with the global maritime community.

2.3.2 Pollutant emissions

The control of diesel engine NOx emissions is achieved through the survey and certification requirements leading to the issue of an Engine International Air Pollution Prevention (EIAPP) Certificate and the subsequent demonstration of in service compliance in accordance with the requirements of the mandatory, regulations 13.8 and 5.3.2 respectively, NOx Technical Code 2008 (resolution MEPC.177(58) as amended by resolution MEPC.251.(66)).

The NO_x control requirements of Annex VI apply to installed marine diesel engine of over 130 kW output power other than those used solely for emergency purposes irrespective of the tonnage of the ship onto which such engines are installed. Definitions of ‘installed’ and ‘marine diesel engine’ are given in regulations 2.12 and 2.14 respectively. Different levels (Tiers) of control apply based on the ship construction date, a term defined in regulations 2.19 and hence 2.2, and within any particular Tier the actual limit value is determined from the engine’s rated speed. The Tier III controls apply only to the specified ships while operating in Emission Control Areas (ECA) established to limit NOx emissions, outside such areas the Tier II controls apply. In accordance with regulation 13.5.2, certain small ships would not be required to install Tier III engines.

A marine diesel engine that is installed on a ship constructed on or after the following dates and operating in the following ECAs shall comply with the Tier III NOx standard:

- 1 January 2016 and operating in the North American ECA and the United States Caribbean Sea ECA;
- 1 January 2021 and operating in the Baltic Sea ECA or the North Sea ECA.

In order to control sulphur dioxide emissions, an Exhaust Gas Cleaning System may be installed on board. The Resolution on Guidelines for Exhaust Gas Cleaning system describes the ratio between sulphur dioxide and carbon dioxide as a method enables to verify compliance with fuel oil sulphur content limits.

Regulation 4 of Annex VI is particular important to identify possible alternatives to the standards set forth in Regulations 13 and 14. In particular, the Administration of a Party may allow any material or apparatus to be fitted in a ship or other procedures, alternative fuel oils, or compliance methods used as an alternative to that required by Annex VI if such amendments are at least as effective in terms of emissions reductions as that required by Annex VI.

An example of these compliance methods is the Exhaust Gas Cleaning System for SO_x; the most commonly used is the scrubber. These systems may be installed on board only once they have been approved and certified by the flag authority. To do this, administrations should follow the requirements set out in guidelines adopted in 2015 by MEPC with the Resolution MEPC.259(68) - 2015 Guidelines for Exhaust Gas Cleaning systems, come into force on 15 May 2015.

This resolution declares that if an EGC is installed on board to control SO_x emissions, it may be approved or through periodic parameters and emissions checks or through a continuous SO_x emissions monitoring system. The guidelines describe the SO_2/CO_2 ratio method that simplifies the monitoring of SO_x emissions. This method enables direct monitoring of exhaust gas emissions to verify compliance with fuel oil sulphur content limits. For example, using a fuel with 3,5% sulphur content in an area where should be used a fuel with 0,1% sulphur content, the ratio emissions SO_2/CO_2 must not exceed 4,3.

2.3.3 Waste management

The EU waste policy provides a framework to improve waste management, stimulate innovation in separate waste collection and recycling, limit the use of landfilling, and create incentives to change consumer behaviour. It also aims to reduce the actual quantity of waste generated and the amount of harmful substances it contains [22].

Figure 2.4: The waste hierarchy

To protect the environment and human health, the EU Waste Framework Directive has two key objectives: to prevent and reduce the negative impacts caused by the generation and management of waste and to improve resource efficiency. The Directive defines a ’hierarchy’ to be applied by EU Member States in waste management. Waste prevention and re-use are the most preferred options, followed by recycling (including composting), then energy recovery, while waste disposal through landfills should be the very last resort.

Chapter 3

Models and methods

Among the overall impact of the maritime sector along its lifecycle (materials, energy consumption, end-of life), this study aims to analyze their feasibility and their contribution to mitigation measures in the use phase.

The following issues are assessed:

- Air emissions: monitoring of GHGs and pollutants
- Waste management: analysis of alternatives

3.1 Air emissions monitoring

Several types of ships, characterized by different propulsion system configuration, are analyzed in order to define environmental that can be used as a decision support system for on board personnel in order to compare of the ship performances and the exhaust gas cleaning systems efficiency in different operating conditions.

These environmental performance indicators are developed following evaluation of:

- data collected on board from specific instrumentation;
- marine exhaust gas cleaning systems;
- existing legislations.

They may be used as new tools, added to existing instrumentation that can be implemented to minimize the environmental footprint of the ship providing a tool for assessing the environmental impact of various types of ships, capable of complying with the directives of current legislation and guaranteeing a survey of the level of pollution in real time.

Data provided by CETENA, a company within the Fincantieri Group, are collected for the purpose of the research.

Several types of ships, characterized by different propulsion system configuration: in particular, one cargo ship and one ro-ro passenger ship are studied. In addition, two cruise ships are taken into account, one of which is studied in traditional and fuel cells - dual fuel configuration.

The cargo ship studied in the present work is a reefer that is typically used to transport commodities that require to be maintained at a controlled temperature [23].

This ship is characterized by a length overall higher than 185 meters, about 15000 gross tonnage, one low speed diesel engine and it can transport about 560 containers on deck.

A ro-ro passenger ship is designed to carry passengers and wheeled cargo, in fact they have typical ramps used to drive it on and off the ship.

The ro-ro passenger ship studied is characterized by a length overall higher than 220 meters, about 55000 gross tonnage, four medium speed diesel engine and two propeller shafts. It can transport about 2000 passengers and more than 200 cars, and it is equipped with scrubbers.

The last ship type considered is a cruise ship that is a passenger ship used for tourism. This type of ship requires a large amount of energy, because of the onboard services and facilities for passengers. Therefore, it has equipped with some diesel generators that supply the power for the propulsion and also for hotel and auxiliary services.

Two cruise ships in particular are taken into account in this study.

Ship three is a traditional cruise ship equipped with five diesel generators connected to two pods characterized by a length overall higher than 320 meters, about 130000 gross tonnages, and can transport about 4000 passengers. It is equipped with three scrubbers.

Ship four has characteristics similar to the previous one and it is studied in traditional configuration and fuel cells - LNG configuration.

In traditional configuration, Ship four-a (4a) is equipped with four diesel engines, and it uses conventional marine fuel.

Instead, Ship four-b (4b) is equipped with fuel cells [24] [25] [26] [27] [28] [29] [30] [31] [32] that supply about eighty percent (80%) of the power required by auxiliary services and four dual fuel engines, in diesel mode during start and in gas mode with LNG in steady-speed operating conditions. In the following tables are shown ships main data.

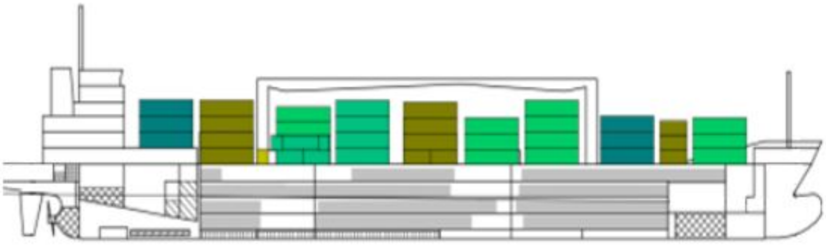


Figure 3.1: Cargo ship longitudinal section

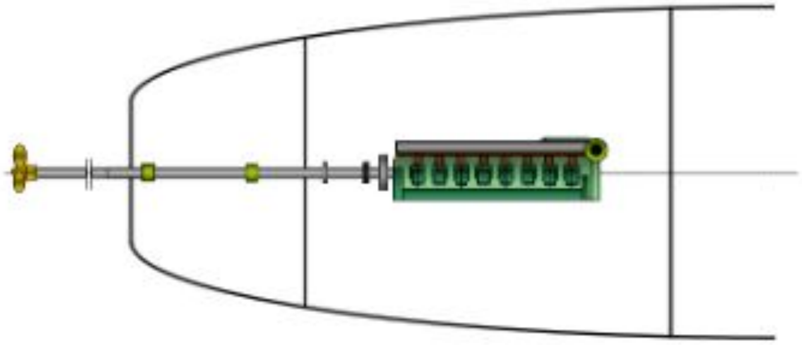


Figure 3.2: Simplified propulsion system configuration

Cargo ship	
Characteristics	
Length overall (Loa)	>185 m
Breadth (B)	>20 m
Gross Tonnage	∼15000 GT
Design speed	>20 kn
Propeller shafts	1
Engine	1x GMT-Sulzer 8RTA62U
Maximum Power	18280 kW @ 115 rpm
TEU	560 on deck
	Pallets in cargo holds
Equipment	None

Table 3.1: Ship 1 main data

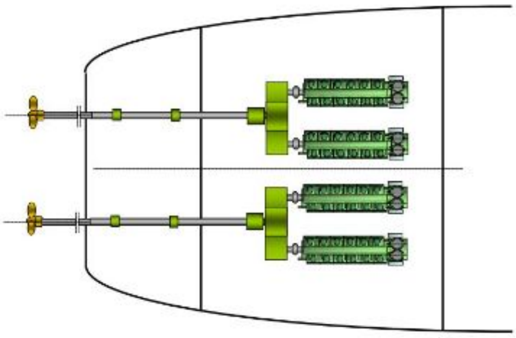


Figure 3.3: Simplified propulsionsystem configuration

Ro-ro passenger Ship	
Characteristics	
Length overall (Loa)	>220 m
Breadth (B)	>30 m
Gross Tonnage	∼15000 GT
Design speed	>25 kn
Propeller shafts	2 with CCP propellers
Engine	4x Wartsila 12V46D
Maximum Power	13860 kW @ 500 rpm
Total Power	55440 kW
Crew	∼150
Passengers	∼2150
Garage	>200 cars (or >170 trucks)
Equipment	Scrubbers

Table 3.2: Ship 3 main data

Figure 3.4: Examples of cruise ships equipped with pod

Ship 4a - 4b	
Common characteristics	
Length overall (Loa)	>300 m
Breadth (B)	>35 m
Gross Tonnage	∼140000 GT
Design speed	>20 kn
Crew	∼1350
Passengers	∼3600

Table 3.3: Ship 4a main data

Traditional configuration - Ship 4a	
4 x Wartsila Diesel Engine 14V46F.14	Propulsion + Aux
Total engine power	67200 kW
Equipment	None
Fuel Cells - Dual Fuel configuration - Ship 4b	
Fuel Cells	80% Aux
4 x Dual Fuel engines with LNG Wartsila Diesel Engine 12V46DF.12	Propulsion + 20% Aux
Total engine power	54960 kW
Equipment	None

Table 3.4: Ship 4b main data

3.2 Waste management

The proposed research topic is to propose an innovative integrated system for the optimization of ship waste management and the consequent reduction of emissions.

During the preliminary phase, the biomass to be used, spent vegetable oil (OVE), the fraction of solid organic waste (FORSU) and sewage sludge were characterized.

The entire chain was examined by means of mass and energy flow analysis, in order to optimize the waste treatment system as a whole. The collected and regenerated waste vegetable oils were characterized, and the combustible properties determined, focusing on the possible thermochemical conversion that will result in a syngas consisting mainly of CO, H_2 and to a lesser extent CH_4.

In the final phase, the different systems analyzed will be integrated and compared, and the overall layout will be optimized through energy, thermo-economic and environmental impact analyses.

At this point, the research focuses on the harmonization, calibration and finalisation of the proposed strategies through the drafting of a guideline. It is important to emphasize that there are still no certified and recognized methodologies for the maritime sector to exploit greenhouse gas reduction strategies implemented on board.

Table 3.5 summarizes the implementable waste management measures preliminary identified as feasible by different authors [33] [34] [35] [36].

Some strategies have been supported by bibliographical research in order to analyze the aspects considered interesting.

ID.	Waste stream	Type of waste	Description	Measure
1	Organic	Food scrap	Characterization of substrates deriving from food scrap and organic waste	Pre-treatment
2	Organic	Organic waste	Thermo-chemical treatment of materials with high organic content for syngas production.	Treatment
3	Oil/Sludge	Waste oils and sludge	Thermo-chemical treatment of waste oils and sludge for the obtaining of fuel oils.	Treatment
4	Oil/Sludge	Oily water	Separation system for oily water through a cyclone separator, recycling of waste oils and use in engines and subsequent treatment of separated water, with possible reuse onboard or unloading into sea.	Treatment
5	Organic	Oily water	Systems of anaerobic conversion with thermophilic bacteria for organic matrixes of various types.	Treatment
6	Oil/Sludge	Waste vegetable oils	Cleaning and characterization of the combustion properties of syngas/biogas derived from waste. Optimized energy conversion of syngas/biogas derived from waste in internal combustion engines (gas turbine/alternative engine) also with supply of waste vegetable oils	Treatment
7	Other waste	Waste Heat	Waste Heat Recovery. The measure consists in the adoption of Organic Rankine Cycles (ORC), which have a good operating flexibility, high safety due to low operating pressures and would allow the heat recovery of waste heat from other systems	Treatment
8	Other waste	CO_2	Carbon capture and storage (CCS) onboard through adsorption due to solid substances - such as calcium hydroxide and potassium hydroxide - as sorbent directly to the unloading and the next CO_2 recycling through calcination. Possibility of combination with methanation and/or union to another syngas	Treatment
9	Oil/Sludge	Grey/black water	System of biologic treatment grey/black water through separation of solids, disinfection, drying	Treatment
10	Other waste	All waste	Installation of a waste-to-energy plant and next energy recovery.	Treatment
11	Organic	Garbage	Onboard separation of garbage with a dedicated space.	Pre-treatment
12	Packaging consumables	Plastic	Plastic grinding and treatment for possible use of 3D printer for gadgets and items production.	Best Practice
13	Packaging consumables	Paper	Decrease of paper use, through an increase of the digitalization.	Best Practice
14	Packaging consumables	Glass	Decrease of glass use through installation of dispenser and re-usable containers.	Best Practice
15	Packaging consumables	Packaging	Decrease of packaging on board.	Best Practice
16	Other waste	All waste	Installation of a grinding and compaction system for multi-material treatments.	Treatment

Table 3.5: Waste management measures preliminary identified

These measures were first assessed in relation to their emission reduction potential through the following methods:

- SWOT analysis to evaluate strengths and weaknesses, opportunities and dangers of each measure [37];
- UNFCCC methodologies for the development of greenhouse gas reduction projects related to the waste sector [38];

- Life Cycle Assessment [39].

The oil sludge design data, reported in Table 3.6, have been provided taking into account different sources:

- Information about average sludge production on board from a private communication of the Carnival Corporation;
- Chemical analysis of a sludge sample kindly provided by GNV, an Italian Ro-Ro ferry company, made by the Research Centre for Alternative and Renewable Energy, Florence, Italy;
- Data from the literature.

Parameter	Value
Average quantity of oily sludge	1057 t/y
Water contained in oily sludge	63,4%
Process yield on secondary fuel oil	30%
Gas production	17%
Solid production	32%
Water production	21%
Quantity of settled oily sludge	390 t/y
Secondary fuel oil obtained by pyrolysis	118 t/y
Gaseous product obtained by pyrolysis	65 t/y
Solid product obtained by pyrolysis	125 t/y

Table 3.6: Pyrolysis process design data

In the case study analyzed, the use of exhaust gases from the incineration plant for cooling the refrigerating room, was considered in particular as a measure to reduce greenhouse gas emissions.

It based on the following parameters:

- f_{cap} = 1, because the amount of energy generated by waste for the project activity is the same as the energy that would have been necessary for the operation of the plant before the introduction of the project activity itself;
- f_{wcm} = 1, since the energy necessary for the operation of the refrigeration system is provided in total by the waste-to-energy plant.

Furthermore, the following system data were considered even though they have not been used for the calculation of GHG emissions:

- System working only during navigation outside 12 miles;
- Utilisation factors set equal to 25%, 50% and 75%;
- Daily operation of 11 hours;
- COP (coefficient of performance) = 2.12, related to the equipment that would be replaced with the use of the ammonia-water absorption cycle;
- Using of ammonia steam generator with an assumed power of 900 kW supplied by exhaust gases;
- Consumption of fuel (diesel) in the primary engine = 200 g/kWh (data obtained from a previous study carried out on a cruise ship);
- Installed electric power of 195.5 kW relative to the plant dedicated to refrigeration of the cold room.

Data were collected onboard and retrieved from a paper published within the framework of the research activity [40].

Parameter		**Value**	**Annotation**
f_{cap}	Ratio between the energy generated by the waste and the total energy used in the project activity to produce useful energy (in year y)	1	The amount of energy generated by waste for the project activity is the same as the energy that would have been necessary for the operation of the plant before the introduction of the project activity itself
f_{wcm}	Ratio between the electricity generated by the project activity and the energy generated by the waste used to produce it	1	The energy necessary for the operation of the refrigeration system is provided in total by the waste-to-energy plant
EG_i	Amount of electricity supplied	0.019135 TJ	In the absence of project activity would have been purchased during the year y
EF_{Elec}	CO_2 emission factor for the energy source replaced	73.3 t CO_2/TJ	Energy source replaced by the project activity, during the year y
$\eta_{Plant,j}$	Overall efficiency of the identified existing plant	0,365	η diesel engine = 0.40, η mechanical transmission = 0.99, η electric generator = 0.97, η electric transmission = 0.99, η converter = 0.96.

Table 3.7: Parameters to calculate emissions

In order to understand the significance of the paper material streams with reference to the complex macro-system of a cruise ship, a material flow analysis (MFA) has been here carried out as a propaedeutical step prior classifying and evaluating the potential issues and sustainable practices. The MFA findings for the case study revealed that the amount of loaded paper material is around 7000 kg per weekly cruise. With reference to the total inflow of materials from weekly supplies, the paper/paperboard flow consists in 30% share, whilst 50% is represented by glass, 15% by plastics and 5% by metals.

The activities that take place on board can be grouped into two main groups: management of passenger services and management of the ship. Each group leads to production of waste streams, including paper, which are then classified and disposed of according to MARPOL regulations.

The analysis of data collected by the inventory office revealed that paper streams onboard include the provision of information communicated by means of brochures, flyers, leaflets, etc., distributed in single cabins and spreaded within the venues of the ship, together with menus and lists available at restaurants and bars. In addition to these streams, large amounts of materials of service (i.e. towels, toilet paper, etc.) and paper devoted to bureaucratic and administrative activities within the offices (Figure 3.5).

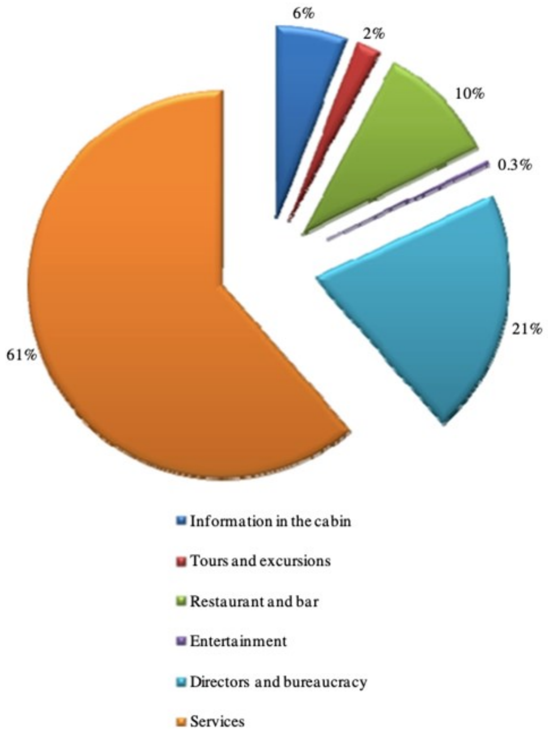


Figure 3.5: Paper streams in input to cruise ship

According to the potential green practices that can be adopted onboard a cruise ship in order to enhance the environmental performance of the cruise with particular attention to paper input and output flows in a waste minimization perspective.

A comparative life cycle assessment (LCA) of management scenarios of paper streams onboard a cruise ship is performed. Here, in fact, the comparison is built in order to show the differences among the scenarios where the green practice are applied, respectively, for three measures considered and a reference scenario (scenario R) representing the usual condition. In such a simplified approach, a cut-off rule is applied for all flows that are qualitatively and quantitatively identical across the various alternative systems considered.

All elements of the cruise resulting to be common to the compared scenarios are thus omitted from the analysis, including ship propulsion, supply of goods and waste treatment not related with the proposed measures, energy consumption related to conventional activities onboard, etc. It should be noted that in this study, the subsystems excluded are precisely comparable with respect to technologies, properties, qualities and quantities of the flows supplied or produced. In this way, the results of the comparison are still outcomes of a life cycle perspective, by considering a cradle-to-grave approach for all the processes included, and they indeed reflect only the effects of the implementation of each ”different” practice with respect to ”no-action”.

For each alternative, the same function is delivered, i.e. the provision of cruise service for passengers. In order to compare each scenario with the reference case (in absence of the practice implementation), the functional unit is defined as 1 day of cruise.

The life cycle inventory procedure is set up by creating different scenarios and specifying only those parts of the systems that differ between the alternatives and the reference scenario, corresponding to ”no-action” alternative (Figure 3.6). The different scenarios for the green practices analysed inthe case-study ship, corresponding to different reduction rates of paper waste streams with respect to scenario R, are here summarized:

- Digitalization: the digitalization practice of Today is assessed. For this purpose, different scenarios have been assessed with progressive simulated reduction rates, from25 to 100%, i.e. scenarios D25, D50, D75 and D100. Moreover, the installation of additional Totems has been evaluated with different shares, thus generating variations evaluable in the respective scenarios;
- Consumables: the reduction of toilet paper and paper towel use through installation of auto-cut single extraction dispensers is assessed, with global estimated reduction of 25%, i.e. scenario C25;
- Guidelines: the reduction of paper consumption in the offices, in particular by the 50% of the A3 printed paper and 50% of the A4 printed paper, is assessed as potential result of the diffusion of dedicated guidelines, i.e. scenario G50.

According to difference analysis approach, the system boundaries for the scenarios related to digitalization encompass the paper production stage with variation from 100% (i.e. reference case) to 0% (i.e. total digitalization) and, consequently, the ashore pre-printing phase of the main headings of the newspaper, the onboard printing phase of the daily contents and the final incineration. The option of installing a set of additional Totems is evaluated as supplementary alternative. In this way, the impacts are evaluated both with and without this inclusion and also by variation of the number of devices. The installation of additional devices entails their manufacturing, use and disposal phases from a life cycle perspective [41].

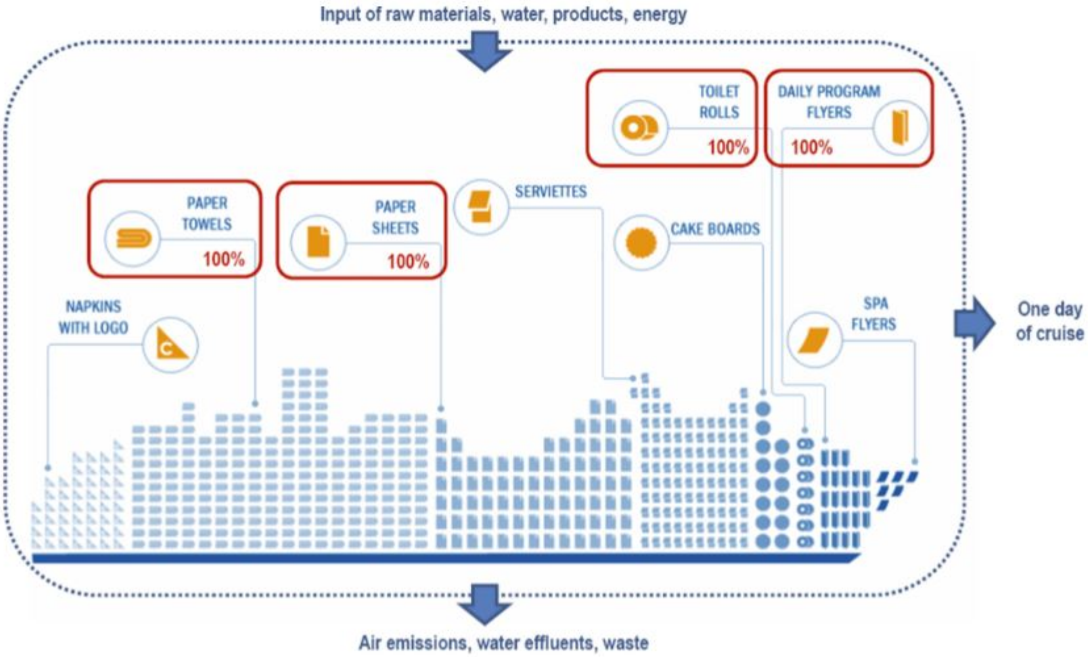


Figure 3.6: System boundaries for scenario R through difference analysis

Also this work investigates a potential innovative pattern of recycling food waste from cruise ships for use as feed in aquaculture, in terms of environmental sustainability. The feed mixture considered, is constituted by two main components: i.e. a crop-derived products mix and a fish-derived products mix (Table 3.8). The foreground data to compute the inventory for the traditional feed product for salmon are retrieved from a robust comparative study available in literature [42], both for Norway and UK scenario. These feed formulations were also reclaimed as source of specific entries for the composition of the mix from further recent studies [43].

Background data such as the inventories for life cycle of fuels, as well as data related to electricity use scenarios, were gathered from Ecoinvent database v.3.1 [44].

Product	**Origin**	**Norway feed mix (kg/t)**	**Uk feed mix (kg/t)**
Crop derived			
Fava bean	UK	16.0	36.3
Maize starch	France	2.0	38.8
Protein pea	France	49.3	43.8
Rape oil	France	62.2	7.1
Soybean meal	France	79.6	87.3
Soybean oil	France	9.2	-
Protein soybean	France	54.0	-
Sunflower seed	France	60.5	37.4
Sunflower oil	France	9.2	-
Wheat grain	France	51.5	41.8
Wheat gluten meal	UK	43.3	17.4
Total crop-derived		436.8	309.9
Fish Derived			
Anchoveta meal	Peru	60.7	157.3
Anchoveta oil		49.7	93.4
Blue Whiting meal	Norway	94.9	26.7
Blue Whiting oil		39.7	4.0
Capelin meal	Iceland	2.5	0.5
Capelin oil		0.7	5.0
Atlantic herring meal	Canada	91.9	76.1
Atlantic herring oil		68.3	78.6
Mackerel meal	Norway	7.1	-
Menhaden meal	US	31.4	-
Menhaden oil		27.6	-
Cod meal	Canada	-	90.0
Cod oil		-	24.8
Sand eel meal	Norway	5.0	4.5
Sand eel oil		2.8	0.5
Sprat meal	Norway	38.4	71.0
Sprat oil		42.5	57.7
Total fish-derived		563.2	690.1
Total fish feed (kg)		1000	1000

Table 3.8: Commercial feed formulations for Norway and UK

Regarding solid waste generation on board of a cruise ship, in this study it is considered a ship with a gross tonnage of about 141,000 tons, carrying up to 5400 people. The below tabel reports the data about the solid waste production onboard.

Type od Waste	**Total Mass Daily Production [kg/day]**	**Lower Heating Value [MJ/kg]**	**Total Recoverable Energy [MJ/day]**
Plastic	1188	36	42768
Paper and cardboard	5360	14.3	76707
Food waste	10800	5.7	61535
Glass	3672	-	-
Aluminum	108	-	-
Total	21128	-	181010

Table 3.9: The solid waste production onboard

3.2.1 SWOT analysis

The measures listed in Table 3.5 were analyzed through the SWOT analysis using five evaluation criteria:

- GHG emissions reduction potential: assessment of a significant contribution of the measure to the reduction in GHG emissions;
- cost: analysis of potential costs for installation and management of the measure;
- feasibility/replicability: analysis of potential replicability in the maritime sector and evaluation of the possible difficulties in the implementation;
- environmental sustainability: assessment of the environmental sustainability of the measure in terms of impacts different from the GHG emissions;
- existence of an approved specific methodology: analysis of internationally recognized CO_2 calculation methodologies (e.g. UNFCCC, IMO).

For each criterion, the belonging group (strength, weakness, opportunity and danger) has been identified based on the binary composition of the evaluation factors of controllability and usefulness reported in Table 3.10.

	Usefulness	**Controllability**
Strength	Possible achievement of the goals of reduction in GHG emissions	Achievement of the goals depending on internal factors
Weakness	Difficulty in achieving the goals of reduction in GHG emissions	Achievement of the goals depending on internal factors
Opportunity	Possible achievement of the goals of reduction in GHG emissions	Achievement of the goals depending on external factors
Danger	Difficulty in achieving the goals of reduction in GHG emissions	Achievement of the goals depending on external factors

Table 3.10: Usefulness and controllability related to Strength, Weakness, Opportunity and Danger

Usefulness is defined as the potential of GHG reduction. Therefore, an action is defined as “useful” if there is a reduction in GHG emissions after the implementation of the strategy considered. On the contrary, it is defined as “not useful” when the GHG emissions reduction is not checked or is not very significant.

Controllability is defined as the possibility to keep the achievement of the greenhouse gas reduction targets proposed under control of the entity that implements the measure. Therefore, an action is defined as “controllable” when the achievement of the reduction targets is dependent on the choices and operations performed. On the contrary, it is defined as "not controllable" when external factors (environmental, regulatory, etc.) can influence the achievement of the reduction target.

For the evaluation of usefulness and controllability, the following parameters were examined as external drivers: regulatory constraints; technical constraints; available technologies. In order to improve the applicability of the results, a qualitative evaluation was proposed, and a score was assigned for each category considered. The score is assigned based on the relevance of strength, weakness, opportunity and danger of each individual action.

Table 3.11 shows the assigned scores related to strengths, weaknesses, opportunities and dangers.

Score	0	1	2	3
Strength	Not present	Low	Medium	High
Weakness	Not present	Low	Medium	High
Opportunity	Not present	Low	Medium	High
Danger	Not present	Low	Medium	High

Table 3.11: Scoring criteria

The aforementioned strategies were evaluated on the basis of the parameters of controllability and usefulness. Strategies that report strength values are always considered useful and controllable with different intensity, whereas those that report danger values are to be considered not useful and not controllable with different intensity.

3.2.2 UNFCCC methodologies

Since there are no available methodologies for plants implemented on board, for the purpose of the study UNFCCC methodologies have been analyzed for the determination of the reduction in GHG emissions, resulting from the implementation of specific small- and large-scale measures and projects in the waste sector.

UNFCCC methodologies for the development of greenhouse gas reduction projects are related to the waste sector. Since there are no available methodologies for plants implemented on board, for the purpose of the study UNFCCC methodologies have been analyzed for the determination of the reduction in GHG emissions, resulting from the implementation of specific small- and large-scale measures and projects in the waste sector.

- AMS-II.I. Efficient utilization of waste energy in industrial facilities;
- AMS-III.H. Methane recovery in wastewater treatment;

- AMS-III.I. Avoidance of methane production in wastewater treatment through replacement;
- AMS.III.L.Avoidance of methane production from biomass decay through controlled pyrolysis;
- AMS-III.P. Recovery and utilization of waste gas in refinery facilities;
- AMS-III.Q. Waste energy recovery;
- AMS-III.Y. Methane avoidance through separation of solids from wastewater or manure treatment systems;
- AMS-III.AF. Avoidance of methane emissions through excavating and composting of partially decayed municipal solid waste (MSW);
- AMS-III.AJ. Recovery and recycling of materials from solid wastes;
- AMS-III.AX. Methane oxidation layer (MOL) for solid waste disposal sites;
- AMS-III.BA. Recovery and recycling of materials from E-waste;
- AMS-III.BJ. Destruction of hazardous waste using plasma technology including energy recovery;
- ACM0017 Production of biofuel;
- ACM0022 Alternative waste treatment processes;
- Methodological tool for emissions from solid waste disposal sites;
- Methodological tool for baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation;
- Methodological tool for upstream leakage emissions associated with fossil fuel use.

3.2.3 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a methodology to evaluate the potential environmental impacts deriving from products, processes, or services along their life cycle. The scope of a LCA study considers not only the actual processing stage (core processes) but also the upstream (e.g. raw material production, agriculture, livestock, fisheries and aquaculture & packaging production) and the downstream (e.g. product distribution, consumption or use phase, and waste disposal) ones including the transport activities needed in all the stages.

The life cycle impact assessment results quantify the multiple environmental impacts by means of several characterisation models - each with its own equivalent unit of measurement - and facilitate the identification of the hotspots (i.e. the life cycle stages and activities associated with the most relevant impacts).

The first studies to look at life cycle aspects of products and materials date from the late 1960s and early 1970s, and focused on issues such as energy efficiency, consumption of raw materials and, to some extent, waste disposal [45].

In 1969, the Midwest Research Institute (MRI) for Coca Cola Company conducted a study to compare resource consumption and environmental releases associated with beverage containers [46]. A follow-up of this study conducted by the same institute for the U.S. Environmental Protection Agency in 1974 [47] and a similar study conducted by Basler & Hofman [48] in Switzerland marked the beginning of the development of LCA as we know it today. The period 1970-1990 comprised the decades of conception of LCA with widely diverging approaches, terminologies, and results. There was a clear lack of international scientific discussion and exchange platforms for LCA. During the 1970s and the 1980s, LCA studies were performed using different methods and without a common theoretical framework. The 1990s saw a remarkable growth of scientific and coordination activities worldwide, which is reflected in the number of workshops and other forums that have been organized in this decade and in the number of LCA guides and handbooks produced [49]. In 1990, the Society of Environmental Toxicology and Chemistry (SETAC) held LCA workshops and identified the various stages of the LCA framework, terminology and methodology (International Council of Chemical Associations, 1990). Next to SETAC, the International Organization for Standardization (ISO) has been involved in LCA since 1994. Whereas SETAC working groups focused on development and harmonization of methods, ISO adopted the formal task of standardization of methods and procedures [49].

There are currently two international standards:

- ISO 14040 (ISO, 2021b): Environmental management - Life cycle assessment - Principles and framework;
- ISO 14044 (ISO, 2021c): Environmental management - Life cycle assessment - Requirements and guidelines.

ISO 14040 considers the principles and framework for an LCA, while ISO 14044 specifies the requirements and guidelines for carrying out an LCA study.

According to ISO 14040, the principles and framework for Life Cycle Assessment include (Figure 3.7): the goal and scope definition of the LCA; the life cycle inventory (LCI) phase; the life cycle impact assessment (LCIA) phase; the life cycle interpretation phase; reporting and critical review of the LCA; limitations of the LCA; relationship between the LCA phases; and conditions for use of value choices and optional elements.

Among the above-said principles, only the first four constitute the real work phases for an LCA study and are explained in the following paragraphs.

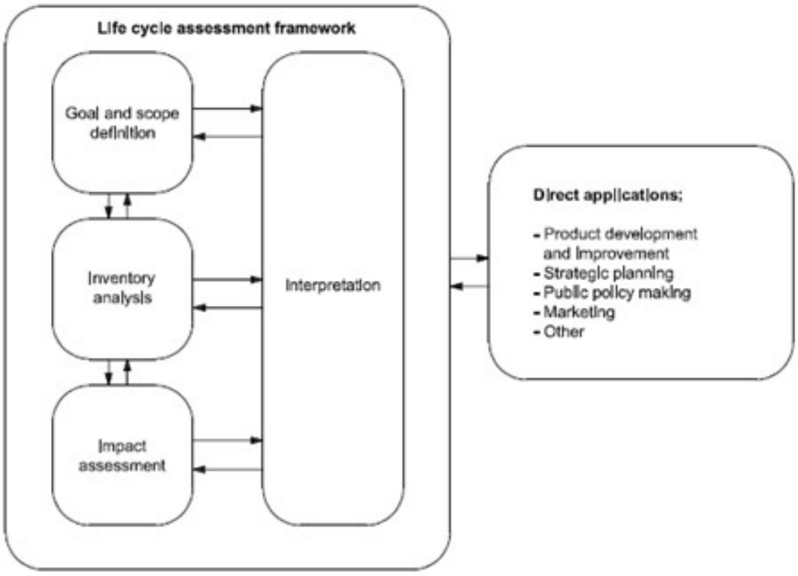


Figure 3.7: Phases of Life Cycle Assessment

The Life cycle interpretation phase runs through the other phases and consists in the identification of the significant issues based on the results of the LCI and LCIA phases, a continuous check on the completeness and the consistency of the data collected and on the sensitivity of the results with reference to the potential uncertainties linked with the data and the definition of the conclusions, limitations and recommendations of the study [50].

3.2.3.1 Goal and scope definition

The ”goal and scope definition” phase is generally meant to clearly identify the intention of the application and may be improved during the study. On the one hand, the goal of the study should state the intended application, the reasons that led to the start of the study, the final audience interested in the results of the study and if the results are meant to be used for comparative evaluations. On the other hand, the scope of the study should describe the product system involved in the study and its functions, the system boundaries, the allocation procedures utilised, the impact categories chosen to be characteristic and representative for the study, the data quality requirements and, in general, all the assumptions and the choices made for the realization of the study. In addition, the scope of the study has to define the "functional unit", providing a reference to which the input and output data are normalised, and the results are referred and allowing the comparison with other systems - and then LCA studies - with the same functional unit.

A functional unit is a measure of the performance of the functional outputs of the product system. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results. Comparability of LCA results is particularly critical when different systems are being assessed to ensure that such comparisons are made on a common basis [50].

The system boundaries include all processes linked to the product supply chain related to the functional unit. The inclusion of all attributional processes from cradle-to-grave is a default approach. System boundaries can be divided into foreground processes and background processes. Foreground processes are processes from the system of primary concern to the analyst, for which direct access to information should be available. The background data include energy and materials that are delivered to the foreground system as aggregated data sets in which individual plants and operations are not identified. Moreover, the life cycle of products can be separated into different life cycle stages: upstream processes (from cradle-to-gate), core processes (from gate-to-gate) and downstream processes (from gate-to-grave). All elementary flows at resource extraction need to be included [51].

Boundaries towards nature are characterised by flows of material and energy resources from nature into the system and by emissions to air, water, and soil when they are emitted from or leaving the product system.

Allocation can be defined as the partitioning of input or output flows of a process or a product system among the output unit under study and other product units. In case of multi-functionality, the following decision hierarchy can be set [50]:

- subdivision or system expansion;
- allocation based on a relevant underlying physical relationship;
- allocation based on some other relationship, such as economic value.

A critical difference between different approaches is that the method of avoiding allocation by expanding the system boundary is considered not applicable within an attributional LCA used [52]. For example, in the context of ISO 14025 (ISO, 2010), the following step-wise procedures are usually applied for multifunctional products and multiproduct processes:

- Allocation is preferable to be avoided, if possible, by dividing the unit process into two or more sub-processes and collecting the environmental data related to these sub-processes;
- If allocation cannot be avoided, the inputs and outputs of the system may be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them (i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system).

Where physical relationships alone cannot be established or used as the basis for allocation, other allocation method can be defined for each process, including economic allocation.

3.2.3.2 Life Cycle Inventory

The “Life Cycle Inventory analysis (LCI)” phase includes data collection and calculation procedures that allow quantifying the input and output flows of a product system. These incoming and outgoing flows have to consider all the energy, raw material and auxiliary inputs and can include the direct use of resources and emissions in the air, water and soil associated with the system. In order to allow the normalization with the functional unit, also data on products, co-products and waste quantities need to be collected. Since data may derive not only from actual measurements but also from calculations and estimations, a check on data validity needs to be conducted during the process of data collection to confirm and provide evidence that the data quality requirements for the intended application have been fulfilled.

The inputs and outputs data can then be allocated to the different products according to clearly defined procedures that have to be stated and explained together with the allocation procedure.

Starting from these data, the study can derive some interpretations, in relation to the goal and the field of application of the LCA study. These data also form the basis for the assessment of the impacts of the life cycle.

3.2.3.3 Life Cycle Impact Assessment

The “Life Cycle Impact Assessment (LCIA)” phase consists in the evaluation of the environmental performance of the system analysed and includes the collection of indicator results for the different impact categories, which together represent the LCIA profile for the product system. The choice of the impact categories has to be coherent with the goal and scope definition in order to define the most representative ones. Each impact category is associated with at least one characterization model which, by means of a set of characterization or emission factors, allows converting all the data collected during the LCI phase into well defined environmental impacts with their own units of measurement.

The application and use of normalization, grouping and weighting methods shall be consistent with the goal and scope of the LCA and it shall be fully transparent. All methods and calculations used shall be documented to provide transparency.

Within the LCIA, many different impact assessment methods may be used. Although these methods vary in several aspects, one main distinction is between midpoint and endpoint methods. These methods use different stages in the cause-effect chain to calculate the impact. An endpoint method looks at environmental impact at the end of this cause-effect chain. Endpoint results are typically shown as an impact on human health, ecosystem quality, and resource depletion. These three endpoints capture the effect of many different midpoints, since many different environmental impact pathways eventually end up as damage to human health, damage to ecosystems, or as depletion of resources. A midpoint method looks instead at the impact earlier along the cause-effect chain before the endpoint is reached. It is at this point that it determines potential environmental impact.

Optional elements and information of the LCIA which can be used depending on the goal and scope of the LCA are:

- normalisation: calculating the magnitude of category indicator results relative to reference information;
- grouping: sorting and possibly ranking of the impact categories;
- weighting: converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices; data prior to weighting should remain available;
- data quality analysis: better understanding the reliability of the collection of indicator results, the LCIA profile.

The optional LCIA elements may use information from outside the LCIA framework. The use of such information should be explained and the explanation should be reported.

3.2.3.4 Interpretation

Interpretation is the phase of LCA in which the findings from the inventory analysis and the impact assessment are considered together or, in the case of LCI studies, the findings of the inventory analysis only. The interpretation phase should deliver results that are consistent with the defined goal and scope and which reach conclusions, explain limitations and provide recommendations.

The interpretation should reflect the fact that the LCIA results are based on a relative approach, that they indicate potential environmental effects, and that they do not predict actual impacts on category endpoints, the exceeding of thresholds or safety margins or risks.

The findings of this interpretation may take the form of conclusions and recommendations to decision-makers, consistent with the goal and scope of the study.

Life cycle interpretation is also intended to provide a readily understandable, complete and consistent presentation of the results of an LCA, in accordance with the goal and scope definition of the study.

The interpretation phase may involve the iterative process of reviewing and revising the scope of the LCA, as well as the nature and quality of the data collected in a way which is consistent with the defined goal. The findings of the life cycle interpretation should reflect the results of the evaluation element.

3.2.3.5 Impact Categories

The impact categories considered in this study are:

- Climate change (a.k.a., global warming or carbon footprint) - A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the Earth's absorption of radiation emitted by the sun, increasing the greenhouse effect. This can in turn have adverse impacts on ecosystem health, human health and material welfare.

- Acidification - A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value (e.g., acid rain). Potential effects include fish mortality, forest decline and the deterioration of building materials.

- Particulate matter (a.k.a., dust and aerosol emissions) - A measure of particulate matter emissions and precursors to secondary particulates, such as SO_2 and NO_x from sources like fossil fuel combustion, wood combustion and dust particles from roads and fields. Particulate matter causes negative human health effects, including respiratory illness and an increase in overall mortality rates.

- Non-Renewable Energy Demand (NRED) - A measure of the consumption of energy resources from non-renewable origin, here reported as non-renewable energy demand (NRED), calculated according to the Cumulative Energy Demand method [53]. This approach for energy accounting is intended to overtake the consideration of cumulative fossil energy demand [54]. The accounting of such impact indicator is in line with consistent methodologies discussed in literature [55], comprising fossil energy and nuclear energy.

- Water Scarcity Index (WCI) - A measure of the consumption of freshwater. The use of such a fundamental resource are currently still evolving [56], in this study it's condidered only the consumptive use through a recent developed method [57] for computation of water scarcity index. It is built on a consumption-to-availability ratio, calculated as the fraction between consumed (otherwise referred as blue water footprint) and available water. Although non-comprehensive, this indicator is in line with the assessment of a so-called water scarcity footprint according to the requirements of recently published ISO 14046 [58] evaluate water resources vulnerability.

Chapter 4

Results and discussions

4.1 Air emissions

As described in the previous chapters, in this study the calculation of CO_2, NO_x, SO_2 emissions is performed.

Moreover, environmental performance indicators are developed taking into account:

- existing legislation;
- data collected on board from specific instrumentation;
- marine exhaust gas cleaning systems;
- and instantaneous emissions for every ship and substance considered.

4.1.1 CO_2 emissions

Carbon dioxide instantaneous emissions can be calculated multiplying the fuel consumption monitored on board by the emission factor in tonnes of carbon dioxide per tonne of fuel used.

In case where the fuel consumption is not monitored on board, it developed empirical regressions based on real data for the specific ship type, considering a direct correlation between the ship speed and the total power with a third order equation and a direct correlation between the total power and the fuel consumption.

Combining these correlations, the fuel consumption can be estimated depending just on the ship speed. For example, this is the regression for Ship 2.

$$Emissions = FuelConsumption \cdot EF$$

Fuel	EF [tCO$_2$/tfuel]
Heavy Fuel Oil (HFO)	3,114
Marine Gas Oil (MGO)	3,206
LNG	2,75

Table 4.1: Emission factors of different fuel [59]

Empirical fuel consumption regressions:

$$P = a1 \cdot v^3 + a2 \cdot v^2 + a3 \cdot v$$

$$Fc = a4 \cdot P^k$$

$$Fc = a4(a1 \cdot v^3 + a2 \cdot v^2 + a3 \cdot v)^k$$

$$Fc = 0,00005(1,3431 \cdot v^3 + 9,8821 \cdot v^2 + 153,98 \cdot v)^{1,133\,57}$$

$$y = -146,8x^3 + 10346x^2 - 238707x + 2E + 06$$

$$R^2 = 0,988$$

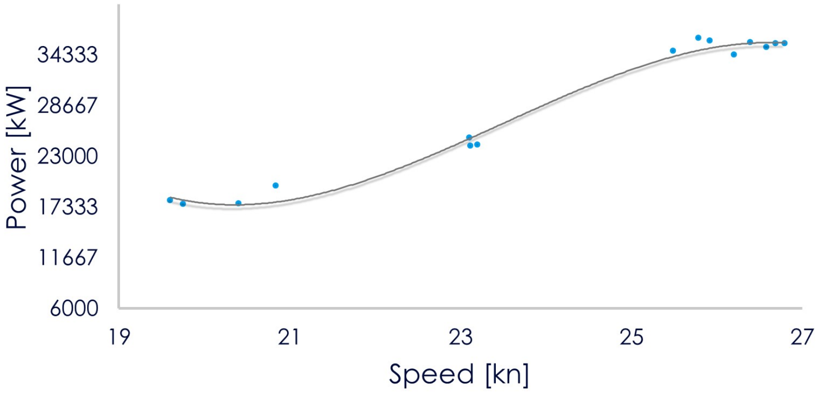


Figure 4.1: Speed - power fitting for Ship 2

$$y = 5E - 05 \cdot x^{1,1336}$$

$$R^2 = 0,9858$$

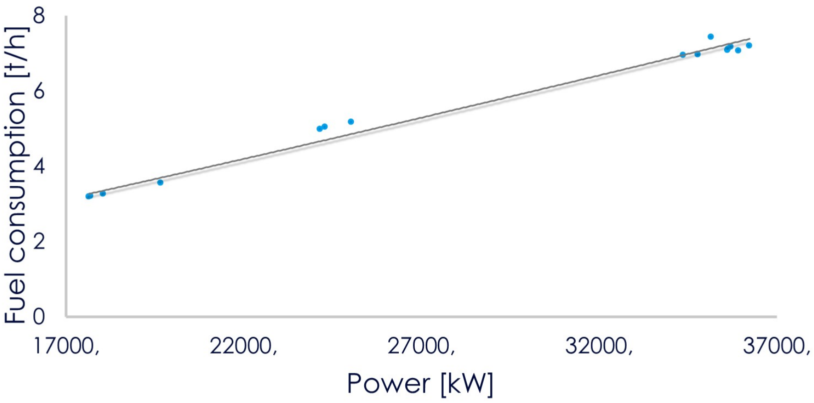


Figure 4.2: Power - fuel consumption fitting for Ship 2

4.1.2 NO_x and SO_2 emissions

Nitrogen oxides emissions are monitored instantaneously on board in ppm [60]. In order to compare them to the limits it is necessary convert ppm to gram per kilowatt hour using power and exhaust gas flow values. The values of exhaust gas flow are known from the engine manufacturer depending on engine operating load. In general, they are presented in tabular form.

From these values the specific fitting regression curve can be obtained, depending just on the power and they are presented in graphical form as Brake Specific Exhaust Flow depending on engine speed and power.

% MCR	Power [kW]	Exhaust gas flow [kg/s]
50	6930	18
75	10395	21,8
85	11781	23,4
100	13860	25

Table 4.2: Engine manufacturer data (Ship 2 engine)

Sulphur dioxide emissions can be monitored on board or calculated from the fuel Sulphur content. In this work they are calculated multiplying fuel consumption by fuel oil Sulphur content. Fuel consumption can be calculated multiplying Brake Specific Fuel

Consumption, that is in general known from engines manufacturer, by the power of the engine.

In order to perform the calculations, these information are considered for each ship, outside and inside emission control areas. To comply with regulations, each ship is considered equipped with selective catalytic reduction system to nitrogen oxides reduction, even the ones not really equipped except for Ship four-b which has diesel generators compliant to Tier THREE. Only Ship two and three have scrubbers on board to Sulphur dioxide reduction with an efficiency of ninety-seven percent. Ship one and four-a switch the fuel from the traditional to low-sulphur one in emission control areas and Ship four-b doesn't emit Sulphur dioxide when it uses LNG.

$$Emission = Fc \cdot FuelOilSulphurContent$$

$$Fc = BSFC \cdot P$$

In the table 4.2 are shown the main ships data.

$\eta = 97\%$ [61] [62]

	Outside ECA				**ECA**			
Ship	**Fuel**	**S content [%m/m]**	**SCR**	**Scrubber**	**Fuel**	**S content [%m/m]**	**SCR**	**Scrubber**
1	HFO	3,50	OFF	Not installed	MGO	0,10	ON	Not installed
2	HFO	3,50	OFF	OFF	HFO	3,50	ON	ON
3	HFO	3,50	OFF	OFF	HFO	3,50	ON	ON
4a	HFO	3,50	OFF	Not installed	MGO	0,10	ON	Not installed
4b	LNG	0	Tier III	Not installed	LNG	0	Tier III	Not installed

Table 4.3: Fuel characteristic and ship equipment

The evaluation of ship emissions is performed developing two indicators as a "traffic light" based on the compliance between instantaneous nitrogen oxides and Sulphur dioxide emission values and their limits. It is decided that values lower than ninety percent of the limit correspond to a good environmental performance while, values greater than the limit, correspond to excessive emissions which require corrective actions and the yellow central zone is so far enough good, but it can become unsuitable. As can be seen, nitrogen oxides and sulphur dioxide emissions are compared with the corresponding limits calculated in and outside emission control areas while the values of carbon dioxide emissions aren't compared with limits because of the lack of legislation and it's only possible to know the emitted quantity. So, this tool can be used as a decision support system to evaluate the ship performance and to verify the compliance with current legislation.

In the following tables are shown ships emissions results.

SHIP 1		Outside ECA			ECA		
LIMITS			14,4	151,7		3,4	4,3
Speed [kn]	**Power [kW]**	**CO2 [t/h]**	**NOx [g/kWh]**	**SO2/CO2 [ppm/%v/v]**	**CO2 [t/h]**	**NOx [g/kWh]**	**SO2/CO2 [ppm/%v/v]**
18,85	11734	6,1	8,09	145,9	6,3	2,66	4,0
20	14043	7,4	10,49	145,9	7,6	3,05	4,1
20	12810	6,7	8,89	146,0	6,9	2,85	4,1
20,46	15051	7,9	8,94	145,9	8,2	3,20	4,1
20,6	12936	6,7	9,69	145,9	6,9	2,93	4,0
20,86	14590	7,7	8,46	146,0	7,9	3,43	4,0
21	13279	6,9	9,85	146,0	7,1	2,92	4,0
21,5	13167	6,9	9,29	145,9	7,1	3,31	4,0
21,53	14300	7,5	8,26	146,1	7,7	3,33	4,0
22,04	14021	7,3	8,07	146,0	7,5	3,24	4,1

Table 4.4: Ship 1 emissions results

SHIP 2			Outside ECA		ECA	
LIMITS			10,54	151,7	2,6	4,3
Speed [kn]	**Power [kW]**	**CO2 [t/h]**	**NOx [g/kWh]**	**SO2/CO2 [ppm/%v/v]**	**NOx [g/kWh]**	**SO2/CO2 [ppm/%v/v]**
20,84	19670	3,2	10,39	146,1	1,23	3,5
25,92	35911	6,4	8,58	145,9	0,79	3,6
26,69	35605	6,4	8,86	146,0	0,79	3,6
25,79	36225	6,5	8,18	146,0	0,79	3,7
23,11	25025	4,7	10,09	146,0	0,99	3,6
26,39	35702	6,5	8,45	146,0	0,78	3,7
26,80	35626	6,5	8,23	145,9	0,79	3,7
19,60	18054	3,0	10,41	146,1	1,25	3,7
20,40	17702	2,9	11,81	146,0	1,28	3,8
23,12	24155	4,5	10,24	145,9	1,02	3,7

Table 4.5: Ship 2 emissions results

SHIP 3				Outside ECA		ECA	
LIMITS				10,54	151,7	2,6	4,3
Speed [kn]	**Power [kW]**	**DDGGON**	**CO2 [t/h]**	**NOx [g/kWh]**	**SO2/CO2 [ppm/%v/v]**	**NOx [g/kWh]**	**SO2/CO2 [ppm/%v/v]**
22,65	53478	5	5,8	9,68	145,9	0,76	3,5
20,54	44088	4	6,1	8,96	145,9	0,73	3,7
17,82	34682	3	6,4	7,90	146,0	0,70	3,6
15,77	30080	3	5,8	8,87	146,0	0,75	3,7

Table 4.6: Ship 3 emissions results

SHIP 4a				Outside ECA		ECA	
LIMITS				10,10	151,7	2,5	4,3
Speed [kn]	**Power [kW]**	**DDGGON**	**CO2 [t/h]**	**NOx [g/kWh]**	**SO2/CO2 [ppm/%v/v]**	**NOx [g/kWh]**	**SO2/CO2 [ppm/%v/v]**
18,73	36804	3	6,8	9,35	140,4	0,75	4,1
20,60	44529	3	8,0	6,62	140,4	0,69	4,1
21,90	50423	4	6,9	6,80	140,5	0,70	4,1
22,66	55800	4	7,5	8,09	140,4	0,68	4,1

Table 4.7: Ship 4a emissions results

SHIP 4b				**ECA**
LIMITS				**2,5**
Speed [kn]	**Power [kW]**	**DDGGON**	**CO2 [t/h]**	**NOx [g/kWh]**
18,73	23840	2	4,9	1,15
20,60	31565	3	4,3	1,11
21,90	37459	4	3,9	0,98
22,66	42836	4	4,4	1,03

Table 4.8: Ship 4b emissions results

The resulting emission values are considered to develop two different Instantaneous Specific Emissions Indexes (ISEI), one for each impact category considered, global warming and acidification.

For both these categories, the corresponding index is calculated through the comparison between the Instantaneous Specific Emissions value, estimated on board the ship in a specific operating condition, and the corresponding reference value.

The Instantaneous Specific Emission is calculated as the ratio between the instantaneous emission produced by all the running propulsion engines, multiplied by the corresponding impact potential value, and the transported payload.

The reference value considers the emission at seventy-five percent of maximum continuous rating and the payload is referred to the design load condition of the ship.

These are the Global Warming Potential (GWP) and Acidification Potential (AP) Indexes formulas; in particular, the denominator that represents the payload is the total amount of the passengers, crew members, cars and containers, each multiplied with the corresponding equivalent weight factor and a generic load.

$$ISEI = \frac{ISE}{ISE_{ref}} = \frac{\frac{Emission \cdot Impacpotenzial}{Payload}}{\frac{Emission(75\%MCR) \cdot Impacpotenzial}{DesignPayload}}$$

$$ISEI_{GWP} = \frac{[kg\mathrm{CO}_{2\mathrm{e}}/t \cdot h]}{[kg\mathrm{CO}_{2\mathrm{e}}/t \cdot h]} = \frac{\frac{E\mathrm{CO}_2 \cdot GWP\mathrm{CO}_2}{NP \cdot WP_{eq} + NC \cdot WC_{eq} + NV \cdot WV_{eq} + W_{gen} + TEU \cdot WTEU}}{\frac{E\mathrm{CO}_{2\mathrm{ref}} \cdot GWPCO_2}{NP_{ref} \cdot WP_{eq} + NC_{ref} \cdot WC_{eq} + NV_{ref} \cdot WV_{eq} + W_{genref} + TEU_{ref} \cdot WTEU}}$$

$$ISEI_{AP} = \frac{[kg\mathrm{CO}_{2\mathrm{e}}/t \cdot h]}{[kg\mathrm{CO}_{2\mathrm{e}}/t \cdot h]} = \frac{\frac{ENO_x \cdot APNO_x + ESO_2 \cdot APSO_2}{NP \cdot WP_{eq} + NC \cdot WC_{eq} + NV \cdot WV_{eq} + W_{gen} + TEU \cdot WTEU}}{\frac{ENO_{xref} \cdot APNO_x + ESO_{2ref} \cdot APSO_2}{NP_{ref} \cdot WP_{eq} + NC_{ref} \cdot WC_{eq} + NV_{ref} \cdot WV_{eq} + W_{genref} + TEU_{ref} \cdot WTEU}}$$

From taking again advantage of the simplicity of a traffic light indicator, the typical three colours are coupled with the different Instantaneous Specific Emissions Indexes values. Values lower than 0,9 correspond to a good environmental performance while, values greater than 1, correspond to a bad situation with excessive emissions. The yellow central zone is so far enough good, but it can become unsuitable.

The following tables (Table 4.9 - 4.10 - 4.11 - 4.12 - 4.13) show the ISEI results.

In particular, for Ship 1 and four-a (4a) we can see that to switch the fuel from the traditional to low-sulphur one in emission control areas leads to an increasing carbon dioxide emissions and it is due to the higher emission factor of the fuel.

So, global warming and acidification potential indexes are applied to every ship studied to simulate their implementation on board.

SHIP 1		**OUTSIDE ECA**		**ECA**	
Speed [kn]	**Power [kW]**	**ISEIGWP**	**ISEIAP**	**ISEIGWP**	**ISEIAP**
18,85	11734	0,95	0,64	0,98	0,27
20	14043	1,15	0,89	1,18	0,31
20	12810	1,04	0,74	1,07	0,29
20,46	15051	1,24	0,87	1,28	0,33
20,60	12936	1,05	0,78	1,08	0,30
20,86	14590	1,20	0,82	1,23	0,34
21	13279	1,08	0,81	1,11	0,30
21,5	13167	1,07	0,77	1,10	0,33
21,53	14300	1,17	0,79	1,20	0,33
22,04	14021	1,14	0,76	1,18	0,33

Table 4.9: Ship 1 ISEI results

SHIP 2		**ISEIGWP**	**OUTSIDE ECA**	**ECA**
Speed [kn]	**Power [kW]**		**ISEIAP**	**ISEIAP**
20,84	19670	0,66	0,55	0,08
25,92	35911	1,31	0,95	0,10
26,59	35605	1,32	0,97	0,10
25,79	36225	1,34	0,95	0,10
23,11	25025	0,96	0,74	0,08
26,39	35702	1,33	0,95	0,10
26,80	35626	1,32	0,94	0,10
19,60	18054	0,61	0,51	0,07
20,40	17702	0,60	0,53	0,07
23,12	24155	0,93	0,72	0,08

Table 4.10: Ship 2 ISEI results

SHIP 3			ISEIGWP	OUTSIDE ECA	ECA
Speed [kn]	Power [kW]	DDGG ON		ISEIAP	ISEIAP
22,65	53478	5	1,06	1,00	0,39
20,54	44088	4	1,11	0,99	0,39
17,82	34682	3	1,17	0,98	0,39
15,77	30080	3	1,05	0,92	0,37

Table 4.11: Ship 3 ISEI results

SHIP 4a			OUTSIDE ECA		ECA	
Speed [kn]	Power [kW]	DDGG ON	ISEIGWP	ISEIAP	ISEIGWP	ISEIAP
18,73	36804	3	0,98	0,92	1,01	0,34
20,60	44529	3	1,17	1,06	1,20	0,39
21,90	50423	4	1,01	0,86	1,04	0,34
22,66	55800	4	1,09	0,96	1,13	0,36

Table 4.12: Ship 4a ISEI results

SHIP 4b			ISEIGWP	ECA
Speed [kn]	Power [kW]	DDGG ON		ISEIAP
18,73	23840	2	1,15	0,54
20,60	31565	3	1,03	0,46
21,90	37459	4	0,93	0,36
22,66	42836	4	1,04	0,43

Table 4.13: Ship 4b ISEI results

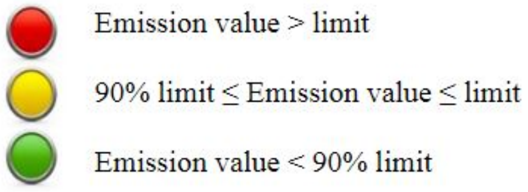
These are some values and the resulting traffic light obtained for each considered Ship.

It can be possible to visualize the Indexes values calculated for the ships in these specific operating conditions.

The Instantaneous Specific Emissions Indexes is also designed to compare the performances of the same ship with different propulsion system.

In this work, this comparison is made in emission control areas calculating the Indexes for each impact category, as the ratio between the Instantaneous Specific Emissions of the innovative propulsion system of Ship four-b and the reference values of the traditional diesel configuration of Ship four-a.

The feedback from the coloration and the values of traffic light is immediate. The evaluation of ship performance is performed developing an indicator as a ”traffic light” based on compliance between NO_x instantaneous emission values and the limit.



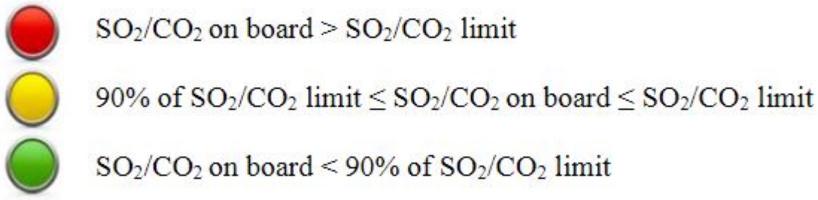
Emission value > limit

90% limit $\leq$ Emission value $\leq$ limit

Emission value < 90% limit

Figure 4.3: NO_x emission traffic light

Also in this case, the traffic light indicator, based on the compliance between calculated emission values and the SO_2/CO_2 ration is the following.



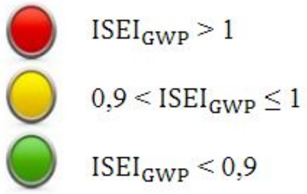
SO_2/CO_2 on board > SO_2/CO_2 limit

90% of SO_2/CO_2 limit $\leq$ SO_2/CO_2 on board $\leq$ SO_2/CO_2 limit

SO_2/CO_2 on board < 90% of SO_2/CO_2 limit

Figure 4.4: SO_2/CO_2 ratio emission traffic light

From taking again advantage ofthe simplicity of a traffic light indicator, the typical three colours are coupled with the ISE_{GWP} values according to the following scheme. Values lower than 0,9 correspond to a good environmental performance while, values greater than 1, correspond to a bad situation with excessive emissions which require actions to reduce them. The yellow central zone is so far enough good, but it can become unsuitable.



$ISEI_{GWP} > 1$

$0{,}9 < ISEI_{GWP} \leq 1$

$ISEI_{GWP} < 0{,}9$

Figure 4.5: $ISEI_{GWP}$ emission traffic light

As predictable, the innovative propulsion has better environmental performance compared to traditional one. It is clearly that this advantage is greater outside emission control areas.

In addition, by comparing instantaneous specific emissions values of the Ship four-a and four-b, it can be seen an approximate fifty percent (50%) decrease in carbon dioxide instantaneous specific emissions and an approximate seventeen percent (17%) decrease in acidification contribute, by using dual fuel configuration.

This emissions reduction is partly due to fuel cells that, in this case, supply about eighty percent of the power required by auxiliary services and partly to the lower LNG carbon factor.

4.2 Waste management

With the aim of evaluating waste management alternatives in a circular economy perspective, the study examines a combined system for the optimization of ship waste management and assesses its possible use for energy purposes.

As described in Material and Methods chapter, measures listed in Table 3.5 are preliminary assessed through a SWOT analysis, which results, expressed as most significant measures in terms of GHG emission reduction applicable to onboard waste management, are shown in Figure 4.6.

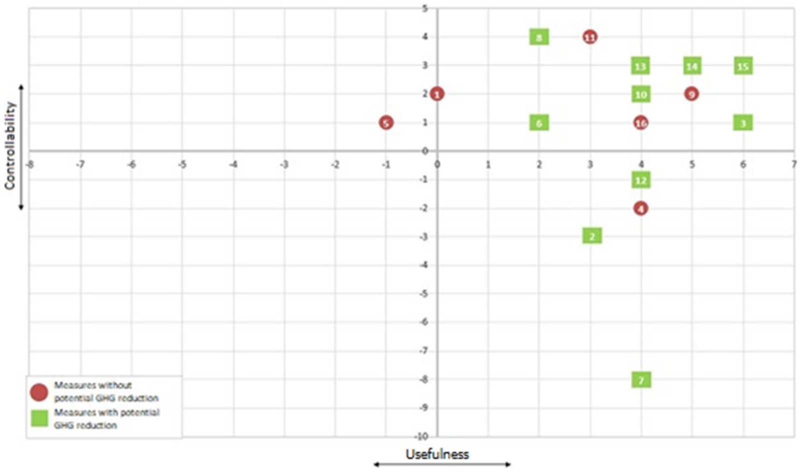


Figure 4.6: Scatter chart on the results of the SWOT analysis of the proposed measures

These results were published in a scientific journal where measures No.13, No.14 and No.15 (Table 3.5) related to the best practices on onboard waste reduction shown good potential both in terms of usefulness and controllability and measures N. 3 and 10 were chosen for further insights [63].

According to the preliminary findings of the SWOT analysis and to qualitative considerations based on waste hierarchy and lifecycle approach, the following waste streams are identified and further analyzed, among which specific measures are quantitatively assessed:

- ORGANIC
- OIL/SLUDGE
- PACKAGING/CONSUMABLES
- OTHER WASTE

In the following, different measures aiming to reduce the impact of these waste stream are discussed.

4.2.1 Organic

This paragraph investigates a potential innovative pattern of recycling food waste from cruise ships for use as feed in aquaculture, in terms of environmental sustainability. Comparative Life Cycle Assessment based on the results of a previously published paper is used to evaluate the possible potential benefits of replacing conventional formulations of feed mix with food waste, generated and processed onboard [64]. A set of three indices, otherwise possible stand-alone indicators, is selected to measure global warming potential, non-renewable cumulative energy demand, and water scarcity index. The basis for comparison is represented by a typical commercial feed product for aquaculture in Norway and UK. The analysis investigates a case-study along the complex patterns within the food and feed integrated network, where feasible food products for human are addressed to feed animals thereafter introduced into the market as food product for humans.

The idea of replacing fish-derived and crop-derived products with recovered material - otherwise lost as waste - is not to be considered as beneficial by default. The impacts from processing and transport phase may be able to offset the potential gains arising from “closing the loop”.

The outcomes of Life Cycle Impact Assessment (LCIA) show very promising results deriving from the application of turbo - drying technology onboard cruise ships for valorization of food waste, whose large amounts are available not only in Mediterranean area, but also at global scale.

Field tests from real application in aquaculture industry are necessary to validate the results of such analysis within salmon farms, with growing levels of replacement, as performed in literature for e.g. algae-based alternative feed [65]. Life cycle assessment is proved as a tool for comparing the environmental implications of using different ingredient types in salmon feeds, but its findings shall not be used in isolation for decision-making.

As for policy issues, it must be specified that normative development is ongoing not only for aquaculture production systems [66], but also for waste management in the maritime sector. As innovative practice, this circular solution is not actually still specifically regulated, thus a dialogue is currently opened among stakeholders and regulators for defining concepts as “by-product” and “end- of-waste” status coherently for the related international, European and national policies at different levels.

The implementation of the selected LCIA methods for the comparative analysis shows that a conventional feed formulation results in higher life cycle burdens for the whole set of considered environmental impact categories, with respect to the analyzed case study by food waste processing. The environmental sustainability of the alternative formulation including circular pattern of food waste is demonstrated with reference to the production scenarios in both Norway and United Kingdom, for the entire triangle of indicators. In particular, the life cycle of a traditional feed product in UK shows the worst performance in two out of three indices, i.e. carbon footprint and non-renewable energy demand, whilst the Norwegian traditional mix is source of the higher impact for water scarcity.

LCIA phase is performed at midpoint level through a set of three indicators, i.e. global warming potential (GWP), non-renewable energy demand (NRED), and water scarcity index (WSI). Globally acknowledged methodologies are selected for characterization of suchimpacts, respectively, on climate change, energy resources, and water, for implementation in SimaPro v.8.0.2 software. Global warming potential is calculated through the use of factors derived from fifth IPCC report [67], in line with the recent requirements of ISO/TS 14067 for carbon footprint studies [68]. According to such approach, contributions to climate change are evaluated by sub-dividing emissions of greenhouse gases from fossil origin, from biological origin, and from direct land use change (dLUC). In this paper removal of carbon dioxide from atmosphere is not accounted, since the system boundaries are set as a cradleto-gate study, where the use stage and the end-of-life stage of the feed product are not included. This approach is in fact coherent with the methodology set by the Product Category Rules (PCR) for arable crops [69] in the framework of ISO 14025 [70].

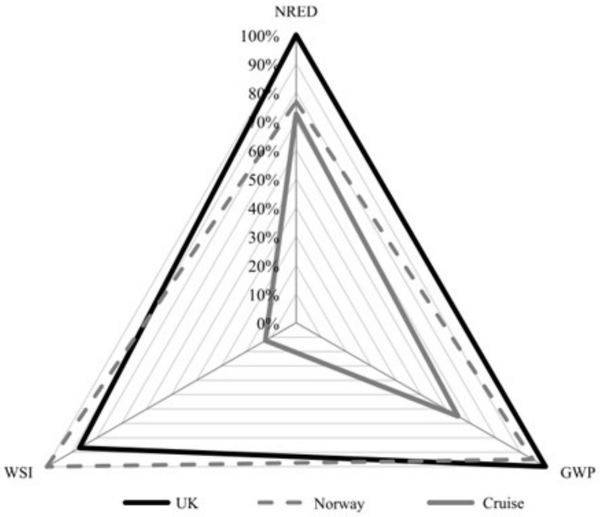


Figure 4.7: LCIA results—distance to worst case (per tonne of proteins)

Major drivers of impact and bottlenecks are addressed by the investigation of the three scenarios, with reference to 1 tonne of feed produced for aquaculture. Owing to a different proteins content in UK and Norwegian commercial formulation, UK and Norwegian feed mixes exhibit a similar performance in terms of water footprint per mass unit. For carbon footprint and energy demand, UK feed mix still represents the worst case, as observed in the LCIA results per tonne of protein (Figure 4.8).

From energy perspective, major impact is attributable to cod fishing gear methods that entail extensive use of fossils fuels. This consumption is responsible for over 36% for NRED of the total amount of fish-derived products, equal to a 28% share on the final product in UK. On the crop side, almost 26% of NRED for 1 tonne of crop-derived mix is instead ascribable to maize starch production, although this contribution is found to be corresponding to 2% share only on the overall impacts per tonne of final feed product.

Cod fishing process is observed as main source of impact also in terms of GWP, with 26% share of total GHG emissions per tonne of final product, and in terms of WSI, being responsible for 16% of the index.

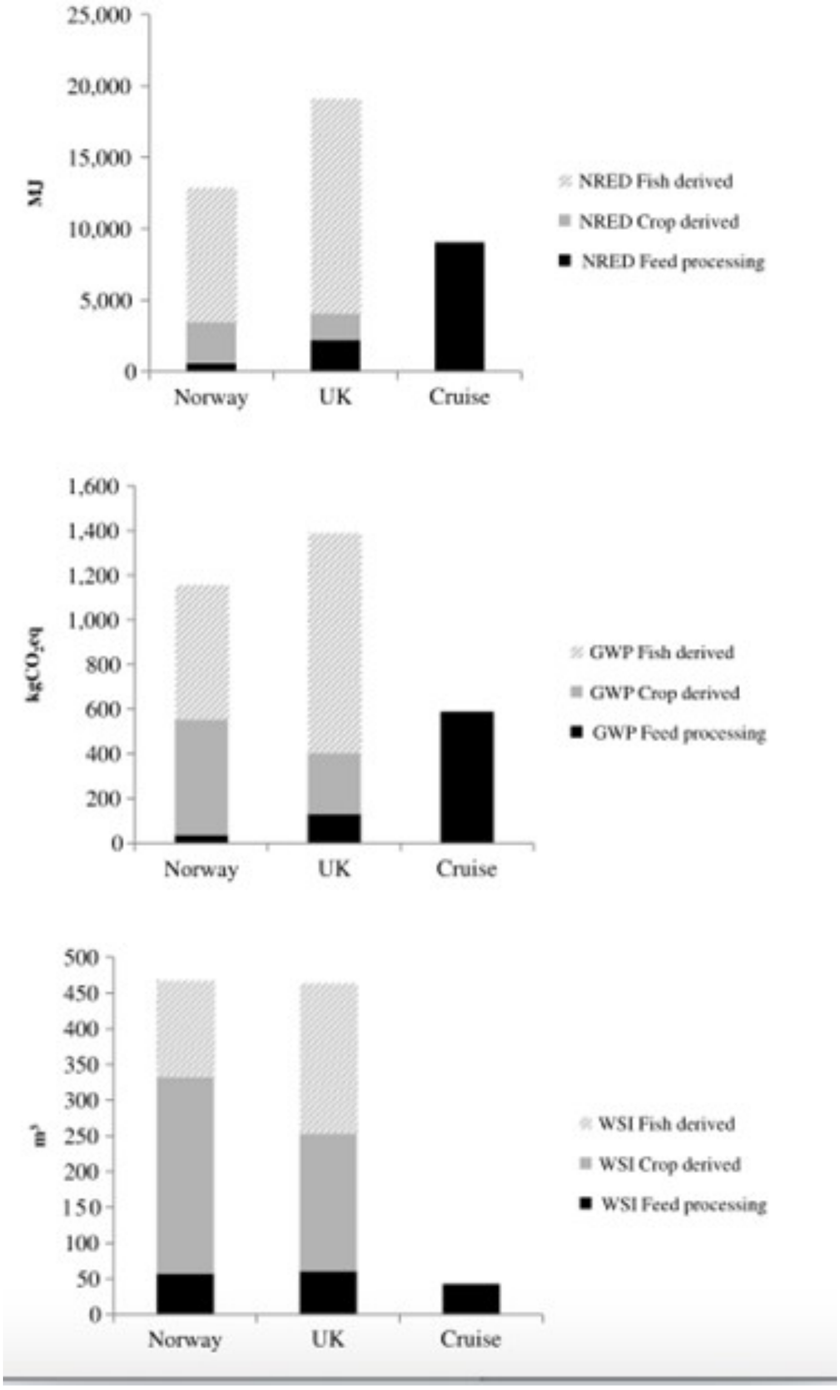


Figure 4.8: Contribution of life cycle macro-stages (per tonne of feed product).

In conclusion, the results of this study may serve as a set of three screening indicators about the environmental performance of a pioneering practice in the sense of circular economy, where the excess amount of food, loaded and not consumed onboard a cruise ship, can be re-introduced in the global food network as feed for further future food products. In particular, in this case study the majority of this material stream, rich of nutrient, would be otherwise dumped, thus destined to become food for fish also in baseline conditions, when discharged to sea.

4.2.2 Oil/Sludge

The chosen measure consists of the pyrolysis treatment of the exhausted oils generated onboard. Oil wastes are mainly sludge resulting from the purification of fuels. Under a business-as-usual scenario, this type of waste is collected and delivered in ports. Pyrolysis is a process for thermal conversion of solid fuels in the complete absence of oxidizing agent (air/oxygen), or with such limited supply that gasification does not occur to any appreciable extent. It is a common technique used to convert urban waste into energy, in the form of solid, liquid and gaseous fuels, which takes place at temperatures in the range 400-800°C. Pyrolysis product distribution is a function of heating rate, residence time and maximum reaction temperature. Pyrolysis oil can be used directly as fuel, gas can be fed to a boiler and solid to an incinerator.

According to the UNFCCC methodologies the Emission Reduction (ER) resulting from a project is calculated according to the following formula:

$$ER_y = BE_y - PE_y \pm LE_y$$

where:

- ER_y = Emission reduction in the year y (tCO_{2e}/y);
- BE_y = Baseline emissions at year y (tCO_{2e}/y);
- PE_y = Project activity emissions in the year y (tCO_{2e}/y);
- LE_y = Leakage emissions in the year y (tCO_{2e}/y).

Baseline Emissions (BE) due to the current system of treatment of oily residues are mainly caused by the disposal of sludge. For the calculation, reference was made to ACM0022 “Alternative waste treatment processes” [71]. This methodology applies to project activities where fresh waste, originally intended for disposal in a solid waste disposal site (SWDS), is treated using any (combination) of the waste treatment options among the following: composting, anaerobic digestion, thermal treatment, mechanical treatment, incineration and gasification. The last one is a treatment very similar to pyrolysis process. The methodology includes the calculation of baseline emissions due to the disposal of waste in landfills where no alternative treatment is applied. Emissions are calculated using [72].

$$BE_{CH_{4,y}} = \varphi \cdot (1 - f_y) \cdot GWP_{CH4} \cdot (1 - OX) \cdot \frac{4}{3} \cdot F \cdot DOC_{f,y} \cdot MCF_y \cdot \sum_{x=1}^{y} \sum_{j} (W_{j,x} \cdot DOC_j \cdot e^{-k_j (y-x)} \cdot MCF_y)$$

Taking into account the data shown in Table 3.6, the baseline emissions are equal to 6.4 tCO_{2e}/y.

Parameter		Value	Annotation
φ	Model correction factor to account for model uncertainties for year y	0,85	Default value for wet conditions
f_y	Fraction of methane captured at the SWDS and flared, combusted or used in another manner that prevents the emissions of methane to the atmosphere in year y	0,7	Typical average value
GWP_{CH4}	Global Warming Potential of methane	30	[73]
OX	Oxidation factor (reflecting the amount of methane from SWDS that is oxidised in the soil or other material covering the waste)	0,1	Default value
F	Fraction of methane in the SWDS gas (volume fraction)	0,5	Default value
$DOC_{f,y}$	Fraction of degradable organic carbon (DOC) that decomposes under specific conditions occurring in the SWSD for year y (weight fraction)	0,5	Default value
$MCFy$	Methane correction factor for year y	0,5	Default value for semi-aerobic managed SWDS
j	Type of residual waste or types of waste in the municipal solid waste		Only oily sludge
$W_{j,x}$	Amount of solid waste type j disposed or prevented from disposal in the SWDS in the year x [t/a]	1057	See Table ?
DOC_j	Fraction of degradable organic carbon in the waste type j (weight fraction)	0,09	Default value for industrial sludge
k_j	Decay rate for the waste type j [1/a]	0,06	Default value for industrial sludge
x	Years in the time period in which waste is disposed at the SWDS, extending from the first year in the time period (x=1) to year y (x=y)	1	To be precautionary and make a comparison relative to a year, only one year of production of sludge to be disposed is considered
y	Year of the crediting period for which methane emissions are calculated	1	

Table 4.14: Parameters to calculate baseline emissions

For the calculation of Project Emissions (PE), it should be considered that there is no specific methodology for calculating the emissions from pyrolysis plants of liquid substances, as pyrolysis process it is not widely applied on an industrial level yet. Therefore, reference was made to the calculation of the emissions caused by a pyrolysis process for the treatment of waste that allows avoiding the production of methane from the waste itself [74].

According to this methodology, PE are calculated according to the following formula:

$$PE_{PIR} = PE_{COM,PIR} + PE_{FC,PIR} + PE_{TRASP,PIR} + PE_{EC,PIR}$$

where:

- $PE_{COM,PIR}$ = Emissions from pyrolysis of non-biogenic carbon in the year y (tCO_{2e}/y)
- $PE_{FC,PIR}$ = Emissions from the consumption of auxiliary fuel by the pyrolysis facility in the year y (tCO_{2e}/y)
- $PE_{TRAS,PIR}$ = Emissions from fossil fuel consumption due to incremental transportation in the year y (tCO_{2e}/y)
- $PE_{EC,PIR}$ = Emissions from electricity or diesel consumption in the year y (tCO_{2e}/y).

For the purpose of the study, the following hypotheses were made:

- As the sludge consists mainly of hydrocarbons, all the sludge fed to the reactor downstream of the sedimentation are considered as non-biogenic carbon;
- Emissions from the consumption of auxiliary fuel by the pyrolysis facility were not considered since the heat recovery is done totally through sources already present on board the ship (incinerator);
- Emissions from fossil fuel consumption due to incremental transportation were not considered as this type of transport is not foreseen;
- Emissions from electricity consumption of agitators and pumps are included.

According to [74], PECOM,PIR are calculated as following:

$$PE_{COM,PIR} = \frac{Q_{m,nonbiogenic}}{Q_{m,total}} \cdot Q_{CO_2,pyro}$$

where $Q_{m,nonbiogenic}$ e $Q_{m,total}$ in this case are the same quantity because they correspond to the sludge fed to the reactor, which consist of non-biogenic carbon: about 390 t/y. $Q_{CO_2,pyro}$ is the CO_2 emitted by the pyrolysis process in the year including the pyrolysis or flaring if the gases and vapours originating from the waste (tCO_{2e}). It is not easy to determine the value of Q_{CO_2}, pyro since there are few data available concerning pyrolysis processes, in first approximation it was considered that all the gas produced by the process was CO_2: about 17% of the sludge fed (Table 3.6). Thus, $PE_{COM,PIR}$ resulted equal to 67 tCO_{2e}/y.

$PE_{EC,PIR}$ emissions are calculated according to [75].

$$PE_{EC,PIR} = EC \cdot \frac{FC \cdot NCV \cdot EF_{CO_2}}{EG} \cdot (1 - TDL)$$

Considering the assumptions and the data reported in Table 3.6, $PE_{EC,PIR}$ resulted equal to about 2 tCO_{2e}/y.

Parameter	**Value**	**Annotation**
Agitator power [kW]	0,7	0,3-1 kW/m3: for agitated vessel [76]
Pump power [kW]	2	From data sheet of a pump similar to that needed in this case
Working hours [h/a]	1400	4 h/d for 50 w/y
Fuel consumption [g/kWh]	171	From data sheet of Wartsila engine: type of engine usually installed on cruise ships
EC - Quantity of electricity consumed [MWh/y]	3,8	Primary Data
FC - Quantity of fossil fuel fired in the plant to produce electricity $[t_{comb}/a]$	0,65	Primary Data
NCV - Average net calorific value of fossil fuel used $[GJ/t_{fuel}]$	41,08	For fuel oil [**?**]
EF_{CO_2} - CO_2 emission factor of fossil fuel used $[t_{CO_2}/GJ]$	0,7648	For fuel oil [**?**]
EG - Quantity of electricity generated in plant	3,8	Primary Data
TDL - Average technical transmission and distribution losses for providing electricity to source	0	Primary Data

Table 4.15: Parameters to calculate emissions from electricity consumption

Considering the above calculations, PE_{PIR} are equal to 69 tCO_{2e}/y.

During pyrolysis process, solid residue is produced (125 t/y, see Table 3.6). It can be download in port and disposed or reused on board. In the second case, no further emissions must be considered, while, in the first one, the emissions due to the disposal of solid in landfill must be calculated. The latter are determined based on the equation reported in [72] (already used to calculate the baseline emissions) and are not very significant: 0.7 tCO_{2e}/y.

The total Project Emissions are 69 tCO_{2e}/y in case of the pyrolysis residue is reused on board, and 70 tCO_{2e}/y in the other case. Leakage Emissions (LE) are negative emissions caused by the new system (i.e. emissions associated with the production of reagents) or positive emissions caused by the system to be replaced (i.e. emissions related to the avoided production of fossil). Since the pyrolysis process would allow the use of secondary fuel, indirectly avoided emissions from the lack of virgin fuel production were considered as leakage emissions. LE are calculated according to large scale consolidated methodology [77]:

$$LE_y = Q_{fuel} \cdot NCV_{fuel} \cdot EF_{CO_2,up}$$

Where Q_{fuel} is the quantity of fossil fuel avoided, $\mathrm{NCV_{fuel}}$ is the net calorific value of fuel oil and $EF_{CO_2,up}$ is the emission factor for upstream emissions associated with consumption of fossil fuel, in this case it is heavy fuel oil (marine type) and it is equal to 9.4 tCO_{2e}/TJ [78]. Considering the possible replacement of 118 t/y of heavy fuel oil, LE_y results equal to 46 tCO_{2e}/y.

According to the above hypothesis, Emission Reduction is negative: -17 tCO_{2e}/y in case the solid is reused on board and -18 tCO_{2e}/y in case of its disposal on ground.

Therefore, this new process shows a slight increase in CO_2 emissions compared to the current management system. However, considering also waste transportation to the treatment plant in the baseline scenario, it is possible to evaluate the minimum distance for which the emission reduction for the analysed measure starts to be positive. Considering an emission factor equal to 0.166 kg CO_{2e}/tkm, in the case where solid residue produced by pyrolysis is reused on board (ER1) the emission reduction gets positive for transport distances above 94-95 km. In the second case, if the solid residue is disposed of in landfills (ER2) – and the distance to the plant is considered equal to that for the avoided transportation – the emission reduction gets positive for transport distances above 114-115 km. The different gradients of the lines are due to the different amounts of overall waste for which waste transport is avoided: 1057 tons in case of ER1; and 932 tons in the case of ER2, being 125 tons of solid residue from pyrolysis still transported to the landfill.

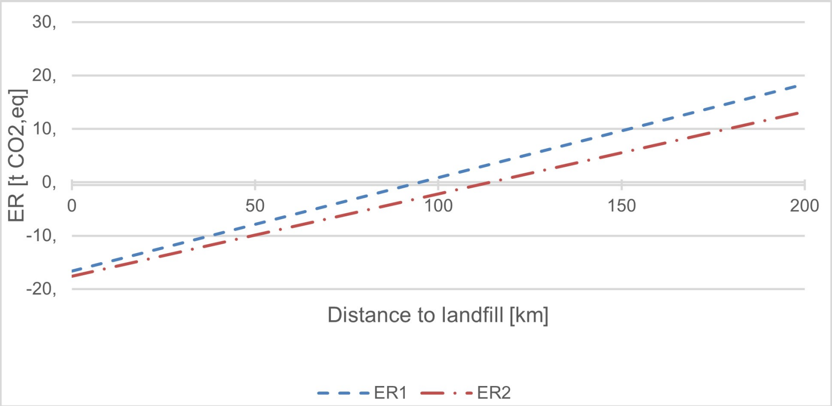


Figure 4.9: ER variation according to waste transport

4.2.3 All waste

The proposed plant relies on the synergic operation of the incinerationplant (IP) and the absorption refrigeration system (ARS), which exploits the thermal energy recovered by the IP to provide refrigerated water for different usages. The potential of an incinerator can be defined either as the maximum waste rate that the plant can burn or as the maximum thermal power that it can produce. In order to provide the best energetic and environmental performance (minimization of dioxin and volatile organic compounds (VOC) emissions), incinerators must be designed and built to operate at different rates, while always maintaining the temperature of the outgoing fumes between 850 °C and 1200 °C. To reach these goals and to fit within the spaces available onboard a cruise ship, the components of a typical incineration plant are piled up vertically as in the subsequent figure 4.11.

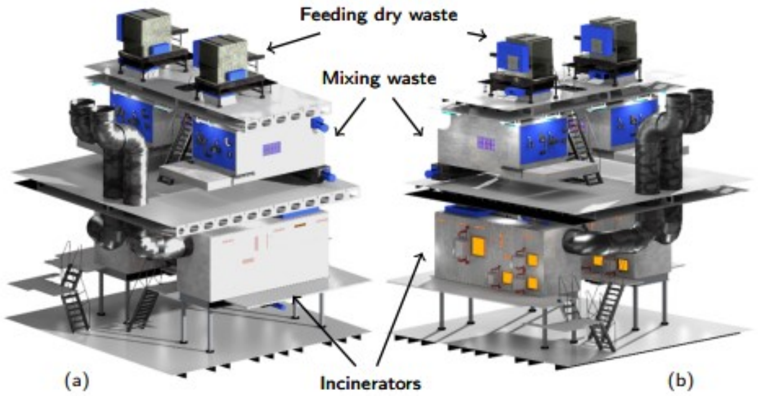


Figure 4.10: Incineration system, composed of two twin plant. (a) front view, (b) rear view

The energy exploitation of the fumes produced by the incinerator as a thermal source appears to be a promising solution, with significant overall efficiency. Supporting the existing heating, air conditioning or refrigeration systems requires installing dedicated heat exchangers together with some further minor system modifications. The energy demand for heating of cabins and shared areas is usually satisfied by the primary engine, with the exception of rare cases during stops in port in the winter season. Therefore, the strategy of committing the energy recovery from the incinerators to support the cabin heating system would not induce a reduction of the fuel consumption. On the other hand, recovered thermal energy can contribute to support the air conditioning systems (HVAC) and the refrigeration systems. The refrigeration systems regulate the temperature inside two different types of stocking areas: one chilled at a temperature above 0

°C, the other at sub-zero temperatures, for frozen food. The aforementioned plants have different power requirements: the cooling power required for air conditioning exceeds by an order of magnitude that generated by the incineration system. The cooling power required by the refrigeration plants is comparable with the one generated by the incinerator. These qualitative arguments hold true for arbitrary cruise ships, independently from their size.

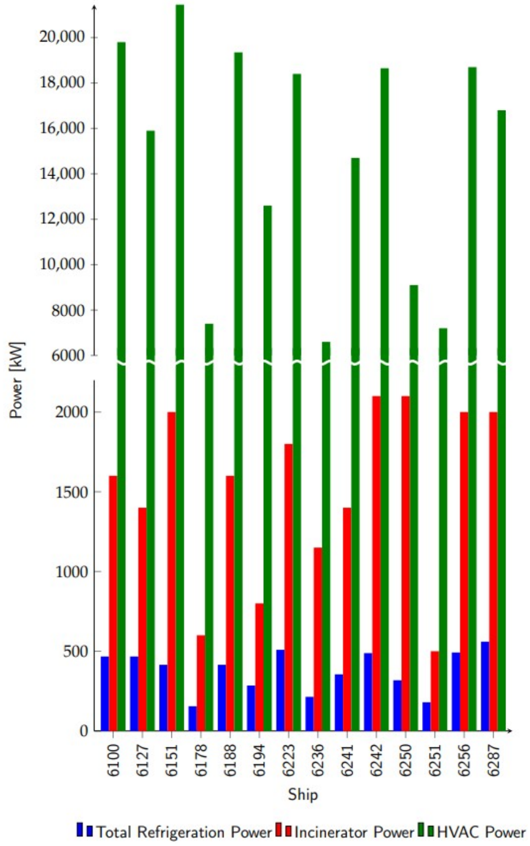


Figure 4.11: Power of thermal plants onboard different cruise ships, carrying amounts of passengers/crew ranging from 800 to 6592 people. The numeric codes in the abscissa axis are internal reference numbers of Fincantieri. for already built and operating cruise ships

The chosen measure within this category involves the installation of a waste-to-energy plant [79] for energy use onboard for heating, air conditioning and refrigeration. The strategy consists in the installation of an incineration plant, within which there is a line dedicated to waste fuel oils. These have the task of feeding and maintaining a constant temperature inside the combustion chamber.

For the calculation of emission reductions, reference was made to the small-scale methodology AMS-III.Q [80].

On the basis of this methodology, BE are calculated as:

$$BE_{elec,y} = f_{cap} \cdot f_{wcm} \cdot \sum_{j} \sum_{i} EG_{i,j,y} \cdot EF_{Elec,i,j,y}$$

where:

- $BE_{elec,y}$ = baseline annual emissions due to electrical energy transfer (tCO_{2e});
- f_{cap} = ratio between the energy generated by the waste and the total energy used in the project activity to produce useful energy (in year y), assumed equal to 1;
- f_{wcm} = ratio between the electricity generated by the project activity and the energy generated by the waste used to produce it, supposed to equal 1;
- EG_i = amount of electricity supplied, which in the absence of project activity would have been purchased during the year y, corresponding to 0.019135 TJ;
- EF_{Elec} = CO_2 emission factor for the energy source replaced by the project activity, during the year y, being:

$$EF_{Elec,i,j,y} = \frac{EF_{CO_{2,i,j}}}{\eta_{Plant,j}}$$

where:

- $EF_{CO_{2,i,j}}$ = the CO_2 emission factor per unit of energy of the fossil fuel used in the baseline generation source i, corresponding to 73.3 (tCO_{2e}/TJ);
- $\eta_{Plant,j}$ = the overall efficiency of the identified existing plant that would be used by j^{th} recipient in the absence of the project activity.

Considering the assumptions and the data reported in Table 3.7, B_{Eelec} = 3.842 t of CO_2 per day for 11 hours of daily operation.

PE are defined as:

$$PE_y = PE_{AF,y} + PE_{EL,y}$$

where:

- $PE_{AF,y}$ = combustion of auxiliary fuel to supplement waste gas/heat;

- $PE_{EL,y}$ = emissions due to consumption of electricity for gas cleaning before being used for generation of electricity or other supplementary electricity consumption by the project activity.

In the absence of auxiliary fuel consumption, but in the presence of electricity consumption due to the circulation pumps of the various fluids involved and the control elements (estimated between 5% and 10% of the cooling capacity), $PE_{AF,y}$ is equal to zero, whereas PE_Y is equal to $PE_{EL,y}$.

Based on the abovementioned assumption, PE are equal to 0.3842 t CO_2 (per day for 11 hours of daily operation).

Based on plant configuration, LE are considered equal to zero.

Therefore, ER are calculated as:

$$ER_y = BE_y - PE_y - LE_y$$

ER_y = 3,842 - 0,384 - 0 = 3,458 t CO_2 (per day for 11 hours of daily operation).

Assuming a daily use, the reduction on an annual basis is equal to 1.262.102 t CO_2.

Considering the efficiency of the identified plant is based on hypothesized values, though reasonable, the trend for the emission reduction according to different overall efficiencies is shown in Figure 4.12 within a range between 0.2 and 0.6.

With respect to the previous measure, no waste transportation is considered or assumed in the baseline scenario since the management of waste fuel oils is usually made on board by means of incineration. Therefore, different assumptions would be unrealistic for the analyzed measure.

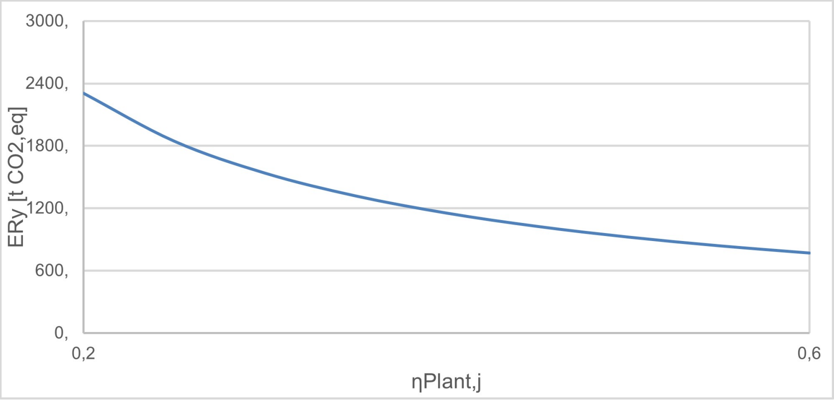


Figure 4.12: ER variation according to plant efficiency

4.2.4 Packaging/Consumables

The aim of this paragraph is to analyze the potential green practices that can be adopted onboard a cruise ship in order to enhance the environmental performance of the cruise with particular attention to paper input and output flows in a waste minimization perspective. A comparative life cycle assessment (LCA) of different management scenarios of paper streams onboard a cruise ship based on the results of a previously published paper is performed [41].

The potential environmental impacts due to three strategic choices about paper and paper waste management onboard a case-study ship have been investigated through a so-called difference analysis, i.e. the digitalization of the daily information journal Today, the reduction of toilet paper and paper towels through the installation of auto-cut single extraction dispensers and the reduction of printing paper through dissemination of specific guidelines. In order to compare each scenario with the reference case in absence of the practice implementation, the functional unit in this study has been defined as 1 day of cruise. The implementation of the analyzed green practices show comparable environmental benefits on-board a pilot ship, on the basis the set of assumptions and hypothesis identified in this simulation. In particular, when comparing the potential GHG emission reductions, it results that the two most realistically feasible scenarios in the communication area, i.e. digitalization of 25% and 50% shares of Today journal, show environmental savings comparable to measures related to reduction of consumables and guidelines for personnel. Nevertheless, the addition of a reasonable number of touch-screen devices for this purpose would not significantly influence the environmental impacts. A set of reduction measures of paper items on-board a cruise ship is able to both avoid the impacts related to production and incineration stages. In the form of forecast scenarios, the results of such modelization may represent a set of indicators to be considered in a feasibility analysis prior to selection of the green practices to be introduced, as a support to decisions for cruise managers. The findings of the life cycle impact assessment phase for the analysed scenarios in three different application fields increase their relevance and significance when the different green practices are compared. When comparing the potential GHG emission reductions, deriving from the implementation of different proposed practices, with a life cycle perspective (Fig. 4.13), it results that the two most realistically feasible scenarios for digitalization, i.e. D25 and D50, show environmental savings comparable to the measures implemented for consumables reduction and personnel behavior. As concerns fossil GHG emissions, on one side, the digitalization of 25% and 50% share of paper copies of Today, without installation of any additional touch-screen device, allows a reduction of about 43 and 86 kg of CO_{2e} per day of cruise, respectively. Nevertheless, the addition of a reasonable number of Totems would not significantly influence the environmental impacts, e.g. an increase of three devices in when half of copied are reduced still entails a saving of about 80 kg of CO_{2e} per day. On the other side, a reduction of 25% share of the consumables through the installation of auto-cut single extraction dispensers is able to determine a saving of about 58 kg CO_{2e} per day of cruise. Finally, a reduction of 50% share of the A3 and A4 printing paper, obtained through a detailed set of guidelines, has been demonstrated to be able to save about 75 kg CO_{2e} per day of cruise. The savings of biogenic GHG emissions may increment this set of indicators in order to communicate the environmental sustainability of such green practices, and they are particularly useful to show benefits deriving from avoided incineration of paper.

Similarly to global warming perspective, for the further impact categories considered as potential environmental impacts, the reduction obtainable in scenario C25 and scenario G50 are comparable to the values related to scenario D25 and D50. From ozone depletion, photochemical oxidation, acidification and eutrophication point of view, it generally results that the potential benefits by reducing printed paper use are almost doubled than savings originable by installation of dispensers for paper towels and toilet paper. When evaluating the environmental sustainability of the different measures by measuring the consumption of energy and material resources, it results that the implementation of guidelines for personnel is the most preferable alternative if reduction of copies of Today is considered up to 50%. On the contrary, scenario D50 results to be the most beneficial for fossil GHG emission savings, although the number of touch-screen devices is increased by 50%.

The formulation of environmental savings calculated for 1 day of cruise is doubtless fruitful for orienting the decisions of cruise managers. Nevertheless, for eventual purposes of dissemination towards passengers, the impacts can be referred also to the single guest for a fixed duration of travel. With this aim, the communication of GHG emissions is to be preferred as the so-called carbon footprint is the most common indicator of environmental sustainability for a non-technical audience. From a life cycle point of view, it results that the proposed measure of digitalization of Today with 25% reduction of hard copies is able to entail a saving of about 80 kg CO_{2e} per passenger per week of cruise, whilst a 50% reduction of printing paper onboard can yield a net balance of 120 kg CO_{2e} Moreover, a 50% reduction of Today hard copies is able to entail a saving of around 160 kg CO_{2e} per passenger per week of cruise, and an equal saving is achievable through reduction of printing paper onboard.

Finally, although economic considerations are conventionally outside the scope of LCA and they may be subject of parallel analysis about cost-benefit, in such a case of waste minimization perspective, the life cycle economic convenience results to be intrinsically guaranteed. It can be safely claimed that such effective environmental management practices can result in significant cost savings associated with both lower input and resource expenses and reduced waste disposal costs, with offset and surmounting of installation outlays for the new devices in the long term. In the following figure the comparison of potential GHG emission reductions from different green practices.

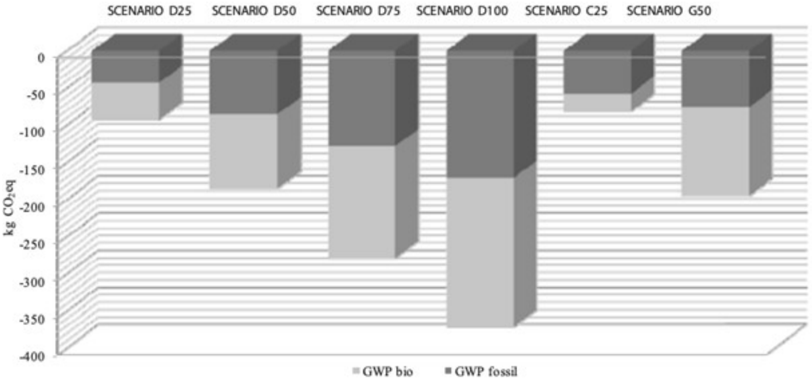


Figure 4.13: Comparison of potential GHG emission reductions from different green practices

Chapter 5

Conclusion and future perspectives

The proposed study analyses different waste management systems and strategies that can be implemented onboard, in relation to their potential to reduce GHG emissions, regardless of the routes travelled and the destination ports. The goal of this study was to identify, among the different methods of waste management, either those for which the reduction in GHG emissions is significant or those for which waste becomes a resource, according to a model of circular economy, which overcomes the concept of end of life for waste, in accordance with the guidelines of the European Union.

The results obtained with the implementation of measures and good practices through the application of different methodologies, are generally desirable for each type of ship considered and therefore reproducible. The limitation of the applicability of some of them is the non-specificity for mobile and maritime installations.

Possible policy implications of the findings could relate to the regulated entry of the maritime sector into EU Emissions Trading System (EU ETS), that is a cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions cost-effectively.

The analysis is not focused on the assessment of the reduction in GHG emissions due to fuel consumption for propulsion, as these emissions will be the object of specific legislation at both EU and international level. Nevertheless, the study analysed the potential of the large-scale introduction of optimal solutions for waste management in the maritime sector, with the aim of also reducing GHG emissions.

Following the analysis of the proposed measures, case studies were identified and the actual GHG emission reductions were calculated, applying the requirements and calculation rules defined by the corresponding UNFCCC methodologies in the case of direct impacts, while an LCA approach was used for case studies for which indirect impacts were calculated.

The obtained results showed that the sustainable waste management strategies onboard support a circular carbon economy perspective.

On the one side, in the case of the thermo-chemical treatment of waste oils and sludge to obtain fuel oil and innovative oil waste management, the system allows the re-use of oil waste, avoiding the disposal to landfill and reducing - even if only slightly - the consumption of virgin fuel according to a circular economy perspective. Reuse of waste and circular economy are issues of great interest to the European Union, therefore pyrolysis of sludge to obtain secondary fuel could be a good opportunity also in relation to European objectives related to sustainable development.

On the other side, in the case of installing a waste-to-energy plant, the proposed strategy allows energy recovery of onboard waste - still valuable in terms of circular economy principles - in addition to a slight reduction in GHG emissions.

The restrained GHG emission reduction potential shown by the analysed measures, trough UNFCCC methodologies for onboard waste management, further highlights the need for the maritime sector to proceed as soon as possible to set specific targets linked to the effective use of fuel for propulsion, which is the true and significant source of GHG emissions. In fact, the adoption of other measures onboard, even if it involves a lower use of the main fuel as in the two proposed case studies, could be not very significant in terms of reduction in GHG emissions.

Finally, it must be noted that for almost all the measures implemented onboard the ship and ana-lysed in this study, there is a lack of methodologies applicable to the maritime sector for the calculation of the reduction in GHG emissions. In particular, the UNFCCC methodologies - created ad hoc for the waste sector - are actually calibrated for stationary plants and therefore do not consider the peculiarities and critical aspects of the plant design and management methods onboard the ship. Therefore, assuming a potential future obtaining of carbon credits from such measures, firstly it would be necessary to partially modify existing calculation methodologies or to propose new specific methodologies for the maritime sector in the UNFCCC.

Air emissions indicators presented in this work are a simple and clear way to provide immediate signs of the environmental performance of the ship, under the operating conditions specified. These indicators are classified into two contributions: global warming and acidification. This is due to the different environmental impacts of gases emitted by ships. Therefore, the implementation of a single index would not be correct. Formulations achieved with this study are easy to implement in a possible emissions monitoring system installed on board, using available information from a measurement system. In fact, the exhaust gas cleaning systems measure continuous pollutant emissions and make it possible to evaluate the environmental impact of the ship in order to take corrective actions to improve energy efficiency.

In case of unexpected values recorded under normal operating conditions, the indicators may be used to alert of a malfunction.

For the short term, they can be used as a decision support system for onboard personnel to operate the ship in an environmentally friendly way. In the long term, they can be a tool to program maintenance of equipment. The use of the indicators is easily applicable to the types of systems present on all the boats studied. Sensors and lifters are common tools in the engine room of each ship.

It is a simple implementation of the system in favour of a great result in terms of reduction of environmental impacts. This will be possible only after a careful awareness of the community and with an increasingly precise regulation.

As for the packaging/consumable waste, through the application of LCA methodology with a difference analysis approach, the environmental sustainability of green practices for paper use reduction onboard a cruise ship has been evaluated. The investigated management measures have been demonstrated to yield not only benefits from waste prevention and minimization point of view but also in terms of consumption of material and energy resources and potential environmental impacts along the life cycle of the cruise. The implementation of the analysed green practices, i.e. digitalization of communication materials, the installation of autocut single extraction devices for consumables and a set of guidelines for crew about the use of printing paper, shows comparable environmental benefits onboard a pilot ship, on the basis of the set of assumptions and hypothesis identified in this simulation. The effects related to the real application of the measures have to be verified, and they may confirm, enhance or worsen the environmental performance calculated. The parameters to be verified, include, e.g., the share of Today copies to be reduced and the number of touch-screen devices to be installed without affecting the communication level towards passengers, the actual reduction rate of consumables stream through a tested installation of green devices and the actual reduction of printing paper stream due to a tested awareness campaign for the crew. Sustainable consumption is pushed when company management is able to demonstrate its commitment to greater environmental responsibility by changing its modus operandi from traditional methods to green practices; nevertheless, training and dissemination programmes are required. The real effectiveness of the whole set of measures, oriented both on passengers and on personnel behaviour, is definitely dependent on the quality and quantity of communicative and educative activities to be developed for sustainable consumption perspective. In turn, intangible assets such as company image and reputation are consequently enhanced with implications on customer and personnel loyalty. In conclusion, there is a very large space for green practices aimed to enhance the environmental sustainability of cruise industry. Paper represents a relevant material input stream and a set of reduction measures is able to both avoid the impacts related to production and incineration of the paper items on board. Through a life cycle model, the benefits related to reductions of potential environmental impacts along the entire supply chain and end-of-life can be highlighted and quantified. In the form of forecast scenarios the results of such modelization may represent a set of indicators to be considered in a feasibility analysis prior to selection of the green practices to be introduced, as a support to decisions for cruise managers. Finally, although economic considerations are conventionally outside the scope of LCA and they may be subject of parallel analysis about cost-benefit, in such a case of waste minimization perspective, the life cycle economic convenience results to be intrinsically guaranteed. It can be safely claimed that such effective environmental management practices can result in significant cost savings associated with both lower input and resource expenses and reduced waste disposal costs, with offset and surmounting of installation outlays for the new devices in the long term.

As for the organic waste, through a life cycle approach, in this study the potential benefits of the implementation of a circular economy strategy are highlighted in terms of carbon footprint, energy accounting and water footprint, i.e. three possible stand alone indicators, here combined in a broader assessment. The analysis investigates a case-study along the complex patterns within the food and feed integrated network, where feasible food products for human are addressed to feed animals thereafter introduced into the market as food product for humans. The idea of replacing fish-derived and crop-derived products with recovered material - otherwise lost as waste - is not to be considered as beneficial by default. The impacts from processing and transport phase may be able to offset the potential gains arising from “closing the loop”. Here the findings from the analysis of a case study in terms of strategy and technology are reported, where delivery stage for food waste processing - and, similarly, for crop and wild fish - is deliberately excluded from the boundaries, so that it can be evaluated for a final balance for feasible implementation on a case-by-case basis. The outcomes of life cycle impact assessment show very promising results deriving from the application of turbo drying technology onboard cruise ships for valorization of food waste, whose large amounts are available not only in Mediterranean area, here investigated, but also at global scale.

Life cycle assessment is proved as a tool for comparing the environmental implications of using different ingredient types in salmon feeds, but its findings shall not be used in isolation for decision-making. Instead, the reductions in the selected indicators can be included in a more comprehensive suite of considerations, after that appropriate mitigation and management strategies are developed to ensure that health risks are minimized below the levels at which animal welfare or human health may be compromised. Although turbo-dryer technology is able to allow a reduction of the bacterial charge of the product, experimental evidences in terms of nutritional optimality should be necessarily accompanied by experimental evidences in terms of health and safety. In conclusion, the results of this study may serve as a set of three screening indicators about the environmental performance of a pioneering practice in the sense of circular economy, where the excess amount of food, loaded and not consumed onboard a cruise ship, can be re-introduced in the global food network as feed for further future food products. In particular, in this case study the majority of this material stream, rich of nutrient, would be otherwise dumped, thus destined to become food for fish also in baseline conditions, when discharged to sea. The large amount of waste produced by the cruise industry, surely being a great loss of valuable materials, would also raise significant environmental impacts when disposed ashore. The comparative aim of this study is able to represent the potential benefits in eluding impacts associated to crop and wild fish supply, that would also encompass further burdens not included in this analysis such as effects related to pesticide use, soil erosion, habitat or biodiversity loss. Moreover, although avoided impacts are not taken into account through substitution method in this LCA approach, it can also be qualitatively described that the disposal of biodegradable waste to landfill would be a significant driver of impacts from carbon, energy and water point-of-view.

Maritime sector have to invest in environmental stewardship for both financial and political reasons.
As things stand, there is still a long way to go, but passenger trends and new sustainability regulations indicate a clear momentum towards sustainable cruises as a future venture.
Even though decarbonisation in the near-term remains a distant goal for most shipping firms, taking a watch-and-wait approach is not the answer to the climate crisis. Instead, encouraging widespread participation in the carbon market could the best alternative. Broadly, two main types of carbon markets exist today: mandatory, also known as compliance, and voluntary. Together, by putting a reasonable yet meaningful price on carbon, these two schemes work to incentivise companies to compensate and increasingly neutralise emissions as they try to meet their net zero targets. However, there is a lot more work needs to be done to bring shipping on board. For one, the wild disparity in voluntary carbon credits today - prices can range from US$2 to US$90 per tonne - needs to be addressed to level the playing field for all parties in the shipping industry. While high carbon prices in the compliance market are a deliberate decision, the huge price differential in the voluntary market is driven by demand dynamics and the quality of carbon credits. Secondly, given the global and fragmented nature of the shipping industry, trying to put in place a uniform emissions trading scheme could prove complex. Currently there is a lack of consensus on how to address the industry's carbon emissions problem, especially when for most companies shipping is considered a cost centre, and cost reductions have often taken priority over sustainability. Solutions could

include implementing a hybrid carbon offset-and-tax approach to overcome the lack of an industry-wide, global system.

A pilot project could be considered, in cooperation with shipping companies and shipowners, to apply the strategies considered so far on a full-scale basis and include a calculation of the total tons of CO_{2e} saved in a year and the eventual marketing of carbon credits on the market as the price value per ton changes.

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