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Waterborne transport in Europe - the role of Research and Innovation in decarbonisation

An analysis of waterborne transport, based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)

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Contents

Abstract

This report provides an overview of relevant European Research and Innovation (R&I) projects dealing with waterborne transport decarbonisation, based on the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS). The report analyses technology trends, operational, coordination and support measures in the waterborne transport sector. After setting out the international and European policy context, the report provides a brief overview of various measures put in place until today to foster waterborne transport decarbonisation. The analysis focuses on publicly funded European R&I projects, it provides an overall assessment and a detailed review of main outcomes as well as the research and policy implications of selected projects. Additionally, it provides an outlook of the evolution of scientific publications and intellectual property activity in the area. The report concludes by providing indications for further research and policy actions.

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Executive summary

The report presents an analysis of Research and Innovation (R&I) projects in the field of waterborne transport decarbonisation in Europe since 2008. It identifies how technological, operational and coordination and support measures could contribute to the target of carbon neutrality in the European Union (EU).

The projects analysed are from the Transport Research and Innovation Monitoring and Information System (TRIMIS) database, which is an open access searchable database containing nearly 8,000 projects and programmes financed by the EU Research Framework Programmes, EU Member States and other countries.

TRIMIS is the analytical support tool for the establishment and implementation of the Strategic Transport Research and Innovation Agenda (STRIA) and is the European Commission's (EC) instrument for mapping transport technology trends and R&I capacities. Seven STRIA roadmaps outline future transport R&I priorities to decarbonise the European transport sector, which are listed below:

- Connected and automated transport (CAT)
- Transport electrification (ELT)
- Vehicle design and manufacturing (VDM)
- Low-emission alternative energy for transport (ALT)
- Network and traffic management systems (NTM)
- Smart mobility and services (SMO)
- Transport infrastructure (INF).

Policy context

International shipping represented, in 2018, about 2.8% of total man-made emissions, (IMO, 2020b), and in Europe, waterborne transport is responsible for 13.4% of greenhouse emissions produced by the European transport sector (European Commission, 2019a), similar to European aviation. Although waterborne decarbonisation can be considered a challenging task, due to its international nature, to the vessels age, to lack or diversity in infrastructures facilities, etc., still the international and European commitment is high in decreasing it.

Emissions in waterborne transport are regulated at international and European level, as the maritime international shipping is a global phenomenon, International Maritime Organisation (IMO) regulations can have a wide spectrum as far as they are ratified by Member States. Complementary or more stringent rules are introduced at European level, which of course apply to the European territory and sea. Until now, measures have focussed on reducing pollution from shipping rather than cutting green house as emissions.

At international level, IMO rules are addressed within the International Convention for the Prevention of Pollution from Ships (MARPOL), Annex VI on the following aspects: accidental and operational oil pollution, noxious liquid substances in bulk pollution, pollution by harmful substances carried in packaged form, sewage, garbage, air pollution and efficiency via the EEDI (Energy Efficiency Design Index) and SEEMP (Ship energy efficiency management plan).

In Europe, the actions defined in the European Green Deal pursue the objective to obtain a sustainable European economy, where no net greenhouse gas (GHG) emissions will be present by 2050, including a 90% reduction in emissions from European transport. With its 2030 Climate Target Plan, based on a comprehensive impact assessment, the Commission has proposed to increase the EU's ambition on reducing GHG by at least 55% by 2030. The last Strategy for a Sustainable and Smart Mobility set the pathway to reach a European transport system which should be sustainable, smart and resilient by 2050 (European Commission, 2020d). The strategy covers the entire transport sector, identifying concrete policy measures, around 10 key areas, with different milestones set for 2030, 2035 and for 2050. When looking at the shipping industry, the EU's strategy towards reducing GHG emissions (European Commission, 2013) foresees a three step approach and includes a list of key measures, such as: the implementation of the MRV system, the definition of GHG reduction targets for maritime transport and the implementation of market based measure.

Main findings and conclusions

Overview on European Waterborne Decarbonisation Research funding

- Under the 7th Framework Programme (FP7) and Horizon 2020 (H2020) around €995 million has been invested in waterborne transport decarbonisation research projects. This includes €760 million of EU funds and about €239 million of own contributions by beneficiary organisations.
- Spending on waterborne transport decarbonisation research under FP7 and H2020 increased within 2012 and 2018, which are related to the concluding activities from the two framework programmes. Moreover, the percentage of decarbonisation projects related to waterborne transport changes substantially in H2020, with great increase in the budget allocated to these projects and reflecting increased attention within EU policies towards decarbonisation.
- 133 waterborne transport projects, in FP7 and H2020, deal with decarbonisation, with the majority of them being technical projects and practically the same number of operational and coordination and support measures projects.
- The Vehicle Design and Manufacturing (VDM) STRIA roadmap is the most present for the full list of decarbonisation projects, a similar situation is observed for technical projects. Project dealing with operational measures belong mainly to Network and Traffic management (NTM) and Connected and Automated Transport (CAT) roadmaps. Coordination and support projects are more general and cross-cutting across all STRIA roadmaps.
- The technology analysis highlights that the majority of the technologies is under the initial research step.

Project related findings by sub-theme

Under the ***sub-theme on hull design***, this review has identified research projects focussing on lightweight composite materials for structural components, improved hydrodynamic hull design, reducing hull friction and innovative repair methods and hull surface protection.

- Research shows that there is interest on using composite materials for conventionally fuelled ships to make fuel savings; friction stir welding technology should allow ships built from conventional steel to be made lighter, with consequent improvements in efficiency. As some challenges have been identified in using this technology, mainly related to tooling issues, future research could investigate solutions to these problems, enabling the technology to be employed on a large scale.
- The research on the use of composite materials in ship manufacture is progressing towards implementation. However, due to fire hazards at present, IMO 'Safety of life at sea' (SOLAS) rules limit the use of such materials to vessels of less than 500 tonnes gross weight. There may be a need to work at international level to review and potentially revise the regulations to allow the use of advance materials in larger vessels.
- Technologies to reduce ship resistance due to fouling of the hull by barnacles without harming the environment with toxic substances, demonstrated to improve ship performance; future research in this area should focus on environment friendly coating with extended durability applicable to the full fleet.
- These technologies allow efficiency improvement, which nonetheless cannot be considered a standalone solution to meet the challenging ambition of the EU Green Deal. Therefore, future research should be focussed on combined solutions, capable of delivering significant greater reductions as well as addressing the recyclability of such materials.

The research focus of the ***sub-theme on power and propulsion***, is on topic areas such as wind assisted propulsion, increases in engine efficiency and recycling of waste heat for use elsewhere in the vessel.

- Multiple research projects have demonstrated reductions in fuel consumptions, using different propulsion concepts. As separate technologies provide fuel consumption improvements, future research should investigate how the combination of different technologies onto a single ship could enhanced such positive effects within real world conditions.

- Wind propulsion has been shown to produce savings in fuel consumption, particularly at slower speeds and certain routes. To demonstrate its benefits to ship owners and to increase its penetration in the fleet, reliability and performance must be proven at large scale within harsh marine environments, in order to underpin a full cost-benefit analysis of the technology.

- Research has demonstrated the reductions in fuel consumption that can be obtained by using waste heat from the engines to power the ship's heating and cooling systems. Future policy could encourage operators to adopt this technology to reduce their fuel consumption and emissions.

- Applications in the domain of vessel electrification has shown successful results, namely in cases of fully electric high-speed passenger ferry. Future policy could assist in increasing the range and scale of battery electric applications, as well as promoting the technology to other types of vessels, which benefit from zero emissions due to their proximity to urban areas such as inland waterway and urban commuter vessels which may potentially be commercialised more quickly.

Projects under the ***sub-theme on fuels and alternative energy sources***, have investigated the use of electrification, hydrogen as a fuel, and liquefied natural gas (LNG)/liquefied petroleum gas (LPG) as a fuel. R&I could address the elimination of the release of unburnt methane and maximising combustion efficiency so that the transitional use of such cleaner gaseous fuels can potentially contribute to GHG reduction.

- A number of alternative fuels are under consideration for decarbonising the waterborne sector. However, the ideal mix is not currently clear, as some potential sustainability, infrastructure and distribution drawbacks are associated to some of these options, as in the case of bio-fuels, bio-methane, ammonia, hydrogen or methanol. There would be benefits in investigating the advantages and disadvantages of the various alternative fuels under different waterborne applications, to support scaling up of production as well as their use in vessel engines.

- For the short-term, alternative lower-carbon fossil fuels, such as LNG, LPG and compressed natural gas (CNG) are being suggested as a means to achieve a rapid reduction in pollutions from shipping, however their contribution to decarbonisation is limited depending on the engine type and release of unburnt methane. Further consideration is required as to how the transition from such fuels should be managed in order to pave the way towards low fossil carbon fuels such as bio LNG, bio-diesel, ammonia, methanol or hydrogen and if such transitional fuels may be a distraction from the development of longer-term low, or zero, carbon fuels which risks investment in infrastructure may become stranded assets.

- Multiple projects have explored the use of battery technology for vessels, using different battery chemistries. Although this technology seems to be very efficient, the most promising applications are the ones on short distances, due the large amount of energy required. Future research could be conducted into the benefits and disadvantages of different battery chemistries for different maritime applications (including trade-offs between charge rate, energy density and cost), to assist vessel designers in choosing the optimum option for a new vessel. This would improve the capability of European battery and electrical systems to continue to lead the expanding electric shipping sector.

- The greatest impacts on decarbonisation for the transport waterborne sector are likely to come from the use of alternative energy sources, as fuels such as electricity from renewable sources or hydrogen from electrolysis can offer a pathway to net zero for the waterborne transport industry. A priority for future policy development could be to increase the necessary renewable electricity generating capacity combined with increased production and uptake of these alternative energy sources. Rapid change will be required to contribute to the achievement of Europe's ambitious decarbonisation targets. The Draft Proposal for a European Partnership under Horizon Europe Zero-Emission Waterborne transport paper recognises that radical change will be required to meet the 2050 climate targets, as well as the necessary reduction of emissions by 2030 in line with the European Green Deal. This will require a greater emphasis on the fuels and alternative energy sources, together with efficiency improvements and non-fuel based energies to deliver the necessary decarbonisation of the waterborne sector.

Under the ***sub-theme on operational measures,*** topics such as vessel allocation systems, robotic container handling systems, improved vessel navigation and automation in shipping are being considered.

- The development of robotic container management systems has progressed to the production of design approaches for different sub-systems, fully robotic container terminals are already operational worldwide. Research should focus on the integration of such on shore automated systems with smart scheduling and potentially automated ships, integrating logistic chains and benefiting operational measures to reduce GHG emissions such as slower sailing speeds. Interoperability of technologies at different ports around the world is important. Although benefits have been identified for vessel management systems at ports, it is important that solutions that are implemented can be used by all ships and in particular to benefit those ships which apply operation GHG reduction measures. Policy could be developed for all European ports wishing to use technologies such as these, to create a standard approach to navigation and smart vessel scheduling as well as the seamless integration between port arrivals and GHG efficient hinterland connections.

- Projects have demonstrated the benefits of global navigation satellite system (GNSS) for automated maritime shipping and integrated logistics; building on this technology, could further improve efficiencies, and therefore reduce fuel consumption and emissions. Further research should investigate how the GNSS technologies would interact with autonomous ship technologies, could increase safety, as well as ensuring the resilience of GNSS based systems against failure or malicious intervention.

- In the domain of autonomous ships, research has been proposed on regulations, rules and standards for autonomous ships, including: the definition and the level of responsibility for the different crew members; the role of human operators on board and the allowed/needed manual operations; the management of compulsory systems, devices and procedures that would facilitate crewless vessel operation and the role and responsibilities of remote-control centres. Policy could be developed to include the safe operation of autonomous vessels, aligned across all Member States, including safe operation within complex mixed traffic, integration within logistic chains and resilience against the consequences of system failure. This would help to ensure the safety of autonomous marine and inland vessels and therefore increase the uptake of the technology across Europe and support the EU's market globally.

The ***sub-theme on coordination and support measures,*** includes research coordination and dissemination, networking activities etc. where efforts are focused on the dissemination and consolidation of research in the waterborne transport sector, as well as planning and investigating future strategy for the sector, including both vessel and port design.

- The results of the industry/market trends to 2030 should be reviewed to consider the socio-economic impacts, such as the COVID-19 pandemic, and assess whether the impacts on the waterborne market are likely to be long lasting. Further policy development may be needed to ensure that the 2030 decarbonisation targets are met, and that the industry is aware of what needs to be done to reach these targets. There is a risk that the industry expected trends to 2030 are not in line with the current policy targets; this needs addressing rapidly to reduce the risk of the targets being missed.

- Previous projects have investigated trends and expectations of the maritime industry up to the year 2030. Future research should extend this time period towards 2050 to fit in line with the Green Deal targets. It is important to capture the long-term expected market trends such that the long-term decarbonisation targets can be met and adjusted accordingly.

- Research into the application of telematics solutions to maritime shipping has shown relatively low potential uptake in the markets investigated. Further research in this domain could help understanding the reasons and how to increase the uptake.

Overall, the assessment of projects finding shows that no single measure can be considered as a problem solver, rather a combination of technologies could represent the way to follow.

Scientific research and patents trends

The analysis of the evolution of peer reviewed scientific publications dealing with decarbonisation in the area of waterborne transport shows an increasing interest of the academic community. Scientific publications focus mainly on technical aspects, either linked to the power and propulsion aspect or to fuel and alternative energy sources, mostly related to policy measures addressing more stringent environmental targets. A good part of scientific articles deals also with operational measures addressing CO_2 emissions which leads to think of business strategies supporting maritime companies. European authors hold the leading position in terms of number of peer reviewed publications on this topic, followed by Chinese and United States (US) ones, which denote the strong maritime nature of these countries.

The assessment of international patent applications related to the waterborne topics and sub-topics provides interesting information on their evolution in the last years, informing about the prevalence of power and propulsion patents, together with the ones linked to hull design. It is noteworthy that during the last years the number of patents associated to fuels and alternative energy sources has increased considerably, stressing again the relevance that such topic has on the scientific, business and policy domains.

Related and future JRC work

This TRIMIS report on R&I in waterborne transport decarbonisation in Europe is the first of a series of reports addressing specific transport modes. This report will be followed up by similar ones on aviation and rail transport. Through the continuous effort in consolidating and expanding the TRIMIS data repository the TRIMIS analyses aim to better capture R&I efforts beyond the currently included funding means and to provide more accurate details on the technology assessment which will be further refined.

Quick guide

The report is structured as follows:

Section 1 gives a brief introduction and defines the scope of the analysis. Section 2 defines the state of the art in waterborne transport emissions, including both maritime and inland waterways. Section 3 provides an overview of the international and European policy context. Section 4 illustrates the methodological framework, while Section 5 and Section 6 provide respectively a quantitative and qualitative assessment of projects on waterborne transport. Section 7 analyses the evolution of scientific publications and patents associated to waterborne transport decarbonisation technologies. Finally, Section 8 provides the conclusions.

1 Introduction

Waterborne transport includes maritime and inland waterways transport and represents the mode of transport mostly used for freight worldwide. It has evolved from sailing vessels, to coal and to the most advanced diesel propulsion present nowadays (Stopford, 2009) with a vision towards the future of increased electrification.

Demand for waterborne transport is essentially a derived demand from the transhipment of goods. Over the decades, the correlation between word economy and international shipping has shown to be closely linked, as world seaborne trade goes hand in hand with the world Gross Domestic Product (GDP) and population growth. At present, international maritime transport represents more than 80% of the world freight volume. The last figures show that, in 2018, 11 billion tons of freight were shipped around the globe, however the annual growth fell slightly in 2018, with an increase of 2.7%, below the historical average of 3.0% from 1970–2017 and 4.1% in 2017, in line with global economic slowdown in 2018 (UNCTAD, 2019).

Although the forecast for the coming ten years do not seem to predict a decline in the maritime trade (DNV, 2019), still this trend does not come as a surprise, as the main variables influencing trade are consequently affecting shipping demand: the trade intensity of the global economy has already declined, projections about population and GDP growth indicated a slowdown for the years to come. Other relevant variables influence waterborne trends, namely energy transition towards more sustainable energy sources, increased shares of regionalisation in production and trade (ITF, 2020; UNCTAD, 2019), disruptive climate change events or unexpected health emergencies, such as the COVID-19 recently experienced, have a strong repercussion on waterborne transport (European Commission, 2020a).

Still the role played by this sector in Europe is not negligible, as maritime transport represents 75% of the European Union's (EU) external freight trade and 31.5% of the intra-EU traffic, almost 4 billion tonnes of goods, and 400 million passengers transported, while inland waterways accounted for 3.9% of the total goods transport, in the 28 EU Member States (EU-28) in 2017 (European Commission, 2019a). In terms of employment, the waterborne transport sector employed almost 400.000 people and accounts for more than €35.000 million of GDP (European Commission, 2020a).

Although waterborne transport is among the least carbon intensive modes of transport in terms of CO_2 per ton km transported, due it its scale, it represents 13.4% of greenhouse emissions (GHG) produced by the European transport sector in 2017 (European Commission, 2019a), similar to European aviation.

Also, being powered by large diesel engines, using comparatively low grade fuel, shipping is a substantial source of air pollution, producing more sulphur oxides (SO_x), nitrogen oxide (NOx) and particulate matter (PM) than any other transport mode and within several coastal cities, ships are the main source of air pollution. These emissions are due to combustion and energy processes and may be higher in ports' areas and along the cost. They highly affect air quality, since the waterborne transport sector accounts for 24% of SO_x, 24% of NO_x and 9% of $PM_{2.5}$ totally emitted in the EU-28 respectively (European Environmental Agency, 2020). SO_x emissions have been increasingly regulated in the last decades, including the definition of maximum levels of allowed sulphur in fuel and the introduction of sulphur emission control areas (SECAs) (IMO, 2020a), which have shown to have a positive effect on the maritime SO_x emissions (Boer et al, 2016). Although waterborne NO_x emissions are not regulated at EU level, vessels registered under European flags are among the ones scoring higher when it comes to ships equipped with scrubbers and systems to reduce NO_x emissions (UNCTAD, 2019), showing awareness and growing concerns from the European shipping industry. PM are strictly related to the SO_x and NO_x pollutants, since their increase or decrease affect also PM levels. The EU has developed and is constantly committed in promoting its strategy towards a gradual reduction of waterborne pollution aiming at decreasing emissions up to 90% by 2050, as indicated in the European Green Deal (European Commission, 2019b).

Considering its fundamental importance to the European economy and its global nature, effort is needed to reduce its environmental impact. This sector is among the most difficult to decarbonise, due to the lack of immediately available solutions, moreover the typical long lifetime of the vessels intrinsically imposes a long time-lag before seeing the effects of possible introduced measures. To date, EU legislation and international agreements have focussed on pollution reduction, however now, reflecting the objectives of the European Green Deal (European Commission, 2019b), emphasis on reducing GHG emissions has substantially increased. Various measures can be taken to tackle this issue, whose impact is largely dependent by the total number of large vessels concerned.

The EU actions aiming at reducing waterborne transport emissions vary from technological solutions to operational measures and support and coordination actions. The EU has a key role to play for example through regulatory actions, financial incentives and promotion of Research and Innovation (R&I) to develop or enhance innovative technologies. The European Green Deal identifies R&I as a key aspect to increase European competitiveness where the transport sector represents one of the most important European industries, both in economical and R&I terms.

R&I can boost technological innovation helping to achieve the emissions targets set at European level, in doing so the role played by European Commission (EC) Strategic Transport Research and Innovation Agenda (STRIA) is fundamental. In May 2017 the EC adopted STRIA as part of the 'Europe on the Move' package, which highlights main transport R&I areas and priorities for clean, connected and competitive mobility (European Commission, 2017a). The EC Joint Research Centre (JRC) has developed the Transport Research and Innovation Monitoring and Information System (TRIMIS) in order to support the implementation of STRIA and monitor technology trends and transport R&I capacities, as detailed further in the methodological description (Chapter 4).

Within this framework, the work conducted in TRIMIS provides an overview of measures aiming at decreasing CO_2 waterborne transport emissions.

As previously stated, waterborne emissions are of varying types and have a range of impacts on the environment; in this report, the focus is on CO_2 emissions and on the related technologies and measures aiming at their reduction. Being well aware that this concern is one among a wider list of environmental waterborne issues, any wider measure encompassing the reduction of other air emissions will be mentioned in this report, though without being at the core of the analysis.

This report aims to contribute with the following:

— provide an overview of waterborne transport projects tackling gaseous emissions topics, with a focus on decarbonisation, financed through the different European research Framework Programmes (FP);
— highlight technologies and methods that have been addressed in the areas of control and reduction of waterborne CO_2 emissions.
— identify research gaps and provide recommendations in this direction.

The report will first define the state of the art in waterborne transport emissions, including both maritime and inland waterways (Chapter 2), complemented by an overview of the international and European policy context (Chapter 3). Chapter 4 presents the methodological framework of this work, followed by the quantitative (Chapter 5) and qualitative (Chapter 6) assessment of projects in the TRIMIS database. Chapter 7 analyses the evolution of scientific publications and patents associated to waterborne transport decarbonisation technologies and Chapter 8 provides conclusive remarks on the topic.

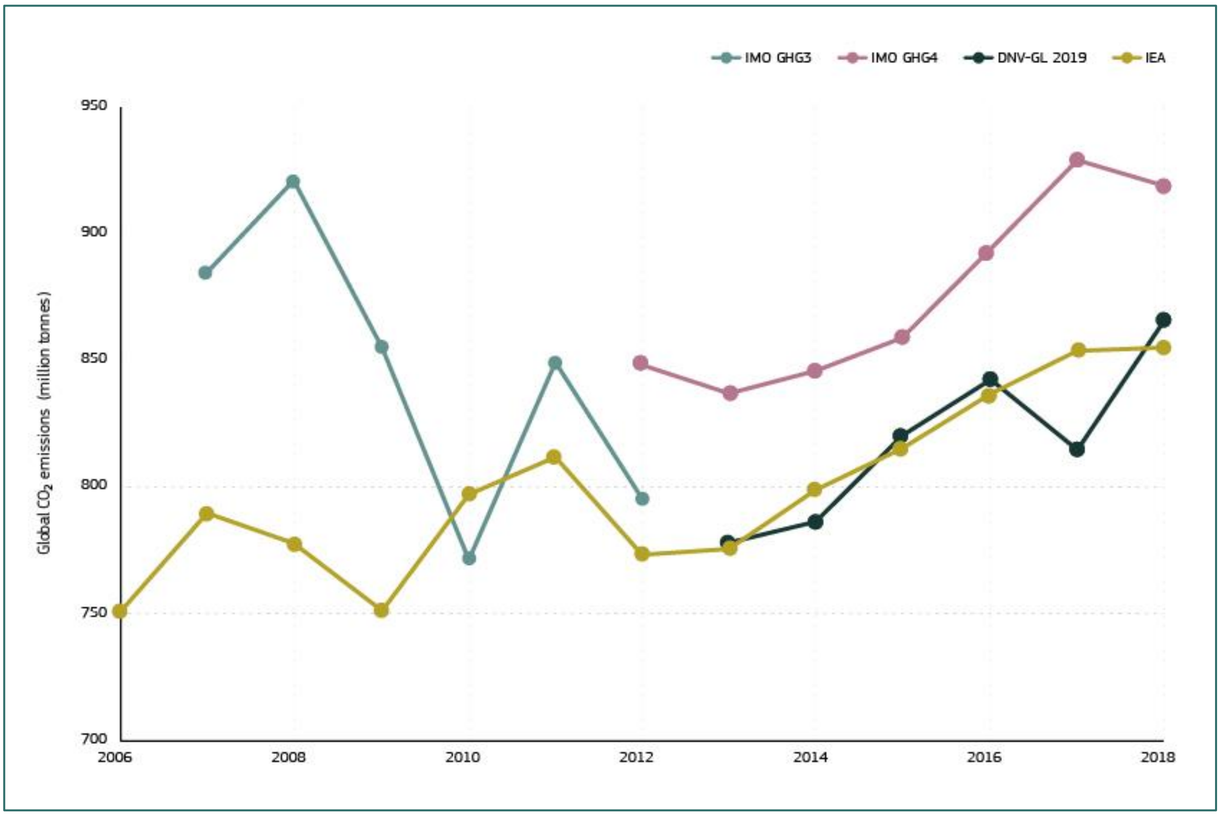
2 State of the art of waterborne transport emissions

2.1 Historic trends in emissions

The International Maritime Organisation (IMO) published its fourth GHG Study 2020 (IMO, 2020b), this estimated that international shipping produced around 1 billion tons of CO_2 representing about 2.8% of total man-made emissions in 2018, indicating also that those emissions could grow up 50% until 2050, compared to the 2018, despite further efficiency gains, as the growth of transport demand is expected to continue.

Other studies have also estimated the development of emissions over time. Figure 1 shows estimates of historical emissions from international shipping from the IMO GHG studies (IMO, 2015, 2020b), the DNV GL Energy Transition Outlook 2019 (DNV GL, 2019) and data published by the International Energy Agency (IEA) (IEA, 2019).

Figure 1: Comparisons of different sources of historical CO_2 emissions from international shipping

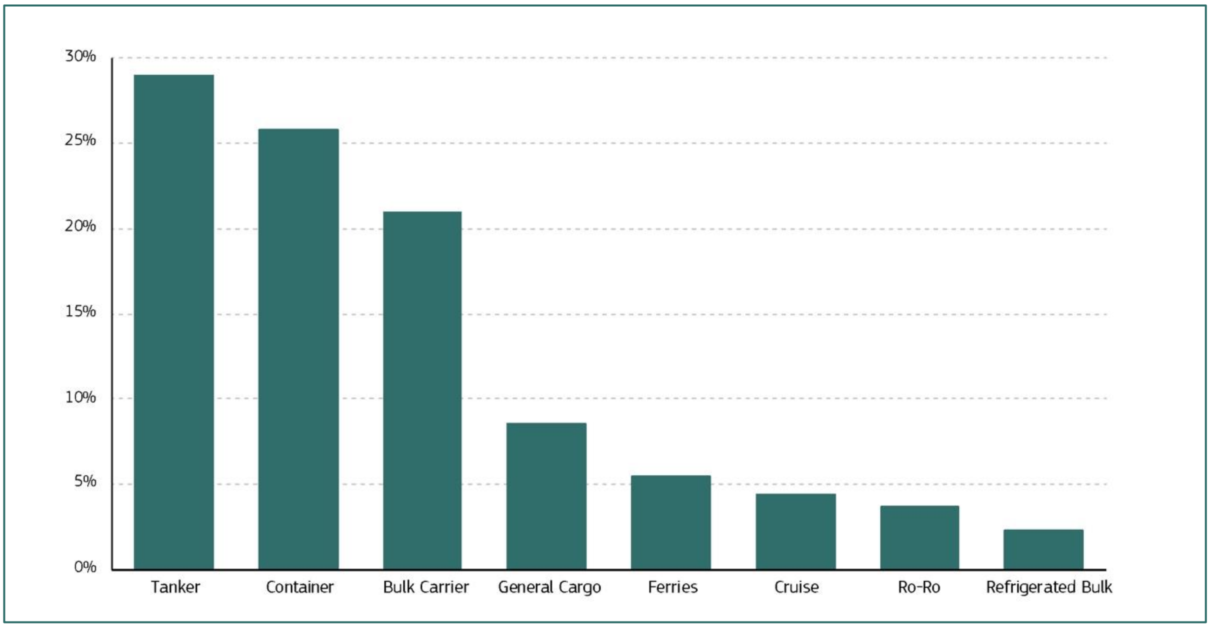


Sources: IMO (2015 and 2020b), DNV GL (2019), IEA (2019).

These studies, being independent from each other and differing in the calculation methods, are in good agreement for the years 2010-2018, although there are some inconsistencies between the IEA and IMO data regarding the years 2007-2009. The DNV GL and IEA studies show very close agreement for the period 2013-2018 (except for an anomaly in 2017). The results for 2018 from these two studies give emissions from international shipping of approximately 860 million tonnes. The average annual increase in emissions between 2013 and 2018 was approximately 2.1% per annum. The recently published fourth IMO study shows a small difference in emissions from those in the third study in 2012 (the only common year between the two studies). The new study includes two allocation approaches ("vessel-based" and "voyage-based"); the values presented in Figure 1 use the vessel-based approach, which is the same as the one in the third study.

Further insights into the distribution of the emissions between the different branches of the maritime transport sector can be obtained from the fourth IMO GHG study (IMO, 2020b). Figure 2 shows the percentage of the total emissions emitted by various ship categories in 2018.

Figure 2: Percentage of total CO_2 emitted by different ship categories in 2018



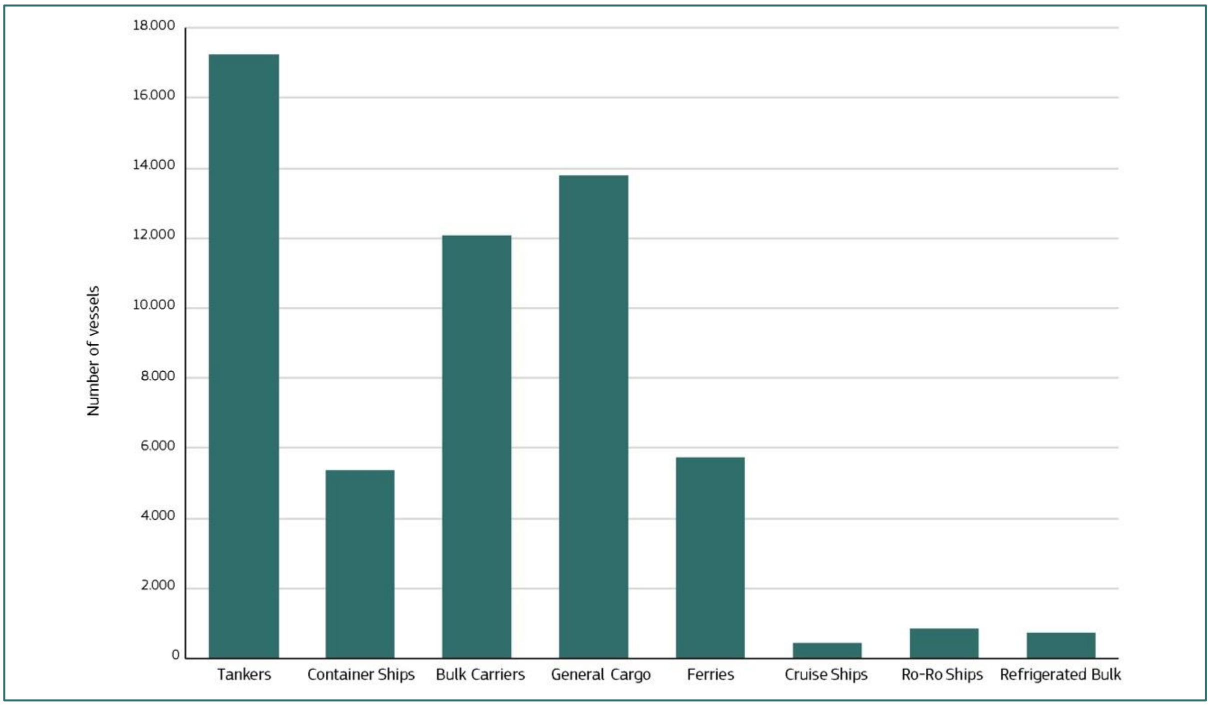
Abbreviation: Ro-Ro: Roll on –Roll off

Source: IMO (2020b)

The three highest emitting types of ship are tankers, container ships and bulk carriers. Between them, these three categories of ship produced 81% of the total GHG emissions from international maritime shipping. Whist the share of emissions attributed to cruise shipping is comparatively small, this is important for the EU since cruise ships are constructed in Europe. Cruise ships are generally equipped with high technology features and, due to their scale, can provide a platform for technology development which can subsequently be deployed towards larger merchant ships deployed globally and supporting the EU's access to this market.

The data from the fourth IMO GHG study (IMO, 2020b) can be compared to the fleet data for the current year, obtained from World Fleet Register (Clarksons Research Ltd, 2020). The results for the same ship categories are shown in Figure 3.

Figure 3: Global vessel fleet by category

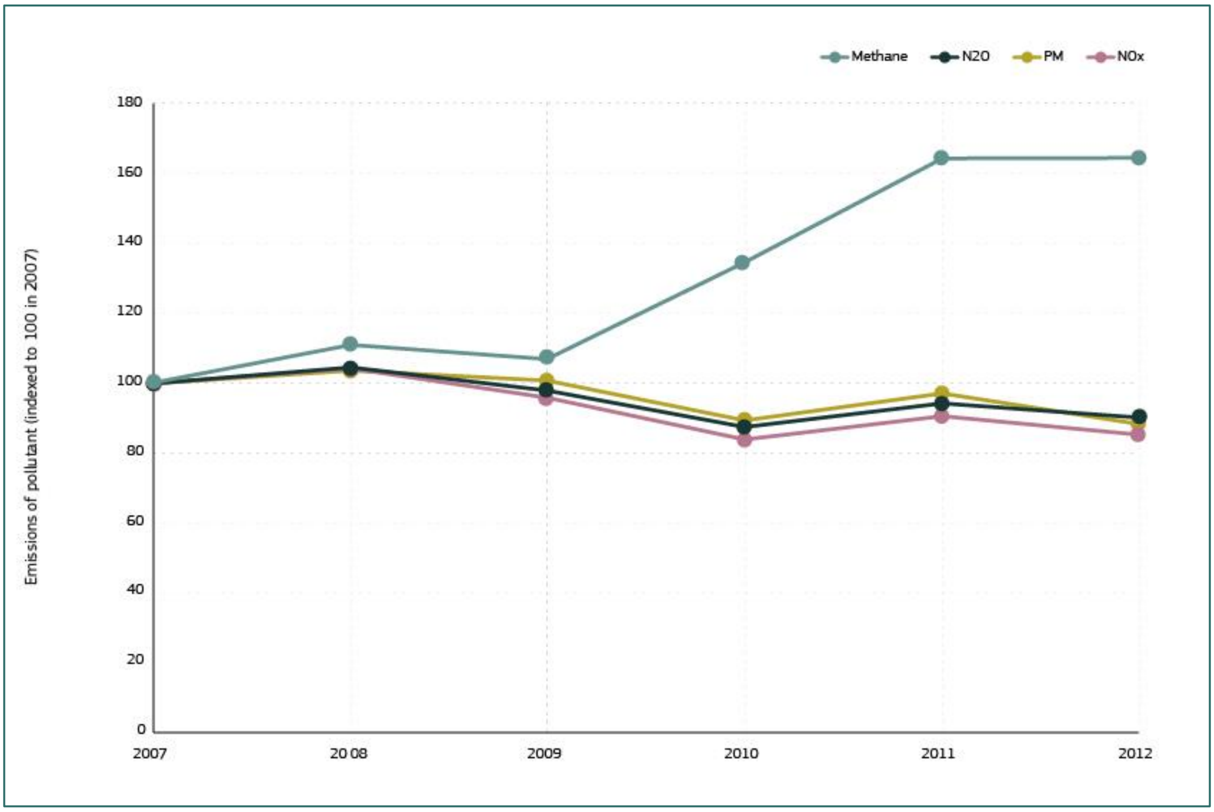


Source: Ricardo analyses of data from World Fleet Register (Clarksons Research Ltd, 2020)

In general, the fleet numbers follow a similar trend regarding the CO_2 emissions, although, due to their size, the number of container ships in the fleet appears small compared to the emissions they produce.

The third IMO GHG study (IMO, 2015) also presented historic evolutions of other emissions, including NO_x, PM, methane (CH_4) and nitrous oxide (N_2O). The first two of these are primarily of concern in relation to local air quality (e.g. around ports), although they are also implicated in climate change, while the latter two are primarily of concern as GHGs. Figure 4 shows the evolution of the global emissions of these four pollutants.

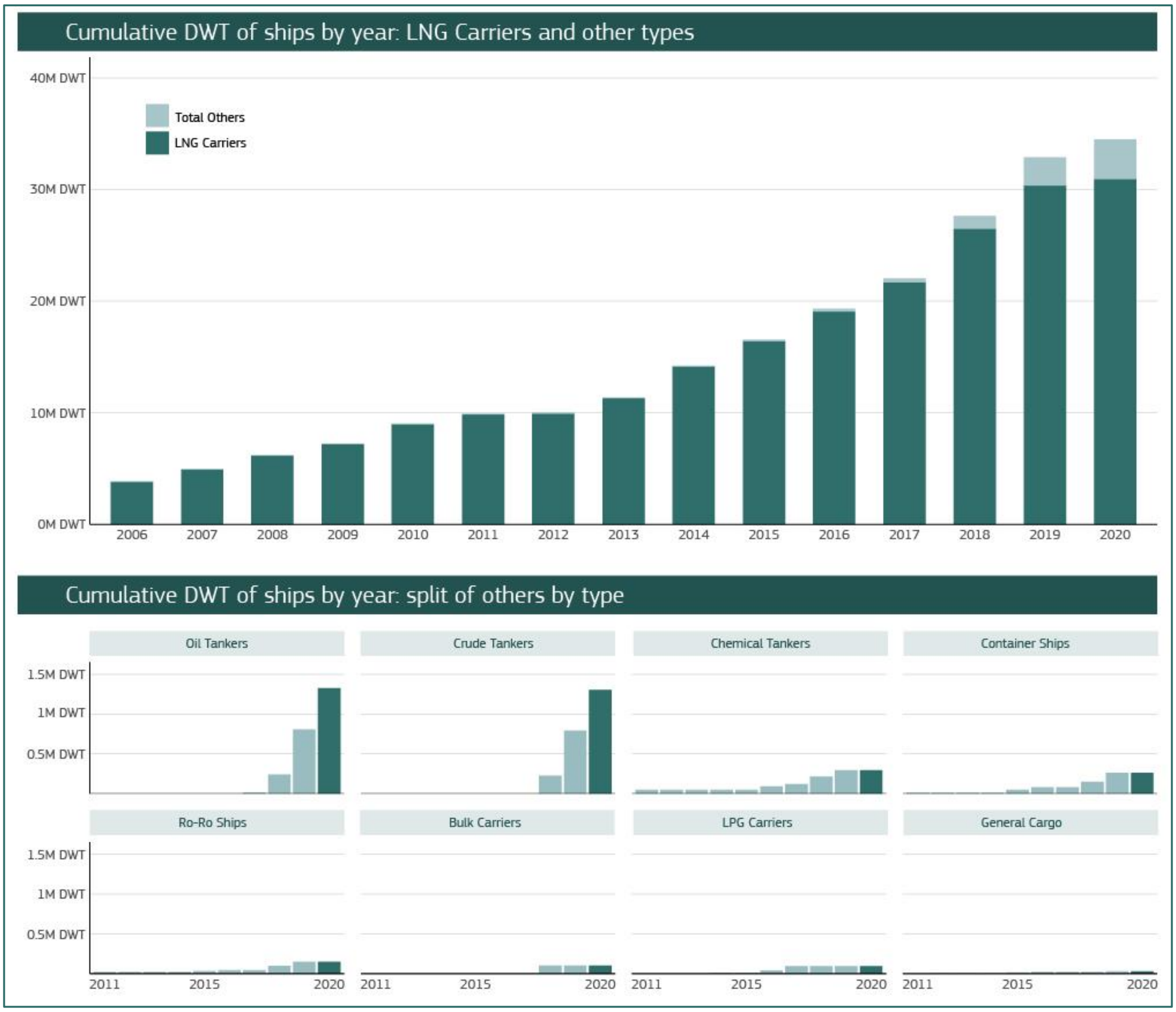
Figure 4: Evolution of emissions of other pollutants, 2007 to 2012 (indexed to a value of 100 in 2007)



Sources: IMO (2015)

The results in Figure 4 show a gradual reduction in NO_x, PM and N_2O emissions (average annual reductions of 3.2%, 2.5% and 2.1% respectively), but a quite rapid increase in emissions (10.4% average annual increase). The actual emissions of CH_4 from shipping are still small in comparison to other sources such as agriculture (global CH4 emissions in 2020 have been estimated at about 9,390 million tonnes CO2, or about 290 million tonnes CH4, so international shipping represents about 0.1% (Global Methane Initiative, 2020) but such a rapid growth could lead to a significantly higher percentage in the future if left unchecked. Figure 5 shows the growth in total Dead Weight Tonnage (DWT) of ships delivered that can use LNG as a main fuel since 2006, showing the continued growth in the LNG-powered fleet, predominately in the LNG carrier category.

Figure 5: Cumulative DWT of ships capable of using LNG as fuel by year



Source: Ricardo analyses of data from World Fleet Register (Clarksons Research Ltd, 2020)

The size of the LNG-powered fleet (in terms of total DWT) is now over six times the size than it was in 2012, however, although growing, at less than 0.5%, LNG ships remains a small proportion of the global fleet[1]. The IMO report notes that their calculations take account of emissions of unburnt methane from LNG-fuelled engines ("methane slip"), with the assumption that all such engines are low-pressure Otto-cycle (spark ignition) engines. More recent LNG-fuelled vessels either use high-pressure diesel-cycle engines (which have low methane slip) or use other technologies to reduce methane slip from Otto-cycle engines, so it is likely that the rate of growth of methane emissions has been reduced since the IMO report was published. A recent commentary from Lindstad (2019) also confirmed that LNG used in two-stroke high pressure dual fuel engines provides an overall reduction in GHG intensity compared to Heavy Fuel Oil (HFO), although the supply chain of LNG delivering to the ships is expected to increase considerably the total methane slips contribution.

In 2019, the EU published information on CO_2 emissions by ships that had performed maritime transport activities related to the European Economic Area (EEA) in 2018, (European Commission, 2019c, 2020b) through the THETIS-MRV portal[2].

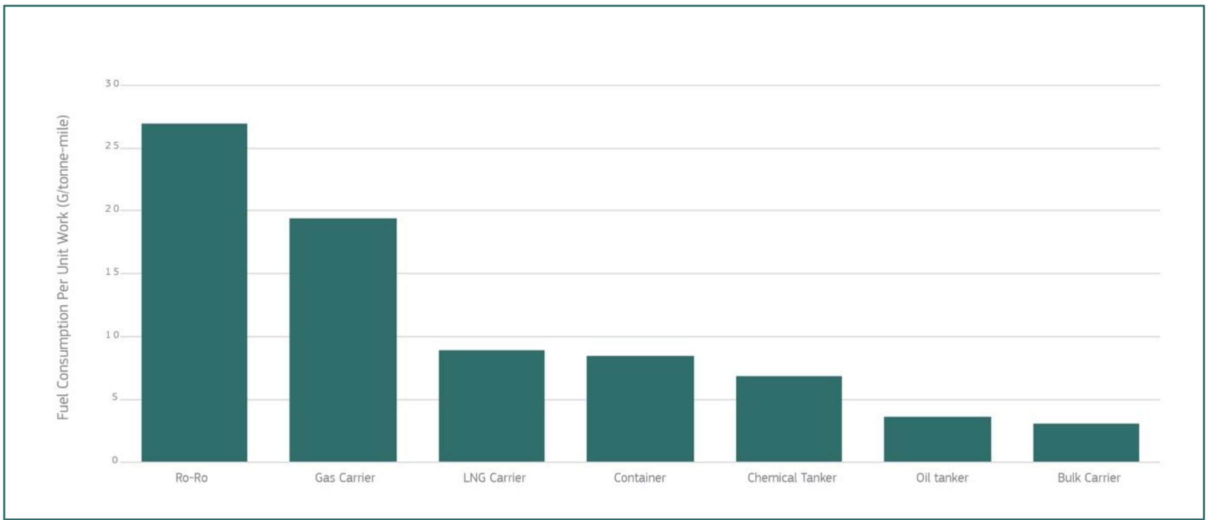
Using the ship data from the World Fleet Register, (Clarksons Research Ltd, 2020) where feasible, the entries in the THETIS-MRV data have been mapped to the relevant ship information. Figure 6 shows the average fuel

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/951092/shipping-fleet-statistics-2019.pdf

[2] https://mrv.emsa.europa.eu/#public/eumrv

consumption per tonne-mile calculated for different ship types. The values presented are calculated from the total fuel consumed by the vessels in the year 2018 and the total tonne-miles delivered in the same year, irrespective of where the voyages took place.

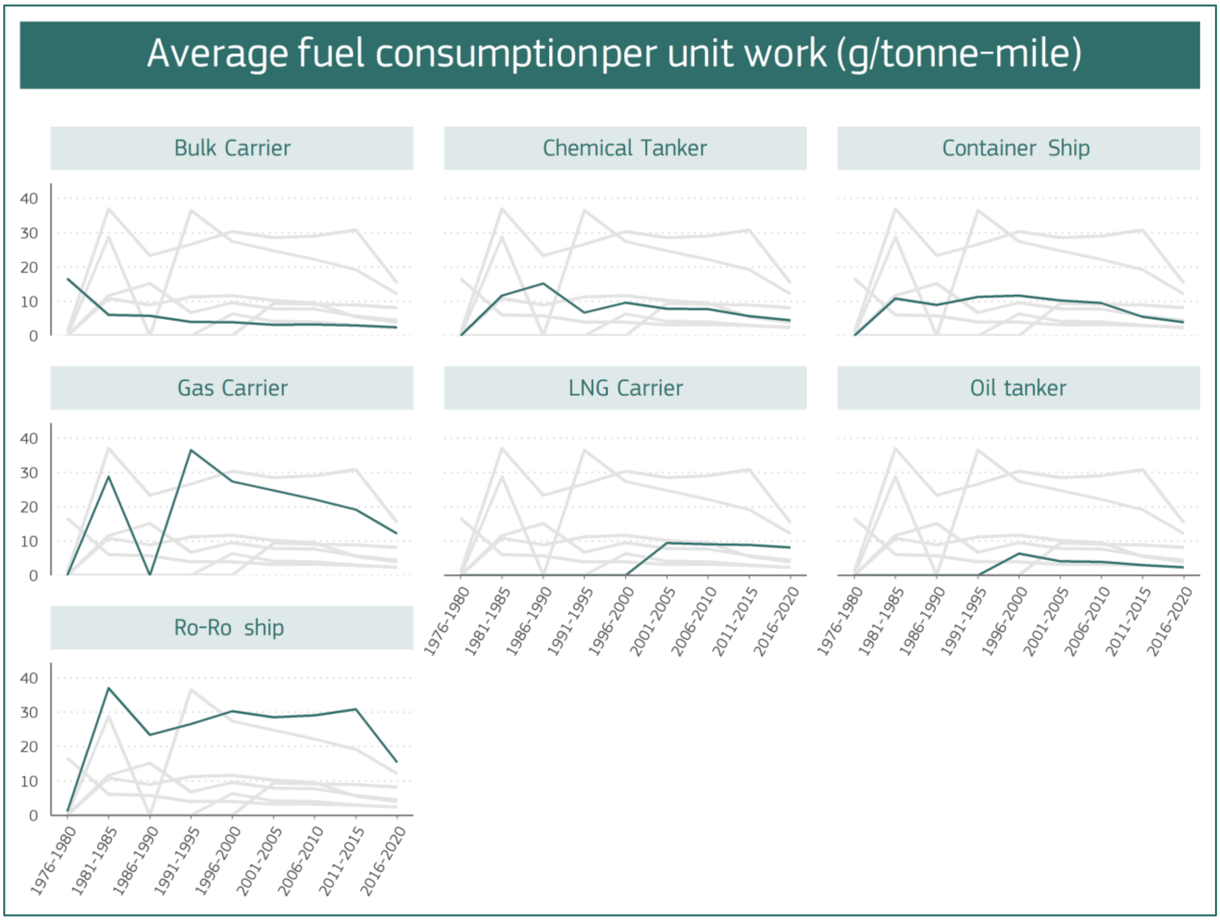
Figure 6: Average fuel consumption per tonne-mile for range of vessel types



Source: Ricardo analysis using EU ship emissions-MRV data (European Commission, 2019b) and World Fleet Register data (Clarksons Research Ltd, 2020)

Figure 7 shows large differences between the fuel consumption per tonne-mile, with gas carriers and Ro-Ro ships having the highest values (of up to 19 and 27 g/tonne-mile) and bulk carriers, chemical tankers and oil tankers generally having the lowest (of down to about 3.0 g/tonne-mile). The total annual CO_2 emissions of the vessels included in the analysis shown in Figure 7 was approximately 106 million tonnes, representing about 12% of the global total shown in Figure 1.

Figure 7: Variation of average fuel consumption per tonne-mile with build year



Source: Ricardo analysis using EU ship emissions MRV data (European Commission, 2019b) and World Fleet Register data (Clarksons Research Ltd, 2020)

For several ship types (e.g. gas carriers, container ships and oil tankers) there is evidence that the fuel consumption per tonne-mile has reduced over time as the newer ships incorporate updated technologies.

Although inland waterways transport is widely recognised as representing a more efficient, and lower emitting form of transport compared to road or rail (European Commission, 2019a), comparatively little information has been published on the current and historical GHG emissions from this mode, either in Europe or globally, for comparison with the above information on maritime transport. A report for the Central Commission for the Navigation of the Rhine (CCNR) in 2012[3] noted that the emissions from inland waterway transport are 'very insignificant' compared to the total from all modes of transport, but also that it is difficult to determine the actual emissions accurately. A more recent analysis, 2018, of the European project PROMINENT[4] looked at the emissions produced by different types of inland waterways vessels deployed in Europe, indicating a total sum 3.8 million tons of CO_2 emissions per year, 51 kilotons of NO_x and 2.2 kilotons of PM, as illustrated in Table 1.

[3] https://www.ccr-zkr.org/files/documents/rapports/Thg_ber_en.pdf https://www.ccr-zkr.org/files/documents/rapports/Thg_ber_en.pdf
[4] https://www.prominent-iwt.eu/

Table 1: Average emissions of IWT vessels

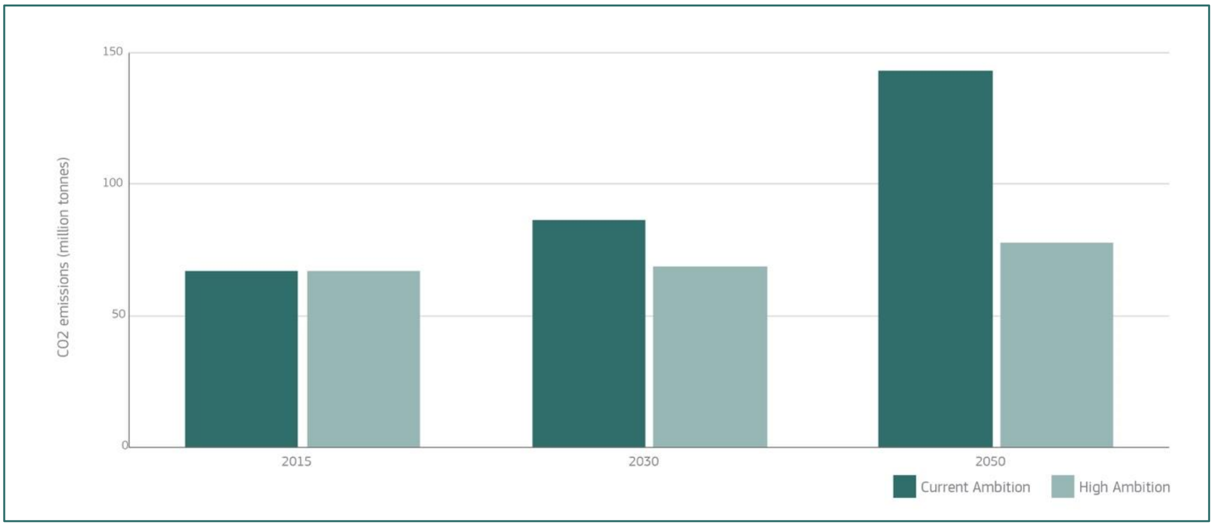
Vessel Information			Estimated current emissions per year		
Fleet families / Vessel Type	Total Number of vessels	Estimated fuel consumption in m3	NO_x (tons)	PM (tons)	CO2 (tons)
Passenger vessels (hotel/cruise vessels)	2553	106516	3895	177	281201
Other push boats <500kw	890	28644	995	49	75620
Push boats 500-2000kw	520	81970	2966	125	216400
Push boats ≥2000kw	36	74520	2647	116	196733
Motor vessels dry cargo ≥110m	610	206740	6681	234	545794
Motor vessels dry liquid cargo ≥110m	602	83168	6089	211	544582
Motor vessels dry cargo 80-109m	1801	291470	11386	551	769482
Motor vessels liquid dry cargo 80-109m	647	153209	5171	219	404473
Motor vessels < 80m length	4463	219456	8707	432	579363
Couped convoys	140	78155	2432	85	206328
Total	**12262**	**1323847**	**50969**	**2200**	**3819976**

Source: Partnership proposal for Zero Emission Waterborne Transport, (Waterborne, 2020) based on Prominent deliverables 6.3&6.5

The Organisation for Economic Cooperation and Development (OECD), in its International Transport Forum (ITF) Transport Outlook 2019[5], provided data on the CO_2 emissions from inland waterway freight transport in 2015 and future projections under two scenarios. These are shown in Figure 8.

[5] https://www.oecd-ilibrary.org/transport/itf-transport-outlook-2019_transp_outlook-en-2019-en

Figure 8: Current and projected CO_2 emissions from global inland waterways freight transport



Source: OECD ITF Transport Outlook 2019

The results shown for 2015 represent approximately 8% of the maritime emissions in the same year (in Figure 1) and about 3.4% of total surface freight transport. Between 2015 and 2050, the emissions from inland waterways are projected to grow by between 16% and 114%, depending on the scenario.

The data on gaseous emissions deriving from waterborne transport do not allow the scale of the problem to be ignored or underestimated. Mitigation, reduction or vanishing measures to address this issue have been widely investigated by researchers, by the industry and by policy makers. The following sections, without claiming to be exhaustive, illustrate the major technological, operational and market based related measures and initiative in this direction.

2.2 Technological measures

A range of technologies for reducing emissions from waterborne transport has either been implemented in the vessel fleet or is currently under development with implementation anticipated in the near future.

At the vessel level, naval architects have developed and refined design techniques for ships to improve the overall hydrodynamic shape to reduce resistance and hence reduce the power required to cruise at a given speed. A further refinement has been introduced in recent years to tailor the ship design to a lower design speed aiming at efficiency increase; this has been introduced in response to the widespread adoption of lower operating speeds to reduce fuel consumption and costs. The associated reduction in maximum available power from the engine, and the adjustments to the propeller design, improve the matching of the propulsion system to the speed of the vessel and reduce the overall weight, giving additional improvements in efficiency. The use of lighter materials in some parts of the ship construction also contribute to reduced resistance.

For some ship types, the use of 'interceptor plates' or 'ducktail waterline extensions' have been found to reduce resistance and fuel consumption by up to 4% and 7%, respectively (Miola et al., 2010). These features extend the rear of the ship vertically downwards (interceptor plates) or horizontally rearwards (ducktail extensions) to divert the water flow and improve the ship hydrodynamics.

On the engine side, the vast majority of ships use large diesel engines of either two-stroke or four-stroke form running on heavy fuel oil (HFO). The design of these has also evolved over time, incorporating enhancements such as the Miller cycle (Wik and Niemi, 2016) (changes to inlet valve opening timing to effectively provide a longer expansion stroke than compression stroke), two-stage turbocharging for increased combustion pressure and advanced fuel injection systems to provide improved fuel spray patterns for improved combustion (Miola et al., 2010). These technologies are already widely implemented in new ship engines. More recently, engine manufacturers have begun to produce engines designed to run on both HFO and natural gas (usually stored as LNG). Although the main driver for operators to adopt these 'dual fuel' engines is the lower price of LNG compared to HFO, the combustion of LNG produces about 20% less CO2 (per unit of energy) than HFO, so this does provide a contribution towards decarbonisation. As already shown in Figure 5, the global fleet capable of using LNG as a fuel has grown since 2006; the majority of those ships are LNG carriers as they can use the gas that they are transporting fuel as well as cargo, but there is a growing number of other types of ships that are now also designed to be able to use LNG.

More advanced ship propulsion technologies that are under development (and have undergone full scale trials) include wind propulsion devices such as Flettner rotors and sails. Flettner rotors are large cylindrical devices mounted on the deck of the ship. They are rotated in their axis (using electric motors) and use the Magnus effect in combination with the wind to provide highly efficient propulsion[6]. Flettner rotors are not suitable for all ship types (due to the need for sufficient space on the decks on which to mount them) and work best when the wind is across the ship, but some sources have indicated savings in fuel consumption of up to 30%, depending on the ship speed (ITF, 2018). Although the number of ships fitted with Flettner rotors to date is small, successful trials are showing both the potential fuel saving and the practicality of their installation,[7] so a wider uptake may be expected in the future.

Advanced sails have also shown the potential to provide significant savings in fuel consumption, although there are additional challenges due to the need to be able to lower them in stormy weather conditions and the dependence on wind direction to be able to use them to their best capability.

For more local shipping, such as in coastal waters and ferries, the shorter journey distances may allow the adoption of electric or hybrid propulsion systems. These can give considerable reductions in net CO_2 emissions and cancel other local emissions (depending on the source of electricity used for charging the batteries), trials of such ships have shown promise and they are now beginning to be used commercially[8],[9],[10].

There has been considerable interest in the use of alternative fuels for shipping, with LNG, ammonia (NH_3), hydrogen and methanol being considered, as well as drop-in fuels such as biofuels and e-fuels. To date, most of these have made few progress beyond concept or research phases. Even once the fuels (along with vessels and infrastructure) develop to widespread adoption, there are still concerns regarding the very large quantities of fuel that will be required and the need for considerable quantities of 'green' electricity for their production, if their decarbonisation potential is to be realised. An exception is LNG, as many gas carriers transport gas in liquefied form, providing a convenient alternative fuel for the propulsion engines. As noted above, the global fleet capable of using LNG fuel has grown substantially over recent years.

As well as maritime shipping, there has also been interest in reducing emissions from inland waterways vessels. This has partly been driven by concerns relating to air quality, as inland waterways frequently pass through, or close to, towns and cities, but also to enable inland waterways transport to contribute to meeting the EU's climate goals. Many of the technologies under development for maritime shipping are also relevant for inland waterways vessels, though with some adaptation due to the lower speeds, lower power requirements and lower draught of the vessels. The EU-funded PROMINENT project (discussed further under sub-theme 5, Section 6.5) reviewed the state of the EU waterborne fleet and identified a short-list of the best available technologies to reduce emissions, both GHG and pollutant:

Focussed on CO_2 reduction:

- support tool for energy efficient navigation with speed and/or track advice
- diesel hybrid propulsion
- right engine sizing (installing a smaller engine).

Focused on pollutant reduction:

[6] https://www.rina.org.uk/Wind_propulsion_gathers_momentum_as_installations_prove_successful.html
[7] https://www.norsepower.com/tanker/
[8] https://www.forbes.com/sites/jamesellsmoor/2019/08/18/the-worlds-largest-electric-ferry-has-completed-its-maiden-voyage/
[9] http://www.ppmc-transport.org/battery-electric-car-ferry-in-norway/
[10] https://www.scandlines.com/about-scandlines/greenagenda/hybridsystem

- LNG as fuel in single- or dual-fuel engines
- installation of a selective catalytic reduction (SCR) diesel after treatment system and/or diesel particulate filter (DPF)
- Gas-to-liquid (GTL) fuel (synthetic diesel made from natural gas)
- installation of new engines complying with CCNR II or future Stage V.

Of particular note is that, due to the lower power requirements and shorter journeys that are typically performed, inland waterways vessels are likely to be able to take advantage of zero emissions technologies, such as battery electric or hydrogen fuel cell propulsion, more rapidly than the maritime shipping fleet[11],[12]. For example, Future Proof Shipping is developing a hydrogen fuel cell propulsion system, combined with battery storage for peak shaving, for retrofit to inland waterways vessels[13].

2.3 Operational measures

The fuel consumption of a ship is strongly related to the speed at which the ship cruises. The selection of that cruising speed depends on a number of factors, principally the income for the operator (a faster delivery may attract higher rates for some products and allows more trips to be made in a given period) and fuel costs. There is effectively a cubic relationship between the speed of a ship and the power required to propel it, thus a higher speed can increase fuel costs significantly. Partly driven by the high fuel prices resulting from the 2007-2008 global financial crisis, there was an increased adoption of slower cruising speeds (sometimes referred to as 'slow steaming') to take advantage of the reduced fuel consumption and costs. For example, a 10% reduction in speed leads to a 27% decrease in power demand; accounting for the lower distance covered, a 10% speed reduction results in a 19% reduction in fuel consumption per unit distance[14, 15]. Such reductions in fuel consumption also leads to similar reductions in emissions of CO_2. The adoption of slow steaming is now widespread amongst maritime shipping operators, with many adopting up to 20% reductions in speed on journeys where it is appropriate.

Another factor that has a bearing on a ship's fuel consumption, and hence emissions, is route planning. A route that avoids poor weather, including adverse winds, may lead to lower fuel consumption than one that is theoretically shorter but encounters difficult conditions. Improved route planning technologies, taking advantage of improvements in weather forecasting capabilities, are now being exploited to help the ships' captains to plan optimised routes to follow (Miola et al., 2010).

When berthed in ports, ships generally use their on-board auxiliary engines to provide power to run the ship's system, including heating and air conditioning. The use of *cold ironing* to replace the use of the auxiliary engines can give significant reductions in pollutant emissions, including GHGs such as CO_2. The EU Directive on the deployment of alternative fuels infrastructure (Directive 2014/94/EU) (European Commission, 2014a) requires all ports on the Trans-European Transport Network (TEN-T) core network to install shore-side power as a priority and all other ports to do so by 2025 (unless there is no demand). Whilst several major EU ports have installed shore-side power facilities, more progress is still required to reach the potential reduction in emissions that they can offer.

2.4 Market based measures

To ensure that targeted emissions reductions are achieved on a 'net' basis, some sectors have introduced market based measures such as emissions trading or offsetting. For example, in aviation, intra-EU flights have been subject to the EU Emissions Trading System (ETS) since 2012, while a new global measure, the International Civil Aviation Organisation (ICAO) Carbon Offsetting and Reduction Scheme for International

[11]https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf
[12] http://www.inlandnavigation.eu/media/88852/SRA-20190121.pdf
[13] http://www.inlandnavigation.eu/media/92406/Future-proof-shipping-presentation-191016.pdf
[14] https://www.cleanshipping.org/download/Slow-steaming-CE-Delft-final.pdf
[15]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816019/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs-technical-annexes.pdf

Aviation[16] (CORSIA) will be introduced starting in 2021. The EU ETS requires aircraft operators to return allowances for each tonne of CO_2 emitted; some of these allowances are made available to the sector freely, while others (up to a pre-determined 'cap' on the sector's emissions) can be traded within the sector. If the sector needs to emit more emissions than the cap, additional EU allowances can be traded with other sectors that have been able to reduce their emissions sufficiently below their caps.

To date, no similar schemes have been introduced for maritime transport. However, Directive (EU)2018/410 (European Commission, 2018b) notes that all sectors of the economy should contribute to the reduction of greenhouse gas emissions and the last Strategy for a Sustainable and Smart Mobility (European Commission, 2020d) points at extending the EU ETS to the maritime transport sector. It notes that the IMO has adopted an initial emissions reduction strategy, which should be encouraged and supported. The Directive requires the Commission to keep progress under regular review and that it should report to the European Parliament and to the Council on progress and on 'accompanying measures' to ensure that the sector contributes to the efforts to meet the Paris Agreement objectives.

In Regulation (EU) 2015/757, (European Commission, 2015), the EU introduced a requirement for all large ships entering EU ports to report (and have verified) their emissions via a monitoring, reporting and verification (MRV) scheme known as THETIS-MRV[17]. This scheme was seen as a first step in a staged approach to the inclusion of maritime emissions in the EU's GHG reduction commitment. These data are made public (emissions data for 2018 and 2019 have been released to date).

[16] https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx
[17] http://www.emsa.europa.eu/ship-inspection-support/thetis-mrv.html

3 Policy context

Emissions in waterborne transport are regulated at international and European level, as the maritime international shipping is a global phenomenon IMO regulations can have a wide application scale as far as they are ratified by Member States. Complementary or more stringent rules are produced at European level, which of course apply on the European territory. A brief overview of the main regulations is presented hereafter, both for IMO and for the EU.

3.1 IMO regulations

The international regulatory authority that is responsible for global shipping safety, security and environmental regulation is the International Maritime Organization. The IMO, established by the United Nations (UN) in 1948, entered into force in 1958 with the aim to promote cooperation among the organisation's members and the shipping industry, to reduce marine pollution and to improve maritime safety and security. At present, IMO has 174 Member States and three Associate Members. (IMO, 2020c). The convention proposed by IMO enter into force only when ratified by the minimum required Member States. The ratification process could be a lengthy procedure, which explains the time lag between the adoption of the convention and the entry into force.

The initiatives promoted by IMO include a series of measures intended to prevent shipping accidents and to minimise their consequences. Moreover, environmental threat caused by routine operations are also at the core of IMO policy. One of the most important measures is the International Convention for the Prevention of Pollution from Ships (MARPOL), adopted in 1973 and modified by the protocols in 1978 and of 1997. The 1997 protocol was adopted to amend the Convention and a new Annex VI was added, which entered into force in 2005. MARPOL currently includes six technical annexes covering the following aspects: accidental and operational oil pollution, noxious liquid substances in bulk pollution, pollution by harmful substances carried in packaged form, sewage, garbage and air pollution.

The one dealing with air pollution is the Annex VI, which entered into force in 2005 and which sets limits on SO_x, NO_x and GHG from ship exhausts and prohibits deliberate emissions of ozone depleting substances.

Several additions have been incorporated in the MARPOL convention, including definitions of higher standards in defined geographical areas or energy efficiency levels for ship design or management plans.

Concerning the stricter emission regulation related to defined geographical areas, the Emission Controlled Areas (ECA) have been introduced in 1997 and strengthened in 2005. The ECA can be designated for SO_x, NO_x and PM, or all three types of emissions. There are already four ECAs areas which cover European and North America seas, they include: Baltic Sea, North Sea, North American ECA, including most of United States (US) and Canadian coast, US Caribbean ECA, including Puerto Rico and the US Virgin Islands. The emissions limits vary according to the ships' construction dates and have become more stringent in 2005 (IMO, 2017).

Another initiative promoted by IMO is the on the Energy Efficiency Design Index (EEDI) which, by measuring CO_2 emissions, provides a performance index to measure new ships' energy efficiency. EEDI defines minimum thresholds (grams of CO_2 per tonne mile) according to ships' types and size (IMO, 2012). With this measure IMO tries to foster maritime decarbonisation through innovation and technological improvements, setting increasingly stringent targets up to 2025 (Balcombe et al., 2019), being nonetheless only restricted to CO_2 emissions. It has been estimated that the global shipping fleet will be entirely compliant with the EEDI regulation by 2040-2050 (International Council on Clean Transportation, 2011).

Another addition to the MARPOL convention is the Ship Energy Efficiency Management Plan (SEEMP) which aims at enhancing energy performance through operational measures. The IMO measure, SEEMP, can support ship operators to consider new technologies and practices, at each stage of the management plan, trying to optimise the ships' performance (IMO, 2017). The two regulations apply to all ships of 400 gross tonnage and above from 1 January 2013.

In April 2018, the IMO adopted an Initial Strategy on the reduction of GHG emissions from ships (IMO, 2018) with a target to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008. The strategy aims at strengthening the EEDI requirements and includes a list on short, medium and long terms targets a number of other measures to reduce emissions, such as operational efficiency measures, further speed reductions, measures to address methane and Volatile Organic Compounds (VOCs) emissions, alternative low-carbon and zero-carbon fuels, as well as market-based measures. For the short term (2018-2023) the focus is on broader implementation and possible enhancement of the EEDI and SEEMP, aiming at improving technical and operational ship efficiency. The strategy will be revised after this initial phase, while for the medium term (2023-2030) additional measures including effective uptake of alternative low and zero-carbon fuels as well as possible opportunity provided by market-based measures will be included. For the long run (after 2030) a continuation and broader application of identified measures will be included (Doelle and Chircop, 2019). In the recent IMO Marine Environment Protection Committee (MEPC75) held in November 2020, a further step has been moved towards the preliminary approval of a new package of technical and operational measures covering GHG emissions in the short run aiming at achieving IMO targets (IMO, 2020d).

3.2 European regulations

The EU is highly committed in addressing GHG emissions, aiming at achieving a climate-neutral economy. In the Climate Change and Energy Package (European Parliament, 2009a) the target of achieving a 20% reduction of emission by 2020, compared to 1990 levels was set. For the next decade a more ambitious target was defined by the 2030 Climate and Energy Framework (European Commission, 2014b), which aimed at achieving a 40% cut of GHG emissions by 2030. The final target would be to reach a climate-neutral impact of the European economy by 2050, which is part of the EU long-term vision (European Commission, 2018a). This is in line with the global directions present in the Paris Agreement which lay out a framework to avoid dangerous climate change by limiting global warming below 2°C, aiming to limit it to 1.5°C (United Nations, 2015). The actions defined in the European Green Deal (European Commission, 2019b) support the objective of obtaining a sustainable European economy, where no net GHG emissions will be present by 2050. In the EU strategy, transport plays a key role as it is expected that by 2050, the EU will achieve a "cleaner, cheaper and healthier forms of private and public transport". This target should be reached also through the support of environmentally-friendly technologies.

In the 2030 Climate Target Plan, GHG emissions are set to be reduced to, at least, 55% below 1990 levels by 2030; in this context the entire transport sector is called to contribute to such reduction by means of efficiency improvements, fuel mix changes, increase of sustainable transport modes, digitalisation and other incentives. (European Commission, 2020c).

Such measures have been included in the last Strategy for a Sustainable and Smart Mobility which set the pathway to reach a European transport system which should be sustainable, smart and resilient by 2050 (European Commission, 2020d). The strategy, which cover the entire transport sector, identifies concrete policy measures, around 10 key areas, with different milestones set for 2030, 2035 and for 2050.

Waterborne transport is not exempted from taking actions in this direction and environmental progresses have been made since the Maritime Transport Strategy 2009-2018 was published (European Commission, 2009).

In the same year, the Directive 2009/29/EC of the European Parliament and the Decision No 406/2009/EC (European Parliament, 2009b) defined that the maritime emissions should be included in the overall commitment of reducing the EU GHG emissions of 20%. Moreover, the Decision specified, that, if no international agreement on reduction of maritime emissions, would be put in place by 2011, *"the Commission should take action proposing to introduce international maritime emissions in the Community reduction commitment with the aim of the proposed act entering into force by 2013".*

In the Transport White Paper (European Commission, 2011), a target for the overall transport was set to reduce emission by 60% against 1990 levels by 2050. For what concerns the maritime transport the established target was to reduce CO_2 emissions by at least 40%, if feasible up to 50%, by 2050 compared to 2005 data.

The next step in the EU maritime decarbonisation pathway was introduced 2013 with the integration of maritime transport in the EU's greenhouse gas reduction policies (European Commission, 2013). The three step approach proposed by the strategic document consisted in acting through a list of key measures: such as the implementation of the MRV system, the definition of GHG reduction targets for maritime transport and the implementation of market based measure. In this direction, in 2015, it was adopted the first European regulation for monitoring, reporting and verifying CO_2 emissions (European Commission, 2015) from vessels above 5.000 gross tonnage when performing maritime transport activities related to the EEA. The monitoring process started in 2018 covering more than 11.600 ships, including ro-ro passenger ships, bulk carriers, tankers and container ships; in the first reporting year more than 138 million tonnes of CO_2 emissions were registered.

In 2016, the EC published a working document on the implementation of the Maritime Transport Strategy (European Commission, 2016) where progress made since 2009 were presented, complemented by indications for further actions to be implemented in five areas of which "Environmental Sustainability and Decarbonisation" of one of those.

The maritime transport is also included among the sectors that are encouraged to reduce emission, also thought the EU ETS, as indicated in the by Directive (EU) 2018/410 (European Parliament, 2018).

In February 2019, the European Commission adopted a proposal (European Commission, 2019c) to revise the Regulation (EU)2015/757 on the maritime CO_2 monitoring, reporting and verification of CO_2 system, aiming at aligning the EU and IMO data collection systems.

The last Strategy for a Sustainable and Smart Mobility (European Commission, 2020d), defines how the waterborne transport will be affected by decarbonisation policy measures aiming at boosting the production and uptake of sustainable maritime fuels through the upcoming FuelEU Maritime initiative, which aims to increase the use of sustainable alternative fuels focusing on market barriers and reduce the uncertainty related to technical options and their market-readiness[18].

The European body that mostly deal with inland waterways emissions is the CCNR which defines rules for navigating on the Rhine River. The CCNR started to regulate pollutant emission in 2002, with the CCNR Regulation I, followed by CCNR II in 2007; both regulations are comprised in the Rhine Vessel Inspection Regulations. The specific limits defined in the two regulations apply differently according to the diverse engine power, covering NO_x, PM, carbon monoxide and hydrocarbon emissions. The emissions limits set in the CCNR II are similar to the ones defined at European scale and included in the directive to regulate emission produced by non-road mobile machinery (NRMM), called Stage III A (Directive 2004/26/EC) (European Parliament, 2004); since 2007 the EC standards apply. New standards have been defined with the Stage V NRMM Regulation (Stage IV was skipped) defined in EC Regulation 2016/1628, (European Parliament, 2016) which entered into force in 2017. (Pillot et al., 2016) In addition, the CCNR renewed its commitment to strongly reduce air pollutants by 2050[19] and the Naiades II EC expert group expressed its support for the strategy towards the implementation of the Inland Waterway Agenda for Europe.[20]

For inland waterways, the NAIADES III programme (European Commission, 2020d), will be developed with the scope of completing the links with the rail network, ensuring climate resilient infrastructure, renewing barge fleets and improving access to financing.

In this context the Draft Strategic Research and Innovation Agenda for the Zero Emission Transport partnership for Horizon Europe[21] is foreseen to play an important role in providing zero-emission solutions for all main ship types and services before 2030, which will enable zero-emission waterborne transport before 2050. The areas on which future R&I activities will focus have been defined as: increasing use of sustainable alternative fuels, electrification, increasing energy-efficiency, design and retrofitting solutions for the new and existing fleet, digital green to improve efficiency and sustainable bunkering and charging solutions for climate neutral ships. Moreover within the aim of the partnership, effort will be put to exploit a range of dedicated measures such as private investments, Connecting Europe Facility (CEF), Climate Innovation Fund, Regional Funds, etc.

[18] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12312-FuelEU-Maritime-

[19] https://www.ccr-zkr.org/12080000-en.html

[20] https://ec.europa.eu/transport/modes/inland/promotion/naiades2_en

[21] https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf

4 Methodological background

4.1 Database development and labelling

The TRIMIS database[22] contains details of nearly 8,000 research projects. Many of these projects have received support from the EU (mainly through the research Framework Programmes, such as FP7 and Horizon 2020 (H2020), but also other programmes such as CEF, the environment and climate focused LIFE programme and some that have been funded through other routes (such as national research programmes).

The maintenance and updating of the information on the EU-funded projects (including the addition of new projects) is enabled through a link to the EU Community Research and Development Information Service (CORDIS), while national contact points provide the relevant information to add and update the nationally funded projects.

As projects are added to the TRIMIS database (or their records updated), the information on them is reviewed (for completeness, intelligibility and accuracy) and they are assigned various 'tags' to allow for easier searching and analysis (van Balen et al., 2019). One of the key tags is the transport mode. Projects are assigned to one of the following transport mode descriptions, based on the primary focus of the project:

- Air transport
- Rail transport
- Road transport
- Water transport (sea & inland)
- Multimodal transport.

Another important tag is the assignment of projects and the related technologies to Technology Readiness Levels (TRLs). TRLs are indicators of the maturity level of particular technologies, this method provides a common understanding of technology status and addresses the entire innovation chain. There are nine technology readiness levels; TRL 1 being the lowest and TRL 9 the highest. Developed by US National Aeronautics and Space Administration (NASA) in the 1970's, adopted and edited by the EC[23], in 2010 the EC advised that EU-funded R&I projects should adopt the TRL indicator; TRLs were then implemented for the EU H2020 programme, although in practice TRLs are not consistently assigned to all H2020 projects. In TRIMIS, the nine TRLs have been consolidated into four development phases: research, validation, demonstration/prototyping/pilot production, and implementation. These are used to monitor and describe the maturing of each technology in a similar way to the original TRLs. The correspondence between TRLs and the TRIMIS development phases are shown in **Table 2**.

[22] European Commission, TRIMIS Transport and Research and Innovation Monitoring and Information System, 2020e. Available at: https://trimis.ec.europa.eu/

[23] European Commission, HORIZON 2020 WORK PROGRAMME 2016– 2017, 20. General Annexes, 2017b. Available at: https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf

Table 2: Technology readiness levels (TRLs) and TRIMIS development phase allocation.

TRL level	Description	TRIMIS development phase
1	Basic principles observed	Research
2	Technology concept formulated	
3	Experimental proof of concept	Validation
4	Technology validated in lab	
5	Technology validated in relevant environment	Demonstration/prototyping/pilot production
6	Technology demonstrated in relevant environment	
7	System prototype demonstration in operational environment	
8	System complete and qualified	Implementation
9	Actual system proven in operational environment	

Source: Gkoumas et al. 2020, TRL scale based on European Commission, 2014

TRIMIS projects are also classified according to one or more of the seven STRIA roadmaps, as described in the EC 'Europe on the Move' package (European Commission, 2017a; 2017c), which highlights main transport R&I areas and priorities for clean, connected and competitive mobility. The STRIA roadmaps set out common priorities to support and speed up the research, innovation and deployment that leads to technology changes in transport. The seven STRIA roadmaps, covering various thematic areas, are the following:

- Connected and automated transport (CAT)
- Transport electrification (ELT)
- Vehicle design and manufacturing (VDM)
- Low-emission alternative energy for transport (ALT)
- Network and traffic management systems (NTM)
- Smart mobility and services (SMO)
- Transport infrastructure (INF).

4.2 Identification of waterborne transport decarbonisation projects

A central step is to identify those projects that fall under the waterborne transport mode, which in the vast majority of the projects is a straightforward exercise, as the transport mode is clearly defined within the scope of the project. Waterborne topics can, nonetheless, be also captured in projects falling under the multimodal transport category.

As of June 2020, the TRIMIS database contains information on 585 waterborne transport projects. In addition to those ones, multimodal transport projects relevant to waterborne transport were identified. This report reviews those projects that tackle decarbonisation aspects. The selection of those waterborne projects falling within the scope of the analysis, was twofold. An initial selection was based on a list of keywords whose meaning was associated to the topic through a machine learning method, and, as a validation phase, the projects were selected based on their content description. The process lead to a final selection of 133 projects developed under the FP7 and H2020 framework programmes. Earlier projects, projects funded under different actions and the ones funded by Member States, although with possible relevance on the topic, are excluded from this analysis as outdated results or incompleteness of some national data could not substantially contribute to enrich the findings of the study. Waterborne projects loosely linked to the decarbonisation research area were also left out; bearing these limitations in mind, the present research does not claim to be exhaustive, rather to provide an extensive overview of the current research status.

4.3 Waterborne transport decarbonisation project assessment

The review identified a total number of 133 projects which dealt with the decarbonisation theme. The particular areas being studied by these projects were examined and a set of five sub-themes was drawn up based on previous academic research on the topic. (Bouman et al., 2017; Halim et al., 2018; Wan et al., 2018; Balcombe et al., 2019; Serra and Fancello, 2020)

The sub-themes selected are:

- Hull design
- Power and propulsion
- Fuel and alternative energy sources
- Operational measures
- Coordination and support measures, including research, networking activities.

While the first three sub-themes are linked to technological measures, the last two cover mainly other approaches, as easily understandable by their definition.

It should be noted that projects may be relevant to multiple sub-themes and can be researching technologies which are not constrained to just one sub-theme. However, for the purpose of this report the projects were clustered into the above 5 broad sub-themes to allow for similar projects to be discussed under the same theme. When no clear allocation was possible, a multiple sub-themes tag was chosen.

The relevant projects have been reviewed to identify the overall direction of research and progress under each sub-theme; a selection of significant projects has then been examined in detail to illustrate the progress being achieved in particular topics. The selection of these projects has been based on the overall scale of the project (exemplified by its total funding value) and the availability of results and conclusions on the research being performed. In many cases, information on the achievements of the projects is not available until the publication of the final report, so the majority of projects considered in detail are those that are already completed. In some cases, projects which have not yet been fully completed have been included in the project assessment. This is because these projects may be large-scale (i.e. high funding value), researching innovative solutions and/or already have published meaningful results. In addition to the descriptions of the individual projects, assessments have been made of the implications of their results on the future research needs and on policy development.

This report includes EU-27 plus United Kingdom (UK), as the UK continues to participate in programmes funded under the current 2014-2020 Multiannual Financial Framework until their closure[24].

[24] https://www.gov.uk/government/publications/continued-uk-participation-in-eu-programmes/eu-funded-programmes-under-the-withdrawal-agreement

5 Quantitative TRIMIS assessment of waterborne transport research with a focus on decarbonisation

This chapter provides an overview of the waterborne transport programmes and projects present in TRIMIS, first looking at the distribution of waterborne transport projects within the different EU funding programmes and then analysing in detail those linked to the decarbonisation topic.

5.1 Overview of waterborne transport funding programmes in EU

The projects in the TRIMIS database that have been assigned to the waterborne transport mode, have been reviewed identifying the total numbers of projects and the related funding values under the different programmes. The earliest EU-funded projects in TRIMIS start from the Fourth Framework programme (FP4) programme, starting from 1996; nonetheless the projects having greater relevance to this report are the most recent ones, such as the one financed from FP7 onwards. The results are shown in **Table 3** and **Table 4**, respectively for FP7, period covered 2007-2013, and H2020, period covered 2014-2020.

Both the FP7 and H2020 programmes have funded approximately 100 projects on waterborne transport each, with total values of about €500 million for each programme. Under FP7, the majority of projects (88 out of 98, with almost 84% of the total value) were funded by the FP7 Transport action, while under H2020, the majority of the support was provided through the 'Smart, Green and Integrated Transport' action, with 90 out of 101 projects and 85% of the total value.

Table 3: Numbers and values of waterborne projects funded by the EU FP7 programme

Funding action	Number projects	Total funding	EU contribution
FP7-JTI - Specific Programme "Cooperation": Joint Technology Initiatives	1	€ 2,884,876	€ 1,641,194
FP7-KBBE - Specific Programme "Cooperation": Food, Agriculture and Biotechnology	1	€ 11,323,366	€ 9,000,000
FP7-SECURITY - Security	6	€ 57,548,622	€ 40,293,104
FP7-SME - FP7-SME - Specific Programme "Capacities": Research for the benefit of SMEs	1	€ 2,720,232	€ 2,140,961
FP7-SST - Sustainable Surface Transport	1	€ 7,499,604	€ 5,279,859
FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	88	€ 422,687,133	€ 286,574,083
Total FP7	**98**	**€ 504,663,833**	**€ 344,929,201**

Source: TRIMIS

Table 4: Numbers and values of projects funded by the EU H2020 programme

Funding action	Number projects	Total funding	EU contribution
H2020-EU.2.1. - H2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies	3	€ 4,479,170	€ 3,467,433
H2020-EU.2.3. - H2020: INDUSTRIAL LEADERSHIP - Innovation In SMEs	2	€ 2,127,959	€ 1,489,523
H2020-EU.3.2. - H2020: SOCIETAL CHALLENGES - Food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bio-economy	1	€ 26,002,703	€ 8,580,892
H2020-EU.3.3. - H2020: SOCIETAL CHALLENGES - Secure, clean and efficient energy	2	€ 13,501,039	€ 13,431,699
H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	90	€ 392,354,460	€ 324,463,999
H2020-EU.3.7. - H2020: Secure societies - protecting freedom and security of Europe and its citizens	3	€ 18,696,687	€ 17,120,476
Total H2020	**101**	**€ 457,162,018**	**€ 368,554,022**

Source: TRIMIS

Other major EU funding programmes have contributed to finance waterborne transport projects such as CEF, INTERREG, LIFE, etc.

The CEF programme has supported 18 projects on waterborne transport with a total value of €247 million. As would be expected, given the cross-border nature of the CEF programme, the average project value (about €13.7 million) is rather high. Three of the six projects supported through the CEF Transport action are focused on LNG as an alternative fuel for waterborne transport, while one is focused on improved operations in ports. The remaining two investigated options for decarbonising inland waterways transport, particularly through electric propulsion.

Table 5: Number of projects funded by the EU CEF programme

Funding action	Number projects	Total funding	EU contribution
CEF - Connecting Europe Facility (2014-2020)	12	€ 105,957,975	€ 72,513,482
CEF Transport – CEF for Transport (2014-2020)	6	€ 141,179,391	€ 38,625,106
Total CEF	**18**	**€ 247,137,366**	**€ 111,138,588**

Source: TRIMIS

Of the remaining EU programmes, both INTERREG and LIFE have supported significant numbers of projects; under INTERREG, the cross-border and transnational actions (INTERREG IVA and IVB, respectively) have been the most active. Unlike the FP7, H2020 and CEF-funded projects, funding values for the INTERREG, LIFE and other projects are not generally available in TRIMIS, so Tables 6 and 7 show just the total numbers of projects.

Table 6: Numbers of projects funded by the EU INTERREG programme

Funding action	Number of projects
INTERREG IIIB - Trans-European cooperation (Community Initiative) (2000-2006)	5
INTERREG Europe IV - INTERREG IV - Interregional cooperation across Europe (INTERREG IVC) (2007-2013)	2
INTERREG IVA - INTERREG IV - Cross-border programmes (2007-2013)	18
INTERREG IVB - INTERREG IV - Transnational programmes (2007-2013)	33
INTERREG VB - INTERREG V - Transnational programmes (2014-2020)	1
Total INTERREG	**59**

Source: TRIMIS

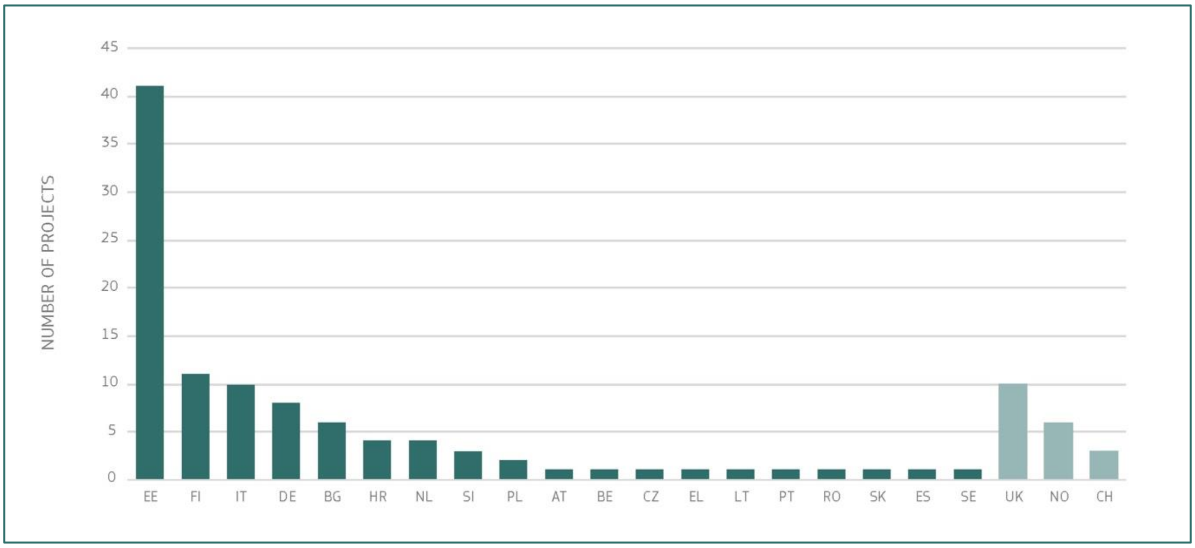
Table 7: Numbers of projects funded by other EU programmes

Funding action	Number of projects
ATLANTICAREA - Atlantic Area Transnational Programme (2014-2020)	1
IEE - Intelligent Energy Europe (2003-2013)	1
LIFE - EU financial instrument supporting environmental, nature conservation and climate action projects (1992-2020)	26
Total other EU	**28**

Source: TRIMIS

Within European national programmes (**Figure 9**), 22 countries (19 European Union of 27 Member States (EU27) Member States plus Norway (NO), Switzerland and the UK have supported maritime research projects, with Estonia (EE), Finland (FI), Italy (IT) and the UK being the most active.

Figure 9: Numbers of projects funded by national research programmes



Source: TRIMIS

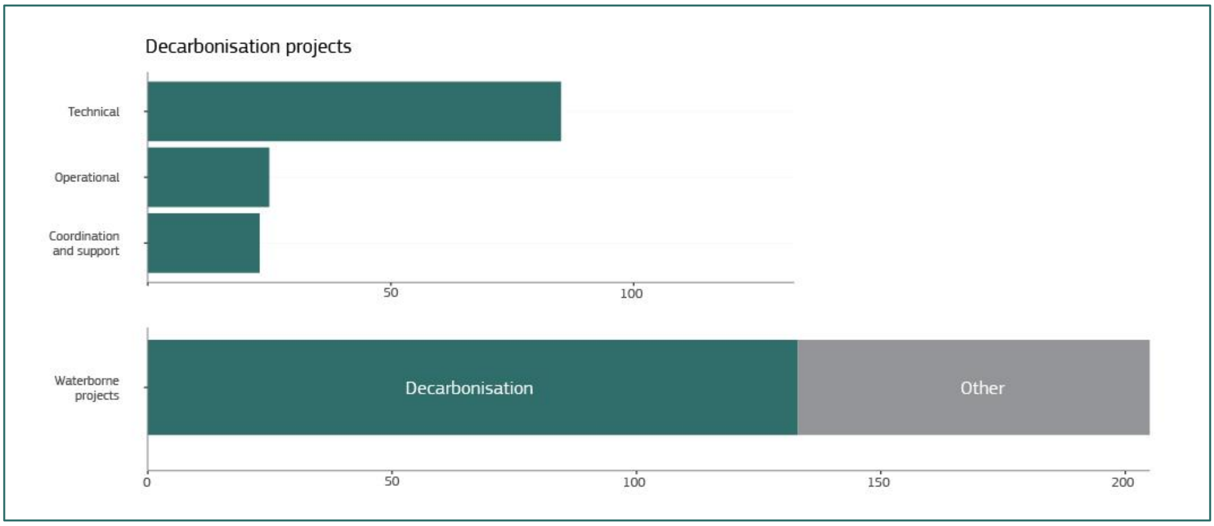
5.2 TRIMIS quantitative analysis on waterborne research projects

The analysis is now narrowed to the waterborne transport projects linked to decarbonisation, for this purpose, relevant FP7 and H2020 waterborne and multimodal projects were selected. Multimodal projects were filtered based on keywords (Annex 1) to determine if they were related to waterborne transport and to the decarbonisation topic.

Based on the project descriptions and results available in TRIMIS, these projects were categorised in decarbonisation and non-decarbonisation projects. Then, the decarbonisation projects were classified in 3 different main themes:

- projects where *Technical Measures* have been presented: these projects relate to ship design and technologies, such as hull design, power and propulsion, alternative fuels, materials;
- projects where *Operational Measures* have been investigated, looking at improving vessel navigation, vessel allocation, container handling systems;
- projects addressing *Coordination and support measures*, which would also include research, networking activities.

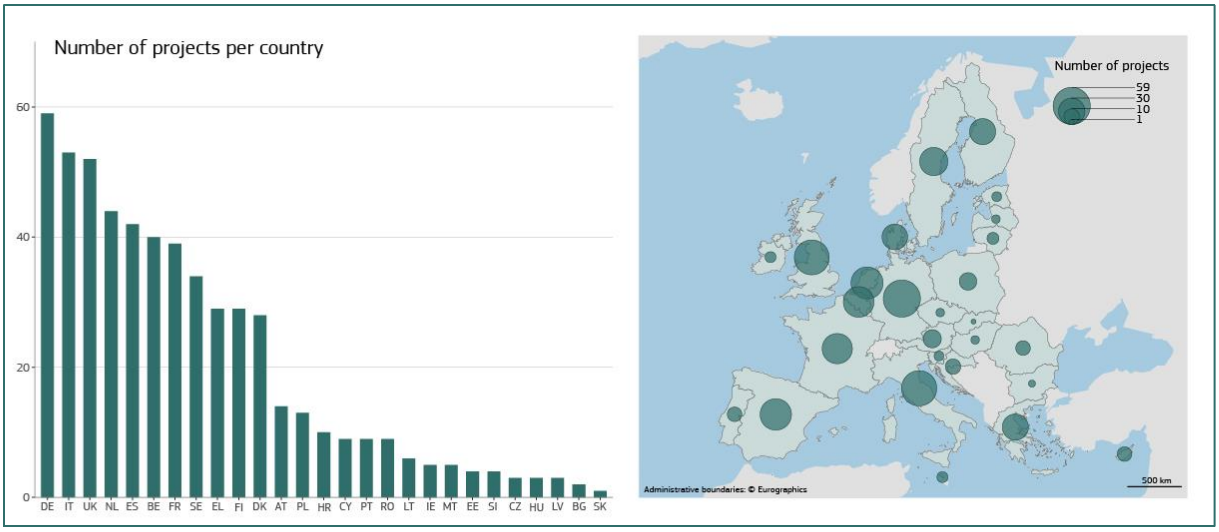
Figure 10: Waterborne projects and theme division



Source: TRIMIS

Starting from the total number of waterborne projects in FP7 and H2020, **Figure 11** shows the total number of those touching upon the decarbonisation topic and the division in main themes presented earlier. Approximately 65% of the waterborne projects deal with decarbonisation, with the majority of them being technical projects and practically the same number of operational and coordination and support measures projects. It is important to note that the sum of the number of projects from the technical, operational and coordination and support measures topics is greater than the number of decarbonisation projects, due to some projects having double labels (e.g. technical and coordination and support measures). In Figure 11, the number of waterborne transport decarbonisation projects per Member States plus UK is shown. Germany (DE) and The Netherlands (NL) are the countries with the most waterborne transport decarbonisation projects, while eastern countries have substantially less projects.

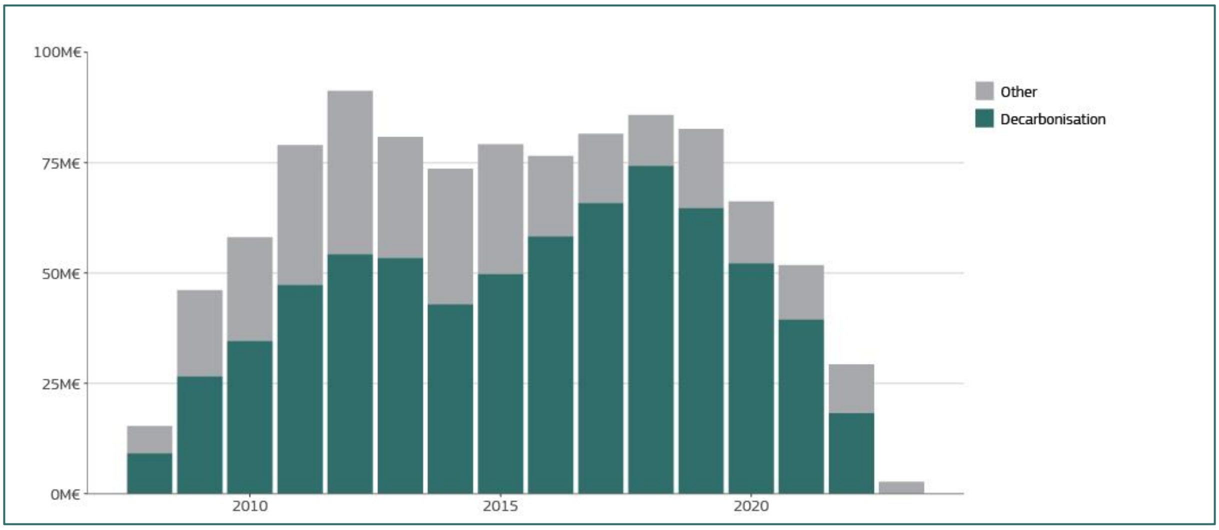
Figure 11: Decarbonisation waterborne transport projects for EU Member States and UK



Source: TRIMIS

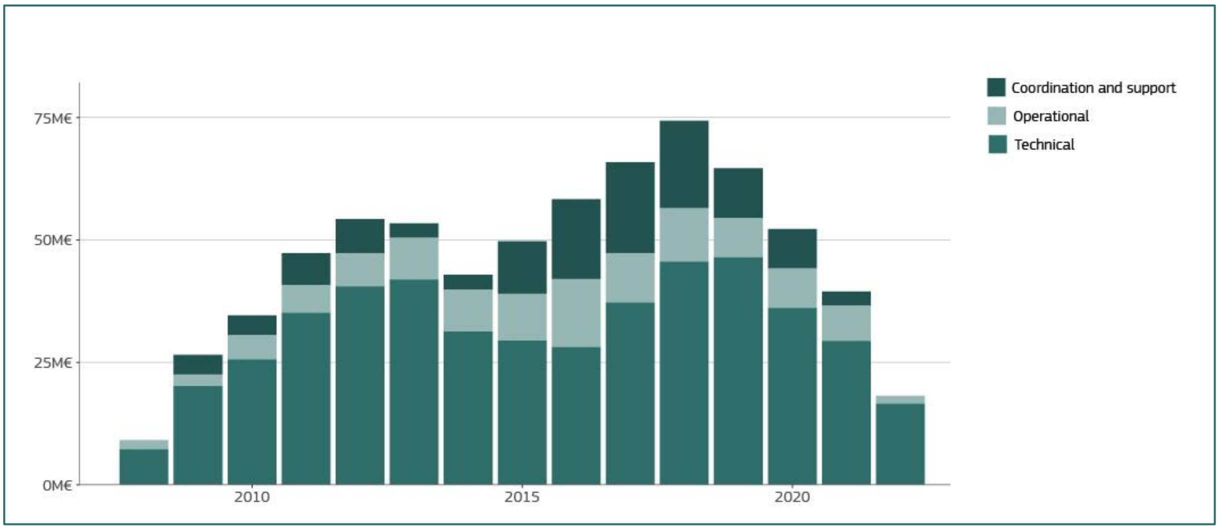
Figure 12 shows the evolution of the waterborne and decarbonisation transport projects costs from 2008 to 2023 and **Figure 13** presents the costs for each theme for the same period. The project costs are calculated by dividing the total project budget by its duration and assigning them to the respective years. Therefore, the budget calculations for 2020, 2021, 2022 and 2023 are estimates based on the expected project costs. Under FP7 and H2020 around €995 million has been invested and are currently spent in waterborne transport decarbonisation research projects. This includes €760 million of EU funds and about €239 million of own contributions by beneficiary organisations. The FP7 programme funded 102 waterborne transport projects, of which 53 are under the decarbonisation theme. During H2020 the number of transport decarbonisation waterborne projects is 80, over a total number of 103 of waterborne ones. The graph shows two peaks (in 2012 and 2018), which are related to peak activities from the two framework programmes. Moreover, the percentage of decarbonisation projects related to waterborne transport projects changes substantially in H2020, with great increase in the budget allocated to these projects, €371 million, over total waterborne budget, which was €464 million. This funding distribution is also observed when looking in detail at the evolution of projects linked to technical, operational and coordination and support measures (**Figure 13**).

Figure 12: Waterborne and decarbonisation waterborne project costs (2008 to 2023, with projections from 2020 to 2023)



Source: TRIMIS

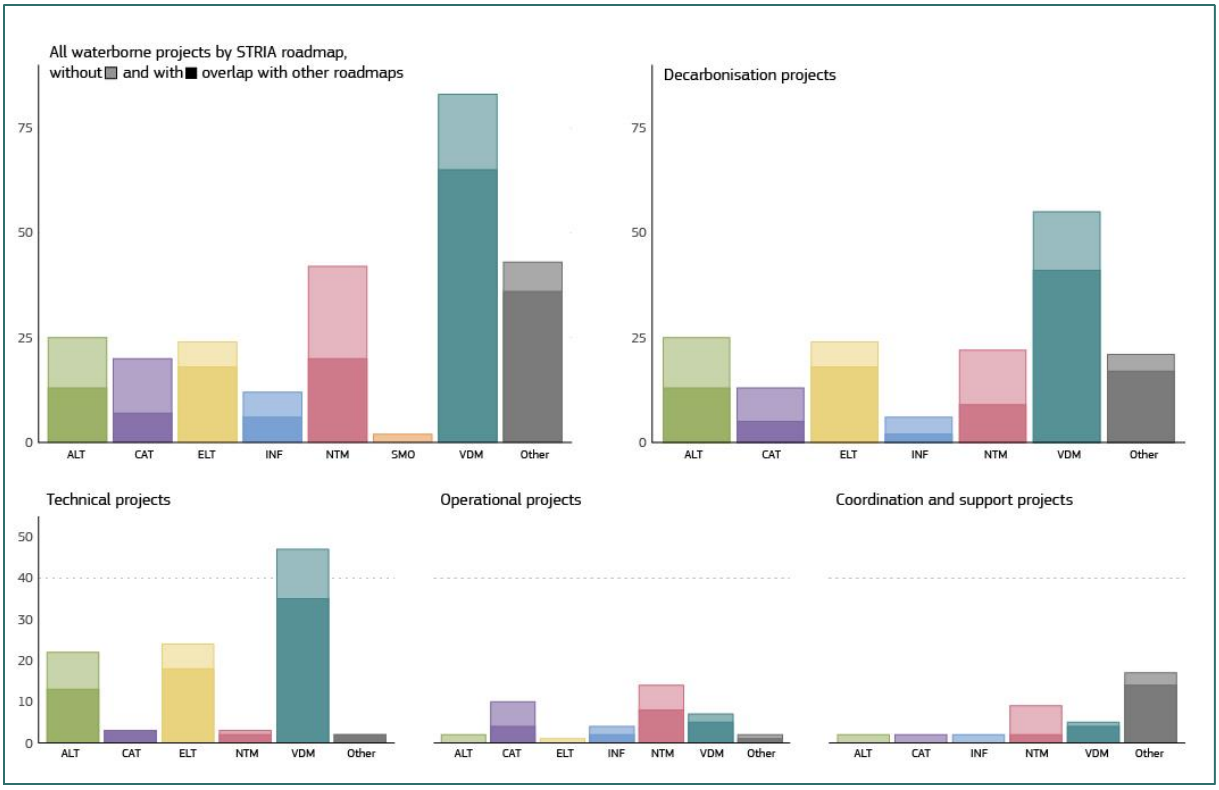
Figure 13: Decarbonisation project themes costs (2008 to 2023, with projections from 2020 to 2023)



Source: TRIMIS

In the TRIMIS database, projects are also tagged according to the seven STRIA roadmaps. Therefore, the waterborne transport projects and its subcategories can also be analysed according to their presence in the various roadmaps. Figure 14 shows this analysis, where it can be seen that the Vehicle design and manufacturing roadmap is the most present for the full list of decarbonisation projects; this applies also for technical projects. The Network and traffic management systems and Connected and automated transport roadmaps hold the majority of projects for the operational theme. For coordination and support measures, most projects were tagged under the “OTHER” tag, meaning that the projects under this category are more general and cross-cutting across all STRIA roadmaps. It is important to note that a project can be tagged under more than one STRIA roadmap, meaning that the sum of the numbers for each category is higher than their total number of projects.

Figure 14: Waterborne projects and themes division per roadmap



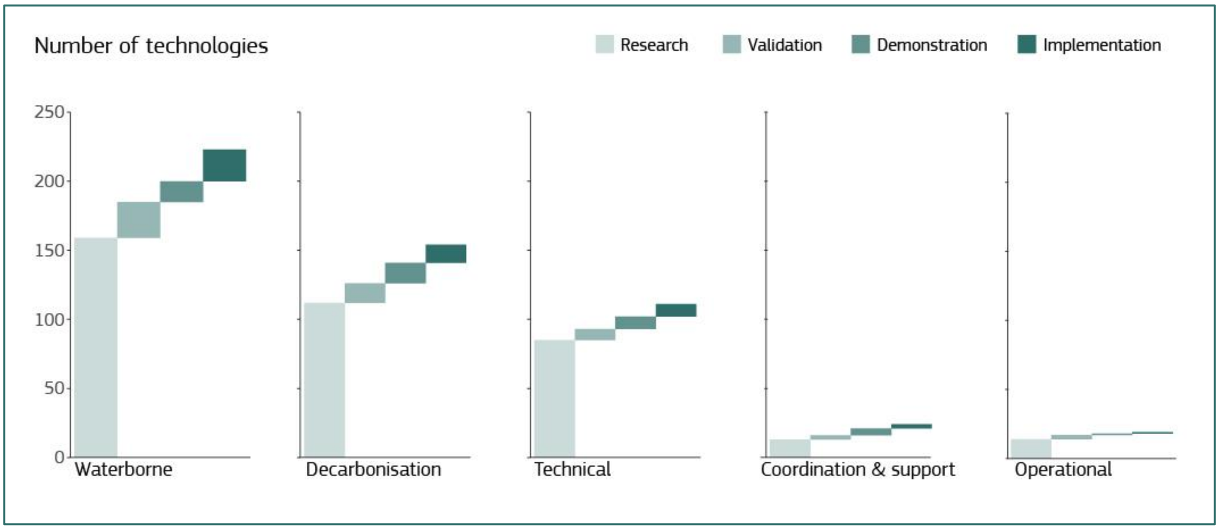
Abbreviations: Connected and automated transport (CAT), Transport electrification (ELT), Vehicle design and manufacturing (VDM), Low-emission alternative energy for transport (ALT), Network and traffic management systems (NTM), Smart mobility and services (SMO), Transport infrastructure (INF).

Source: TRIMIS

The technologies researched in these projects can be assessed to understand their research maturity within the projects and to understand how market ready a certain technology is. For such an analysis, the TRIMIS technology assessment methodology (Gkoumas et al., 2019) is used, where different technologies developed in projects are identified, as well as their maturity level. These are used to monitor and describe the maturing of each technology in a similar way to the original TRLs. (Heder, 2017).

Figure 15 shows the technology maturity breakdown for waterborne projects and the different topics. It is visible that for all categories, the majority of the technologies is under the initial research step, while the number of technologies in the validation, demonstration and implementation stages is quite even, showing that not much difference exists between the various topics.

Figure 15: Technology maturity breakdown for waterborne technology and themes division



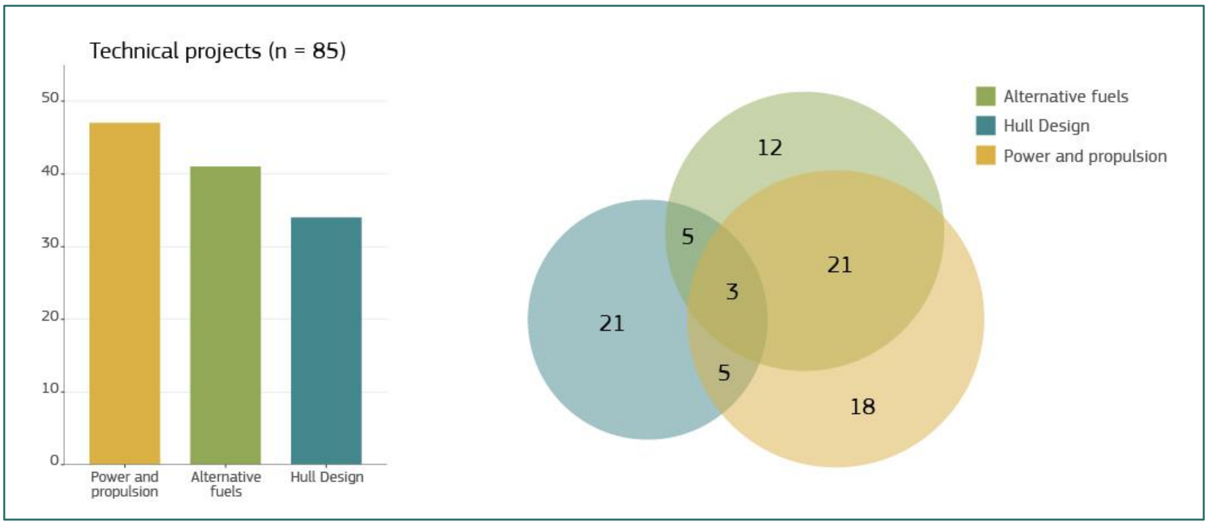
Source: TRIMIS

Moreover, the projects dealing with technical measures were divided in 3 sub-themes:

- *Hull design*: technical projects that investigate innovative designs for hulls, including new shapes and materials.
- *Power and propulsion*: technical projects that research propulsion and power systems in the area of wind assisted propulsion, engine efficiency and recycling of waste heat, etc.
- *Alternative fuels*: technical projects that research the use of alternative fuels such as electrification, hydrogen, natural gas/ liquefied petroleum gas (LPG).

Each project in the technical category belongs to one or more of these 3 sub-themes. Figure 16 shows the comparison between the number of technical projects and the sub-themes tags, as well as the number of projects that belong to multiple sub-themes. The largest sub-theme in terms of number of projects is *Power and propulsion*, while *Alternative fuels* and *Hull design* have a very similar number of projects. Additionally, it can be seen that there is a large overlap between the projects belonging to *Power and propulsion* and *Alternative fuels*, showing that the sub-topics are well linked in the research projects. On the other hand, the *Hull design* sub-topic shows less overlap with the others, representing a more isolated sub-theme when compared to the others.

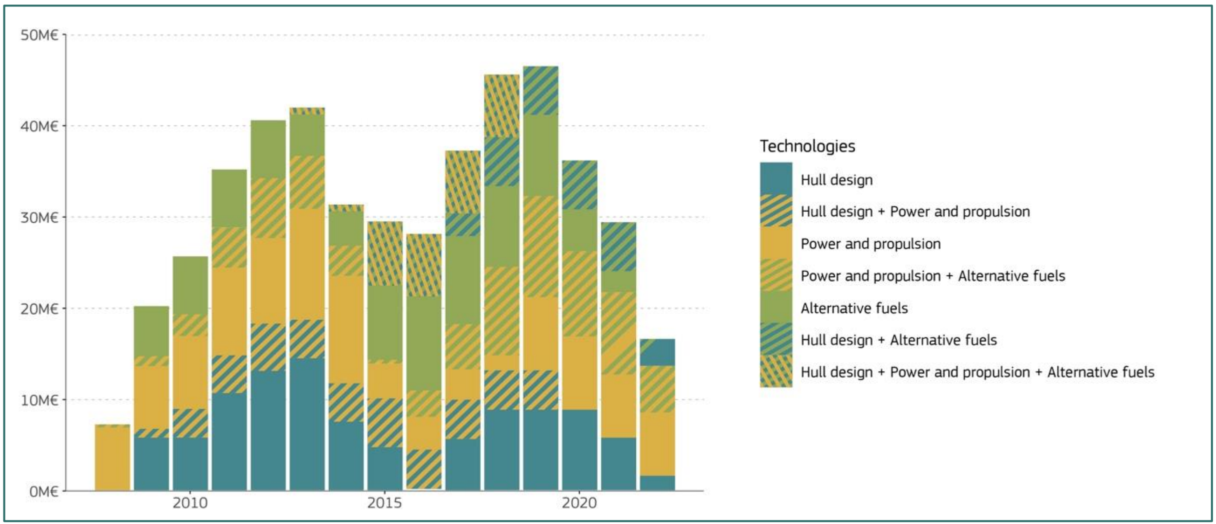
Figure 16: Technical projects sub-themes division and overlaps



Source: TRIMIS

Figure 17 shows the yearly project costs for each technical sub-theme. The two peaks (in 2012 and 2018) are related to peak activities from the FP7 and H2020 framework programmes. Moreover, while in *Hull design* there is a similar proportions of participation in both FPs, *Power and propulsion* shows a decrease in budget for H2020, while *Alternative fuels* present an increase in project funding in H2020. It could be concluded that there is a budget shift between the two well-linked topics, with *Alternative fuels* being the prevalent one in H2020.

Figure 17: Technical projects costs (2008 to 2023, with projections from 2020 to 2023)

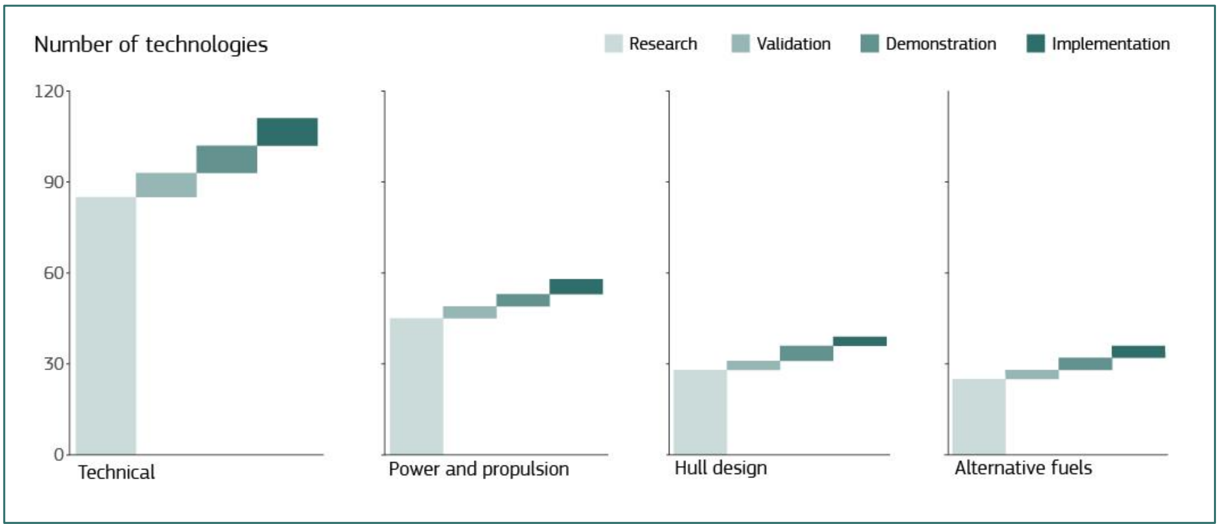


Source: TRIMIS

Finally, the technology maturity breakdown for the technical projects and the sub-themes is shown in

Figure **18**. The technology maturity breakdown for each technical sub-theme shows the same overall trend, with the majority of technologies in the research stage, and with a similar proportion of technologies under the validation, demonstration and implementation steps.

Figure 18: Technology maturity breakdown for the technical sub-theme and themes divisions



Source: TRIMIS

6 TRIMIS Research and Innovation assessment

This chapter analyses R&I projects in the field of waterborne transport decarbonisation under the five sub-themes presented earlier, based on the area identified in literature and supported by actual research topics being undertaken under this transport mode. The analysis provides an overview of the research being performed, its key results and the subsequent implications for future research and policy development. The full list of reviewed projects is presented in Annex 2.

The first three sub-themes: hull design (1), power and propulsion (2), and fuels and alternative energy sources (3), are all directly related to technological advancement within the waterborne transport sector. The other two sub-themes are not directly related to technology; with more of a focus on operational measures (4) and coordination and support measures, including also research, networking activities, etc. (5)

The sub-themes are:

1. *Hull design;*

This sub-theme covers projects focusing on lightweight composite materials for structural components, innovative hull repair methods and hull surface protection.

2. *Power and propulsion;*

This sub-theme covers projects focusing on topic areas such as wind assisted propulsion, increases in engine efficiency and recycling of waste heat for use elsewhere in the vessel.

3. *Fuels and alternative energy sources;*

This sub-theme covers projects focusing on the use of electrification (batteries, hybrid systems), hydrogen as a fuel, LNG or compressed natural gas (CNG) or LPG as a fuel.

4. *Operational measures;*

This sub-theme covers projects focusing on topics such as improved vessel navigation, vessel allocation systems and robotic container handling systems.

5. *Coordination and support measures, including research, networking activities.*

This sub-theme covers projects focusing on the dissemination and consolidation of research in the waterborne transport sector, as well as planning and investigating future strategy for the sector, including both vessel and port design.

6.1 Sub-theme 1 – Hull design

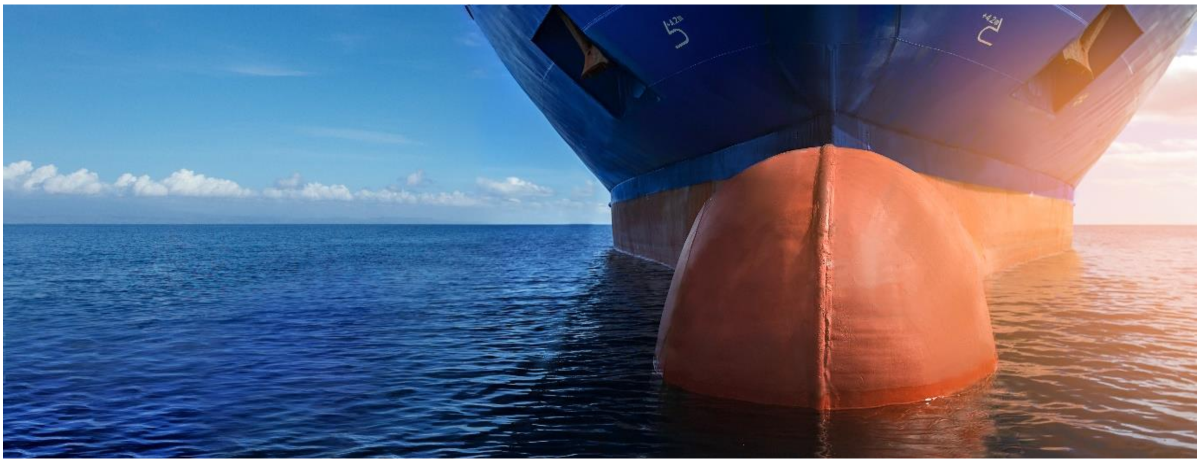


Table 8: Funding level per programme for Hull design

Funding action	Number projects	Total funding	EU contribution
FP7	15	€ 84,613,451	€ 57,253,696
H2020	19	€ 114,972,167	€ 90,138,137
Total	**34**	**€ 199,585,618**	**€ 147,391,833**

Source: TRIMIS

6.1.1 Overall direction of R&I

The research projects within the hull design sub-theme tend to focus on lightweight composite materials for structural components, innovative hull repair methods and hull surface protection. The use of lightweight materials as replacements for heavier materials has the benefit of reducing the overall fuel consumption of the vessel, which subsequently leads to reduced GHG emissions if fossil fuels are used. Another benefit of reducing the vessel energy consumption is that less energy dense fuels (hydrogen, LNG, batteries) may be able to provide sufficient energy to power the vessel, hence paving the way for alternative fuels use in the maritime sector.

A damaged hull, or a hull which is covered by organisms such as barnacles, can increase the overall resistance greatly on a vessel. This can result in an increase in energy consumption of the vessel by up to 40%[25]. This increase in energy consumption directly correlates to increase in GHG emissions, and potentially other pollutants, therefore it is beneficial to reduce the overall resistance on the vessel.

Table 9 shows the selected projects under the hull design sub-theme, along with the corresponding funding programmes and key themes. Projects under this sub-theme cover a variety of technologies and are funded by both FP7 and H2020 programmes.

[25]https://trimis.ec.europa.eu/project/low-emission-antifouling-coatings-based-novel-discovered-post-settlement penetration#tab-outline

Table 9: Selected Hull Design projects and key themes

Project acronym	Funding programme	Key themes
ADAM4EVE	FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	Adaptive hull structures; smart materials
HILDA	FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	Friction stir welding
LEAF	FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	Hull surface antifouling technology
MOSAIC	FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	High-strength low-alloy steels
FIBRESHIP	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Fibre reinforce polymers
COMPA 2GO	H2020-EU.2.1. - H2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies, H2020-EU.2.3. - H2020: INDUSTRIAL LEADERSHIP - Innovation In SMEs	Smart repair service

Source: TRIMIS

6.1.2 R&I activities

The project partners within the ADAM4EVE (2013-2015) project focused on the development and assessment of applications of adaptive and smart materials and structures in the ship building industry. The project investigated three categories of technologies: adaptable ship hull structures for optimised hydrodynamic properties at varying cruise speeds, adaptive materials for noise and vibration damping of engines to avoid induction of vibrations into the ship hull, and adaptive outfitting materials that improve ships' serviceability and safety.

The HILDA (2012-2015) project sought to develop a friction stir welding (FSW) technique which would be suitable for the grades of steel used in the shipbuilding industry. This type of welding would allow for the production of lighter ship structures and therefore reduce overall energy consumption of the vessel. FSW is widely used in aluminium construction for the aerospace and rail sector and the overall objective of this project was to transfer this welding technology to steel for shipbuilding.

The LEAF (2012-2015) project was set up to develop and demonstrate a new antifouling technology that was not based on biocide release or low adhesion. The colonisation of a ship's hull by marine organisms is termed biofouling. So-called hard foulers, such as barnacles, are of particular concern as they can increase resistance on a ship, resulting in up to 40% increased fuel consumption. Researchers worked on a new approach in which the antifouling effect occurs when the barnacles establish themselves and start the process of penetrating the paint. The biocide is only needed in low concentrations, and the coating in which it is held can last for years.

The partners within the MOSAIC (2012-2015) project aimed to replace conventional steel with other materials to minimise the susceptibility to cracking and to reduce the weight of the structure. Project partners introduced high-strength low-alloy (HSLA) steels and composite materials to replace specific structural parts of steel ships. HSLA steels with better mechanical properties and resistance to corrosion are targeted for large structural components in areas of stress concentration. Lightweight composites with resistance to corrosion are envisioned to replace piping or other non-critical parts. The lightweight composites will help to reduce energy consumption of the ship and hence reduce carbon emissions.

The main objective of the FIBRESHIP (2017-2020) project was to create a new EU-market to build complete large ships (over 50m length) in fibre reinforced polymers (FRP) enabling the large-scale uptake of this material. The project will also analyse the life cycle cost benefits of incorporating FRP materials in large ships, developing a business plan for the different actors in the value chain. The business plan will cover the different phases of the life cycle from design, engineering, material production and shipbuilding to the final dismantling of the vessel. The use of FRP materials in large-length ships can result in significant weight reduction (about 30%) and a relevant impact in fuel saving, ship stability, environmental impact, reducing GHG emissions and underwater noise, and increase of cargo capacity. FRP materials are also immune to corrosion and have a better performance under fatigue type loads, which means better life performance and reduced maintenance costs.

The COMPA 2GO (2018-2020) project is aimed at commercialising the service of COMPA repair, a composite repair and reinforcement system for ships, for damaged or corroded ship pipes and structures. Whilst COMPA 2GO is not completely finished to date, the project is included in this assessment as on-board vessel demonstrators are planned, and therefore the project partners are showing technological advancements in the waterborne transport sector. As a follow up on the completed SME Instrument Phase 1 project, the specific Phase 2 project objectives were to:

- complete the development of the COMPA repair service in terms of the design and the procedure by successfully completing specimen tests and on-board vessel demonstrations;
- demonstrate the quality of the solution and gain quality approval of COMPA application standards from relevant maritime certification organisations;
- develop a promotion and sales plan and establish a network of repair application partners for licensing the technology while ensuring intellectual property rights protection and quality management.

6.1.3 Achievements

A set of 15 smart design solutions was developed during the ADAM4EVE project. These solutions help to provide optimised properties of ship hulls and outfitting systems at varying conditions. Five of the prototypes were built in model or large scale, and assessed in terms of technical properties, safety issues, and economic and ecological impact. Each of the prototypes was designed for a specific vessel type and a particular operation scenario. However, the assessments revealed a potential for a broad range of applications. The prototypes included a retractable stern flap to save fuel on ships, lightweight panels with integrated material for storage of latent heat to reduce energy consumption on reefer vessels, and an adaptive bulbous bow that saves energy on inland waterways ships. The retractable stern flap enables a yearly fuel saving of around 5.6%, which directly results in a reduced total global warming potential of around 5.5%.

Project outcomes from HILDA included a developed and validated system with accompanying software for using FSW in industrial settings. Shipyards can use the system to optimise ship construction in line with accuracy requirements. The opportunities for cost reduction, safety improvement and enhanced weld properties that friction stir welding should provide were also identified. Potential disadvantages were also noted, namely tooling-related issues that emerged during the project that need to be addressed in the future. HILDA demonstrated the feasibility of FSW as an innovative joining technique for steel panels and components. With some further improvements, the technology will be brought closer to industrial application.

Project partners within the LEAF project developed new methods for measuring biocide leaching rates and characterising antifouling paint formulations. Field testing of different LEAF formulations was carried out in widely different fouling conditions in the North Atlantic, English Channel, Mediterranean and Brazilian coastal waters. A sustainability assessment of the LEAF coatings was also conducted. This included life cycle analysis comparing traditional copper-based solutions with the system developed by LEAF, as well as ecotoxicology and human safety aspects for LEAF's proposed solution. The effectiveness of LEAF, even with water-based paints, will remove the need for solvents and reduce emissions of VOCs. The LEAF concept can also be developed further for other fields of application where fouling is a problem, such as the renewable marine energy and aquaculture sectors.

Researchers within the MOSAIC project fully tested and characterised composite materials, qualified welding methods between different steels and studied an innovative technique for welding HSLA steels with conventional steel. They also performed fatigue crack growth, fracture toughness and corrosion tests on various welded steels using three different welding methods. Fewer defects will lead to an increase in safety. Lighter marine structures also result in lower fuel consumption, leading to both cost and environmental benefits in terms of reduced emissions. In all, MOSAIC should reduce the lifetime costs associated with production, operation and maintenance of large merchant ships.

Current state-of-the-art regarding the use of composite materials is limited to vessels below 500 gross-tonnes weight, as stated in IMO 'Safety of life at sea' (SOLAS) rules. At the end of the first period of the FIBRESHIP project experimental results and numerical simulations have been performed (and validated) for two selected composite materials. A validated design of a fishing research vessel in composite material has also been produced; a section of this design has been built in FRP as a demonstrator of the project.

eCOMPA Repairs software was developed through the COMPA 2GO project with key functionalities and reporting ability. The technology was presented with a purpose to arrange on board demonstrations, and the application for COMPA Repairs trademark was submitted. Main communication tools were created and ISO 9001: 2015 certificate for quality management was achieved. There are new health and safety procedures introduced to the COMPA Repairs. These procedures include measuring poisonous and flammable gases, and higher standards for the personal protection equipment. Additional obligatory equipment includes head lights, safety vests and the vests to prevent falls from elevated positions. eCOMPA can suggest the optimum patch design for a specific repair and can generate the report and the quotation automatically.

6.1.4 Implications for future research

There is a strong focus on using composite materials for conventionally fuelled ships to make fuel savings (ADAM4EVE, MOSAIC). Whilst minor fuel savings will come with reduced vessel weight, in order for the maritime sector to reduce the ambitious 40% reduction in average carbon intensity per tonne mile by 2030 (compared to 2008, as stated in the Green Deal (European Commission, 2019b)). future research could be focused more on joint implementation of composite materials with alternatively-fuelled vessels.

The LEAF project found that so-called hard foulers, such as barnacles, can result in up to 70% increased fuel consumption. They identified that a reduction in ship resistance will be essential in paving the way for alternatively fuelled vessels, as the new fuel source may not have the same energy density as conventional fuels, and so every increase in efficiency is beneficial. The technology was demonstrated in a variety of field tests and future research should now focus on the wide-scale uptake of this technology such that it could be applied to the whole fleet.

A direct outcome from the HILDA project found that there were disadvantages from using the friction stir welding technology, which included tooling-related issues. If the technology is to be implemented on a large scale, these tooling-related issues would need to be investigated and mitigated accordingly. This could be explored through future research, and an assessment of the cost reduction should be updated to include the mitigations.

6.1.5 Implications for future policy development

Current IMO SOLAS rules state that the use of composite materials is limited to vessels below 500 gross-tonnes weight. After the technology in the FIBRESHIP project has been successfully developed further to reach higher development phases (i.e. implementation), the IMO SOLAS rules should be revised to allow for larger vessels to be built from these composite materials, as these large vessels have the potential to save more fuel from using lightweight materials as weight is such a large component in fuel consumption of the much larger vessels. This will need to be implemented soon, given the average age of a seagoing ship is over 20 years[26], and as such new improvements will need to be implemented in the near future to have the biggest impact.

[26]https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf

6.2 Sub-theme 2 – Power and propulsion

Table 10: Funding level per programme for power and propulsion

Funding action	Number projects	Total funding	EU contribution
FP7	18	€ 118,284,541	€ 75,170,686
H2020	25	€ 120,380,329	€ 88,577,092
Total	**43**	**€ 238,664,870**	**€ 163,747,778**

Source: TRIMIS

6.2.1 Overall direction of R&I

Projects under the power and propulsion sub theme focus on topic areas such as wind assisted propulsion, increases in engine efficiency and recycling of waste heat for use elsewhere in the vessel. All of the technologies in this sub-theme relate to reducing the overall energy consumption of the vessel either directly or indirectly. Improving engine efficiency will increase the energy obtained from the fuel used, and therefore will reduce the total volume of fuel required to perform the same operations.

Auxiliary systems, such as heating and cooling of the cabin, are traditionally powered using the same fossil-fuel source as the engine which increases the overall vessel's energy consumption. By using the waste heat from the engine to power the auxiliary system, fuel is saved and therefore GHG emissions are reduced.

Table 11: shows the selected projects under the power and propulsion sub-theme, along with the corresponding funding programmes and key themes. Projects under this sub-theme cover a variety of technologies and are all funded by H2020 programmes. Projects funded under FP7 programmes have been identified under the power and propulsion sub theme; however, the research undertaken through the H2020 programme has now exceeded the developments through the FP7 programme. Therefore, H2020 projects have been selected for more detailed discussion as presented below.

Table 11: Selected Power and Propulsion projects and key themes

Project acronym	Funding programme	Key themes
RotorDEMO	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Wind assisted propulsion
GFF	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Fully electric ferry
EEECSM-2	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Waste heat to energy
LeanShips	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Increased engine efficiency, emissions abatement technologies
HERCULES-2	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Increased engine efficiency, fuel-flexible engines

Source: TRIMIS

6.2.2 R&I activities

RotorDEMO (2017-2018) was a project to showcase the Norsepower technology in a real-life installation at sea over a 12-month period. This a system of mechanical sails which harness the wind to provide auxiliary propulsion for ships. Under the RotorDEMO project the technology was installed on a cruise ship to carry out a full-scale demonstration and gather information about its performance. The initial target was to save 300 tonnes of fuel per year. The global long-term market potential for the technology is 20,000 vessels and €30 billion.

The GFF (Green Fast Ferry) (2016-2018) project had objectives to engineer, validate and demonstrate the GFF with potential customers and prepare the ferry for commercialisation. Specifically, the GFF prototype, already tested at full scale during the BB Green FP7 project, was to be demonstrated through logged endurance tests, over 500 hours of operation, to obtain the technical documentation and engineer the components and manufacturing. The GFF is a fully-electric, high speed passenger craft, which aimed to be the only zero emission ferry on the market to meet performances of high speed diesel commuters: 30 knots (55 km/h) speed, large autonomy (26 km routes in 30 min) and fast recharge in port of less than 20 minutes.

Project partners within the EEECSM-2 (2016-2018) project (company name COOL4SEA[27]) aimed to reuse the waste heat generated by ships to power heating and cooling systems, and to investigate the optimisation of the circulation of energy on-board sea vessels. By using the waste heat generated by ships, the technology reduces the need to burn fuel oil, therefore reducing both cost and carbon emissions. The technology harnesses its energy from excess energy potential generated from other ship power processes, for example waste heat in the cooling water generated by the ships main and auxiliary engines, to create the electricity needed for the heating and air conditioning systems. This removes the need for fossil fuels otherwise needed to power and maintain operation of conventional cooling systems. The technology is expected to save a typical freighter around 340 tonnes of fuel oil per year, giving a reduction in carbon dioxide emissions of around 1,200 tonnes per year.

The project LeanShips (2015-2019) had an overall goal to develop and demonstrate green technologies, building upon research work carried out in previous projects. The idea behind this was that the missing link between green technology availability and large-scale market uptake is real-world evidence on green technology reliability, impact on energy use and on emissions, both carbon emissions and air pollutants, and

[27] https://www.cool4sea.com/

the economic gains to compensate for the necessary investments. Therefore, the project partners aimed to develop seven demonstrators, for which teams of mainly industrial partners, each with an end-user (i.e. ship operator) in the team, would demonstrate green innovative technologies. The technologies selected were TRL3-4 (and higher), with the aim being to raise these up to demonstration level (TRL5-7).

The project HERCULES-2 (2015-2018) was the outcome of the joint vision by the two major European engine maker groups, MAN and WARTSILA, to develop new technologies for marine engines, with general aims to increase engine efficiency, therefore reduce fuel consumption and CO_2 emissions, reduce gaseous and particulate emissions, and increase engine reliability. More specific objectives of the project included improvements to the fuel flexibility of engines and to achieve near-zero emissions for large marine engines, and the development of advanced after-treatment technologies to abate air pollutants (NO_x and PM). Three consecutive projects, namely HERCULES - A, -B, -C, spanned the years 2004-2014, funded under FP7, and form the basis of the HERCULES-2 project.

6.2.3 Achievements

During the first year of operation, a measurement campaign was conducted to confirm the long-term fuel saving potential of the RotorDEMO project. The work of three independent research parties, ABB, Chalmers University, and NAPA was complemented with Norsepower's own force measurement analysis. It was confirmed that the Rotor Sail reduces power consumption by between 207 kW and 315 kW, equating to 231 to 315 tonnes of fuel every year well in line with original target of the project[28]. This fuel saving is equivalent to a reduction in carbon emissions of around 900 tonnes per year, and the technology is applicable to full-scale RoPax (roll-on/roll-off passenger) vessels. The same technology would be expected to be applicable to several other vessel types, although there would be some exceptions (container ships, for example) due to insufficient deck space or constraints due to cargo. The impacts on the power required from the ship's engines may be different for other vessels types.

The GFF project has met its key objectives, with a technical ship specification ready to be sent to any potential customer along with a price and a selected shipyard. A wide variety of dissemination activities has also been undertaken, with speeches at 25 conferences, references in 354 articles worldwide and a large number of real-world demo tours with potential customers. At the end of the project there were also two concrete offers received for commercial opportunities. The battery pack was tested in use between 5% and 95% state of charge, and the voltage spread was 0.6% despite the cell balance function being deactivated the majority of the time. This low voltage spread will result in slower battery degradation over time.

The EEECSM-2 project has resulted in two demonstration projects. The first was a small pilot unit installed on-board a hybrid ferry, which now operates as the main cooling system. This is supplemented by the existing compressor-driven cooling unit during peak loads. The data obtained from this demonstrator was used for the development of the second, full-scale pilot deployed on-board a large oil tanker. This second demonstrator was the last project before entering the market. The EEECSM-2 (COOL4SEA) technology is now available in two standard models, to account for higher powered vessels, and the technology reduces operating expenses for cooling by up to 94%.

As stated previously, the LeanShips project consisted of multiple technology demonstrators. A specific example was the conversion of a diesel engine to a dual-fuel engine with methanol. The engine was installed with multiple sensors to collect test data for emissions and efficiency. The results showed energy savings of 12%, and subsequent carbon emission savings of 14%, due to an increase in efficiency and the use of dual fuel with methanol. Other pollutant savings included 60% NO_x reduction, 70% reduction in emissions of SO_x and 77% reduction in PM. Another demonstrator investigated the impact on energy efficiency due to the reconfiguration of space layouts and structural configurations to achieve optimal trade-off between weight, performance and payload. The results from this demonstrator found fuel savings, and consequent carbon reduction, of around 7%.

[28] https://www.norsepower.com/cruise-ferry/

From the HERCULES-2 project, a fuel-flexible injection system was manufactured and tested with various fuels in a prototype injection test rig. The ignition and combustion properties of alternative fuels were examined in simulations, at several experimental facilities and also on full-scale engines. A novel engine control system for maximum flexibility for alternative fuels has also been developed. Control strategies of knock margin were implemented, and the full-scale engine tested for retaining engine 'as new' performance using optimised engine control. A multivariable controller was designed and tested in a hybrid diesel-electric powertrain. Work also included the design, manufacturing and testing of a prototype adaptive, fully flexible lubrication system resulting in a 15% reduction in lubricant consumption. Combined diesel particulate filters and selective catalytic reduction catalysts were developed and achieved NO_x conversions from 87% to 100%, with particulate number reduction above 90%.

6.2.4 Implications for future research

The results of the RotorDEMO, LeanShips and HERCULES-2 have shown reductions in fuel consumptions. All of these projects are focused on different technologies, which could be combined onto a single vessel to demonstrate the synergies obtained. As each technology provides minor improvements to fuel consumption, future research could address how to combine these onto a single demonstrator vessel to see how the technologies complement each other and see a combined fuel reduction. This would allow for a much larger combined reduction in GHG emissions compared to a conventional vessel, allowing the industry to see a larger benefit of a multitude of technologies at once.

The RotorDEMO project has shown that wind assisted propulsion can save 231 to 315 tonnes of fuel per year, which is equivalent to €250,000 to €350,000 per year, based on weighted average diesel prices in Europe[29]. A full cost-benefit analysis should be conducted into this technology, which should also account for the carbon savings from the reduction in fuel consumption. This would give both operators and authorities information on how to quantify the benefits on the technology.

6.2.5 Implications for future policy development

The EEECSM-2 project demonstrated the technology for both a small-scale pilot as well as a full-scale pilot on a large oil tanker. The technology is now readily available and reduces the operating expenses for cooling by up to 94%. Future policy could be introduced to ensure that the EEECSM-2 technology, amongst others, is readily available for the shipbuilders and that standards are developed such that these beneficial technologies are implemented at scale.

When assessing the price of the technology, careful consideration must go to the carbon savings of the technology. The tax on the technologies could be adjusted to reflect the carbon savings, with a price per tonne of carbon used to calculate the true benefits of the technology to society. This could also include savings due to reductions in pollutants affecting air quality (NO_x, SO_x and PM). This would incentivise operators to adapt these technologies quicker, with perhaps increasing the tax on the technologies further down the line.

The GFF project has successfully demonstrated a fully electric passenger ferry, which has subsequently seen commercial offers for the technology. This is in line with the Green Deal's objective (European Commission, 2019b) to promote disruptive technologies and the Strategic Research & Innovation agenda (SRIA)[30] for Zero-Emission Waterborne Transport's objective to demonstrate zero-emission solutions by 2030. Future policy could help promote the transition of the GFF technology to other forms of inland waterways vessels, as it has now been demonstrated for a high-speed passenger ferry.

[29] European Commission, Weekly Oil Bulletin, 2020f. Available at:
https://ec.europa.eu/energy/observatory/reports/latest_prices_with_taxes.pdf

[30] https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf

6.3 Sub-theme 3 – Fuels and alternative energy sources

Table 12: Funding level per programme for fuels and alternative energy sources

Funding action	Number projects	Total funding	EU contribution
FP7	9	€ 61,064,068	€ 36,201,553
H2020	28	€ 135,168,235	€ 108,160,707
Total	**37**	**€ 196,232,303**	**€ 144,362,260**

Source: TRIMIS

6.3.1 Overall direction of R&I

Current research projects under the fuels and alternative energy sources relate to the use of electrification (batteries, hybrid systems), hydrogen as a fuel, and natural gas/LPG as a fuel. The benefits of alternative fuels in terms of decarbonisation are clear; reducing the carbon content of the fuel or eliminating the tailpipe emissions, both reduce the overall GHG emissions of the vessels. However, methane leakage throughout the fuel supply chain might partially outweigh GHG emissions and requires further research (Ortega et al., 2019). Moreover, the environmental benefits of alternative fuels with respect to non-regulated pollutants are not clear, and future research should address potential issues (Ortega et al., 2020). For instance, in some cases the use of biodiesel can lead to emissions of exanaldehyde, a non-regulated pollutant that is not emitted when conventional diesel is used.

Hydrogen and battery vessel emissions will depend directly on the upstream, carbon content of producing the fuel/energy, emissions in generating the electricity or producing the hydrogen. As such, there are research projects investigating the use of battery vessels which used 100% renewable electricity.

Table 13 shows the selected projects under the fuels and alternative energy sub-theme, along with the corresponding funding programmes and key themes. Projects under this sub-theme cover a variety of technologies and are funded by both FP7 and H2020 programmes.

Table 13: Selected Fuels and alternative energy projects and key themes

Project acronym	Funding programme	Key themes
BB Green	FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	Vessel electrification; reduced hull resistance
PURE	FP7-JTI - Specific Programme "Cooperation": Joint Technology Initiatives	Fuel-cell auxiliary power unit
E-ferry	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Fully-electric ferry
MARANDA	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Hybrid fuel-cell powertrain system
HyMethShip	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Hydrogen-methanol propulsion system

Source: TRIMIS

6.3.2 R&I activities

The project BB GREEN (2011-2015) was aimed at developing and proving the feasibility of a new, innovative and competitive waterborne transport solution incorporating electrification. The new vessel type was planned to run entirely on renewable energy, stored in an on-board battery. The vessel was targeted to be able to operate at over 30 knots (55 km/h) speed. In addition to the electrification of the propulsion system, the project also targeted a reduction in hull resistance, and planned to build a 20 metre BB GREEN prototype for full scale documentation under real conditions.

The project partners within the PURE (2013-2016) project aimed to develop an auxiliary power unit (APU) for recreational yachts based on fuel cell systems. The main objective of the project was to create a system fuelled by propane/LPG which is then converted into a hydrogen rich stream and subsequently fed into a PEM stack. The system delivers electrical power which is sufficient to cover the 'hotel power', power demand from heating/cooling, etc., demands of a small yacht. The final results of the project were two working prototypes of the PURE system, demonstrated under laboratory conditions and in a real ship.

E-ferry (2015-2019) was a project involving the design, build and demonstration of a fully electric powered passenger ferry. The E-ferry was to be based on a newly developed, energy efficient design concept, including an optimised hull and propulsion system, a high-energy battery pack, and the use of weight-reducing modules and components. The technology was to be demonstrated in full-scale operation over greater distances than any previous electric ferries, over five nautical miles, within the Danish part of the Baltic sea. Compared to similar conventional vessels, the E-ferry was expected to reduce annual vessel-level $CO2$ emissions by 2,000 tonnes, 41,500 kg NOx, 1,350 kg $SO2$ and 2,500 kg PM.

The following two H2020 projects MARANDA (2017-2021) and HyMethShip (2018-2021) have not yet been fully completed. However, they have been included in this project assessment due to the large project values (€3.7 million – €9.4 million) and the innovative alternative fuel technologies investigated. MARANDA is a currently on-going project with the overall goal to develop a hydrogen fuelled proton exchange membrane fuel cell hybrid powertrain system for maritime applications with powertrain power of around 165 kW. The technology was to be validated in bench testing as well as on board a research vessel. There was an emphasis on air filtration systems and the development of hydrogen ejector solutions for both efficiency and durability reasons. In addition to the vessel developments, a mobile hydrogen storage container refillable in any 350 bar hydrogen refuelling station was to be developed, hence increasing hydrogen availability to the marine sector. The fuel cell system was to be tested in arctic conditions, as well as going through long-term durability testing, around 6 months or 4,380 operating hours.

The HyMethShip is aimed at developing a hydrogen-methanol ship propulsion system using on-board pre-combustion carbon capture. The concept includes on-board methanol storage with an on-board reformer which innovatively combine methanol steam reforming and hydrogen separation in a membrane reactor with a CO_2 capture system and a hydrogen-fuel combustion engine in one integrated system. The system is to be developed, validated, and demonstrated on shore with a typical engine for marine applications in the range of 2MW, with the technology to be developed to TRL6. The ambitious target is of reducing GHG emissions by more than 97%, compared to conventional fuels, and almost completely eliminating SOx and PM emissions. The energy efficiency of the ship is aimed at being more than 45% better than the best available technology, renewable methanol as a fuel coupled with post-combustion carbon capture.

6.3.3 Achievements

A reduction in hull resistance of around 40% has been achieved through the BB GREEN project. This has been documented at both model scale and full scale. The planned 20m prototype has also been developed, which includes a permanent magnet battery electric driveline that has been installed and proven at full scale. The battery developed and installed in the prototype was based on lithium titanite chemistry, with a 200 kWh installed capacity. The battery can accept fast charging, in around 20 minutes, and has a life expectancy of over 20,000 cycles.

The APU developed in the PURE project was tested under various conditions, and it has been operated for up to around 800 hours with multiple start and stops and different power levels. No degradation was observed over the testing period. The system can achieve a run time of 1000 hours with 100 stop/start cycles, reaching the initial targets of the project. The PURE system is able to run under nominal conditions of 500W and modulations in power of 80% (100W) are possible. It showed around 25% system efficiency, compared to engines of the same power class with typical efficiencies of 12% (500W) to 15% (1000W). The PURE system has approximately doubled the efficiency with additional benefits of low noise and no smells.

The E-ferry project partners have developed a full-scale electric ferry capable of carrying between 147 and 196 passengers. The E-ferry was equipped with a range of lightweight materials, anchor and mooring winches. The main contribution to weight reduction, however, was a state-of-the-art electric propulsion system which was based on a DC/DC (direct current to direct current) converter such that heavy AC/DC (alternative current to direct current) converters could be placed on-shore instead of on-board the vessel. This saved considerable weight on-board the vessel and allowed for extended operation time. The ferry has been equipped with a 4.3 MWh nickel manganese cobalt battery, the largest ferry battery capacity seen to date. This has the capacity to travel 20 nautical miles on a single charge. A high-powered charger (two 2MW chargers) was also developed, the first high power DC charger of its kind, allowing for charge times of 15 to 20 minutes.

During the first 30 months of the MARANDA project, the work has been focused on developing and validating the technical solutions and preparing for the validation stage. In stack durability measurements, significant improvements have been achieved with latest generation membrane electrode assemblies (MEA). When a slightly accelerated test cycle (compared to expected marine conditions) was used for the PowerCell S3 stack with MEA B for 2500 hours, the average degradation rate was -2.6 µV/h, while the project target is -4.6 µV/h. All 455-cell S3 stacks have been delivered by PowerCell Sweden to project partner Swiss Hydrogen with factory acceptance test documentation. The first 82.5 kW (AC) system has been delivered to VTT by Swiss Hydrogen. This system has been integrated in the container and is ready to be shipped to the durability test site.

Results from the first period of the HyMethShip included a membrane reactor concept design (and subsequently a more detailed design of the reactor) that was intended to withstand the demanding process conditions and supports the functionality of the membrane. A carbon capture process has also been designed that relies solely on waste heat from the engine exhaust and enables the control of GHG emissions. A spark ignition engine combustion system that operates with pure hydrogen produced in the reformer has been developed, thus avoiding the combustion of fossil fuels, providing the methanol fuel was produced sustainably. NO_x emission levels have been achieved below the limits for ECAS. Efficiency projections for the medium-speed engine are close to 48%. Further improvements are expected with hydrogen direct injection; these will be evaluated in the second reporting period.

6.3.4 Implications for future research

The projects E-ferry and BB GREEN explored the use of battery technology for vessels. However, each project used a different battery chemistry. Future research could be conducted into the benefits and disadvantages of different battery chemistries for different maritime applications (including trade-offs between charge rate, energy density and cost), to assist new vessel designs. This would encourage a greater adoption of battery electric propulsion technology for appropriate vessels and align with the objective of the SRIA for Zero-Emission Waterborne Transport[31] to develop and demonstrate before 2030 solutions for the integration of high-capacity batteries solutions as single energy source for short distance shipping, up to 150 to 200 nautical miles.

The HyMethShip is focused on the development of a hydrogen-methanol propulsion system, including on-board carbon capture. The technology uses a combustion engine, similar to conventional fossil fuel engines. Future research could be undertaken to assess the feasibility of developing this technology as a retrofit device for existing vessels; this would help to reduce the cost to shipbuilders/operators and therefore increase the uptake rate of this technology. If a retrofit device is not possible for this technology, then the results from HyMethShip should be compared with those from the MARANDA project, which uses a fuel cell system rather than a hydrogen combustion engine. Fuel cells are more efficient than combustion engines, and so consideration must be given towards future hydrogen vessel development as to which technology is optimal for the maritime sector. Retrofitting current vessels is a key theme within the Draft Proposal for a European Partnership under Horizon Europe Zero-Emission Waterborne Transport paper as a short-term solution for decarbonising waterborne transport[32].

As noted above, there is currently considerable interest in the waterborne transport sector in future alternative fuels for decarbonisation; however, there is currently no clear prioritisation of particular options (LNG, methanol, ammonia[33], drop-in biofuels/e-fuels). The analysis performed for this report has not identified any significant levels of research into these different alternative fuels. Future research of alternative liquid fuels for long-distance maritime shipping, considering the options for scaling up of production as well as their using in ship engines, would be beneficial.

6.3.5 Implications for future policy development

The biggest impacts on decarbonisation for the waterborne transport sector are likely to come from the use of alternative fuels, this is because fuels such as electricity from renewable sources or hydrogen from electrolysis, using electricity from renewable sources, can offer a pathway to net zero for the waterborne industry. Therefore, priority for future policy development could have a focus on increasing the uptake of these alternative fuels to help achieve decarbonisation targets of the industry. The Proposal for a European Partnership under Horizon Europe Zero-Emission Waterborne[34] Transport paper states that radical change is required to meet the 2050 climate targets, as well as the 50-55% reduction of emissions by 2030 in line with the European Green Deal. (European Commission, 2019b) This will not be possible through incremental improvements alone and therefore will require a greater emphasis on the alternative fuels to achieve decarbonisation of the waterborne transport sector.

[31] https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf

[32] https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/european_partnership_for_zero-emission_waterborne_transport.pdf

[33] The H2020 project ShipFC is developing, piloting and replicating a modular 2MW fuel cell technology using ammonia as fuel

[34] https://ec.europa.eu/info/sites/info/files/research_and_innovation/funding/documents/european_partnership_for_zero-emission_waterborne_transport.pdf

6.4 Sub-theme 4 – Operational measures

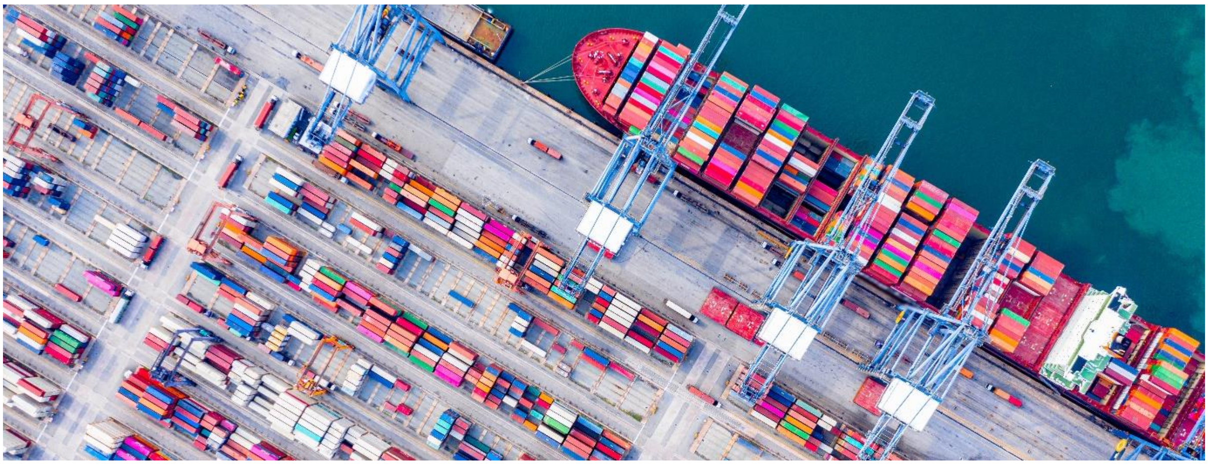


Table 14: Funding level per programme for operational measures

Funding action	Number projects	Total funding	EU contribution
FP7	7	€ 26,864,788	€ 19,043,371
H2020	15	€ 70,130,913	€ 60,996,930
Total	**22**	**€ 96,995,701**	**€ 80,040,301**

Source: TRIMIS

6.4.1 Overall direction of R&I

Projects under the operational measures sub theme address topics such as improved vessel navigation, vessel allocation systems and robotic container handling systems. These operational measures can have potential to increase efficiency and therefore reduce overall fuel consumption. This can have a benefit in reducing GHG emissions from maritime operations.

Table 15 shows the selected projects under the operational sub-theme, along with the corresponding funding programmes and key themes. Projects under this sub-theme cover a variety of key themes and are all funded by H2020 programmes. Projects funded under FP7 programmes have been identified under the operational sub theme; however, the research undertaken through the H2020 programme has now exceeded the developments through the FP7 programme. Therefore, H2020 projects have been selected for more detailed discussion as presented below.

Table 15: Selected Operational projects and key themes

Project acronym	Funding programme	Key themes
RCMS	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Robotic container management system
CLOUD-VAS	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Cloud-based vessel allocation
LOGIMATIC	H2020-EU.2.1. - H2020: INDUSTRIAL LEADERSHIP - Leadership in enabling and industrial technologies	GNSS; route planning
SHIPLYS	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Virtual prototyping, life-cycle assessment
H2H	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Safe vessel navigation
AUTOSHIP	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Autonomous vessels

Source: TRIMIS

6.4.2 R&I activities

The objectives of the RCMS (2015-2017) project were focused on the development of a robotic container management system, which will improve the automation of container handling at ports and make the process more efficient. Specific objectives included the development of a simulation model for RCMS to be evaluated in two terminals (Gdansk and Koper), assessment of RCMS performance against current state-of-the-art technologies at the same two ports, and to assess the impact of RCMS in a simulated transport network in terms of efficiency, reliability, capacity, performance indicators such as travel times, speed etc., and impacts as noise and air pollution.

CLOUD-VAS (2015-2017) was a research project which looked at a cloud-based vessel allocation decision support tool that is widely accessible to large ship owners. The technology helps ship owners make quick decisions on which vessels to charter, which can save chartering costs and fuel consumption and consequently lower CO_2 emissions. The project aimed to provide a flexible and affordable optimisation platform that enables ship owners to minimise operational costs and fuel consumption.

Project partners within the LOGIMATIC (2016-2019) aimed to develop and demonstrate innovative location and navigation solutions for the automation of the operation of straddle carriers in container terminals. Specific project objectives included the development of an advanced automotive navigation solution based on the integration of GNSS and sensors on-board straddle carrier vehicles, implementation of a geographic information system (GIS) based control module compatible with existing terminal operating systems (TOS) for optimised global yard level route planning and fleet management. The solutions were to be integrated, validated and demonstrated in a real port yard.

SHIPLYS (2016-2019) was targeted towards shipyards who need to improve their capability to reduce the cycle time and costs of design and production, to be able to reliably produce better ship concepts through virtual prototyping and to meet the increasing requirements for life cycle cost analysis (LCCA), environmental assessments, risk assessments and end-of-life considerations as differentiators. Specific project objectives included the development of functionality for rapid early design prototyping, rapid production simulation, analysing performance (based on LCCA, environmental sustainability, and risk assessment), and integrating software applications using the SHIPLYS software platform.

The H2H (2017-2020) project was focused on addressing the need for maritime vessels to navigate safely in close proximity of other vessels and objects, both stationary and moving. The project is not finished to date; however, it has shown promising preliminary results in an innovative area. The technology was aimed at assisting navigators in making correct decisions but is also a fundamental condition for autonomous vessels. The project included implementation of a pilot sensor package, to be demonstrated in Norway (NO) for simultaneous operation, in the Netherlands (NL) in relation to auto-mooring operation and Belgium (BE) linked to inland waterways operations.

AUTOSHIP (2019-2022) is a large ongoing project with total EU funding contribution of over €20 million. AUTOSHIP will build and operate two vessels and their needed shore control and operation infrastructure to TRL7. The overall objective is to speed up the next generation of autonomous ships, by demonstrating autonomous vessels in real short sea shipping and inland waterways environments. The technology package will include full-autonomous navigation, self-diagnostic, prognostics and operation scheduling, as well as communication technology enabling a prominent level of cyber security and integrating the vessels into an upgraded e-infrastructure.

6.4.3 Achievements

The comparison of the RCMS technology against other state-of-the-art container handling technologies found that the RCMS technology was advantageous over the other technologies for the two specified ports. Progress has also been achieved in terms of system and subsystem design. A document defining the RCMS from the point of view of logical architecture and functionality has been produced. The system and subsystem design documents present the general design of the system and sub systems, explains assumptions and the decision taken in the process and sets the base for further development.

CLOUD-VAS was conceived as a Cloud-Based and a Software as a Service tool, allowing to have a spread use of the software also to small and medium enterprises. CLOUD-VAS was designed to be a simple, user-friendly plug-and-play solution estimating to save up to 75% of the time normally spent by current practice of vessel allocation with commercial mathematical solvers. CLOUD-VAS was also designed to be combined with an additional software that would measures the operational efficiency of chartered vessels during the trips, monitor them and give accurate, detailed reports.

The project team from LOGIMATIC has developed an advanced localisation and navigation solution based on a combination of Europe's GNSS and robotics technologies. Use of global navigation satellite systems and on-board sensors provides a continuous, reliable and accurate estimation of the position and velocity of platforms. The LOGIMATIC innovation is integrated in port vehicles as part of an on-board navigation unit that communicates with a centralised GIS-based monitoring system to supervise and manage a port's entire fleet. Connected to all port vehicles via a wireless network, the system receives the current position of a platform and real-time progress on daily tasks. The technology speeds up tasks, enabling resource and space optimisation, and allows extended and safer operations.

A result from the SHIPLYS project was the development of various software tools to address the different shipyards issues. These scenarios included the optimisation of hybrid propulsion systems used in a short route ferry ship, a support tool for early design stages of new build ships through inputs from risk based LCAs, and a third scenario addressing early planning and costing of ship retrofitting accounting for LCA costs and risk assessments. SHIPLYS tools will provide shipyard end-users the ability to offer such a value-added service during the tendering process for new building or retrofitting jobs.

Whilst the project H2H has not completely finished, some of the results include the definition of pilot system requirements and the requirements for safe and secure communications. A preliminary business plan has been prepared, which will be finalised after the second period of the project is completed. At the end of first reporting period of the project, the results are promising with regard to expected performance. Presentations at different conferences and other fora have shown a great interest in the H2H concept, and it is expected even more interest when actual demonstrations have been completed in the second period.

The two use cases developed by the AUTOSHIP project will be the first ones out of a series of more vessels to be delivered shortly after the project ends and will be used to demonstrate a complete set of key-enabling technologies for autonomous operations. The project partners have produced a report which identifies and maps the existing regulatory framework including the prevailing regulations, rules and standards at international and national level, for the design, building, testing and operating of the short sea shipping and inland waterways use cases considered in the AUTOSHIP project. A document has also been delivered which provides a framework for autonomous ship system development and assessment methods.

6.4.4 Implications for future research

The technology development in the RCMS project has had design documents produced for the different sub-systems. Future research should use these design documents and further demonstrate the technology in a full-scale container handling port. This would allow for data collection from a demonstrator, and subsequently identify the benefits of the technology and any limitations to the technology and how to improve on these limitations.

The natural development from using advanced GNSS and sensors (similar to those developed in the LOGIMATC and H2H projects, amongst other non-waterborne related projects[35]) is the development of autonomous ships. The development of autonomous ships can further improve efficiencies, and therefore reduce wasted fuel and subsequently reduce GHG emissions. Further research should be undertaken to investigate how the technologies developed in projects such as LOGIMATIC interact with autonomous ship technologies. The improvements to shipping efficiency will directly align with the objective to optimise operations as stated in the SRIA for Zero-Emission Waterborne Transport document[36].

Direct further research has been suggested through the AUTOSHIP report on regulations, rules and standards for autonomous ships, including:

- definition and responsibilities of the master, crew and responsible person;
- regulations requiring the presence and actions of human operators on board, manual operations or indication/alarm on the bridge;
- no provisions for compulsory systems, devices and procedures that would facilitate crewless vessel operation as all tasks will not be moved from crew to remote operators, some tasks will be performed by systems on board;
- functions, rights and responsibilities of remote-control centres, including personnel qualification.

6.4.5 Implications for future policy development

The maritime freight sector has to span ports globally, and so interoperability of technologies at the different ports is important. The cloud-based vessel allocation system developed in CLOUD-VAS may be implemented at one particular port, but upon arrival at the port at the other end of the ship's route there may not be the same technology. To fully use navigation technologies at ports, it would be beneficial to have interoperable solutions such that all ships can use the technology. Policy could be developed for all European ports wishing to use technologies such as these, as this would help to create a standard approach to navigation and vessel allocation technologies at ports. This would align directly with the digitalisation policy outlined within the Green Deal. (European Commission, 2019b)

Results from the AUTOSHIP project already have indicated that there is needs for more regulations and provisions to facilitate autonomous ships, particularly around the responsibilities of the crew in emergencies or system failure, and more in general on the safety aspects of autonomous vessels which then could be aligned across all Member States. This would help to ensure the safety of autonomous vessels and therefore increase the uptake of the technology across Europe.

[35] https://www.gsa.europa.eu/gnss-h2020-projects and https://www.gsa.europa.eu/r-d/gnss-project-portfolio

[36] https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf

6.5 Sub-theme 5 – Coordination and support measures

Table 16: Funding level per programme coordination and support measures

Funding action	Number projects	Total funding	EU contribution
FP7	14	€ 61,707,213	€ 44,177,462
H2020	9	€ 57,002,047	€ 37,482,389
Total	**23**	**€ 118,709,260**	**€ 81,659,851**

Source: TRIMIS

6.5.1 Overall direction of R&I

Projects under the coordination and support measures sub-theme are focused on the research coordination and dissemination within the waterborne transport sector, as well as planning and investigating future strategy for the sector, including both vessel and port design. As new technologies become more developed, it becomes increasingly important that the results and benefits of these new technologies are relayed to the stakeholders in the waterborne transport sector. This will help to increase the uptake of new and innovative technologies which are focused on decarbonisation.

Table 17 below shows the selected projects under the coordination and support measures sub-theme, along with the corresponding funding programmes and key themes. Projects under this sub theme cover a variety of key themes and are funded by both FP7 and H2020 programmes.

Table 17: Selected Market-based projects and key themes

Project acronym	Funding programme	Key themes
MESA	FP7-TRANSPORT - Transport (Including Aeronautics) - Horizontal activities for implementation of the transport programme (TPT)	Dissemination of research
VDRConnect	H2020-EU.3.4. - H 2020: Smart, Green and Integrated Transport	Market assessment of technology
Prominent	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Assessment of technology development areas
DocksTheFuture	H2020-EU.3.4. - H2020: Smart, Green and Integrated Transport	Port technology standardisation, dissemination, networking
MarTERA	H2020-EU.3.2. - H2020: SOCIETAL CHALLENGES - Food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bioeconomy	Coordination of technologies

Source: TRIMIS

6.5.2 R&I activities

The project MESA (2013-2016) had the objective to strengthen the effectiveness of the research and innovation capacities of the European maritime industry. This was to be achieved by optimising the European maritime research and development strategies, improvement of the stakeholder network and increasing the dissemination of research results and fostering the definition of the maritime research and innovation policies. The project focused on four thematic areas, including energy efficiency, safety, production, and E-maritime. Within the energy efficiency theme, analysis focused on research projects covering improvements to ship resistance, efficient ship propulsion, auxiliary energy units, solar, wind, seaway energy, and energy management systems; all of which focused on reducing fossil-fuel consumption and reducing GHG emissions.

The project partners through the VDRConnect (2016-2016) aimed to become the leading players in automatic data collection and performance analysis for vessels, by introducing a disruptive low-cost and low-risk telematics system for vessels. The technology presented within this project was to bridge the big data gap in the maritime transport industry by exploiting the full potential of data. If all vessels were equipped with the VDRConnect solution, it is claimed that over 35 million tonnes of carbon emissions would be saved per year, if the entire world's fleet used the technology. The primary goal of the VDRConnect project was to reach out to the market through full-scale demonstration of the technology's benefits.

Project partners within Prominent (2015-2018) aimed to advance innovation in the inland waterways sector by addressing key needs for technology development, as well as the barriers to innovation and decarbonisation of the European inland waterways sector. Specific focused areas included the large-scale transition towards efficient and clean vehicles, certification and monitoring of emission performance and development of innovative regimes, and harmonisation and modernisation of professional qualifications. Targets for the project included the development of cost-effective solutions applicable to 70% of the fleet and a reduction in implementation costs by 30%.

The DocksTheFuture (2018-2020) project was aimed at defining the vision for the ports of the future in 2030, covering all specific issues that could define this concept including dredging, emission reduction, energy transition, electrification, smart grids, port-city interface and the use of renewable energy management. The project consists by definition of actions primarily encompassing accompanying measures such as standardisation, dissemination, awareness-raising and communication, together with networking, coordination or support services, policy dialogues and mutual learning exercises and studies.

MarTERA (2016-2021) is currently ongoing; however, it has been included in the project assessment due to the large project budget (around €26 million) and the progress made to date. The overall project goal is to strengthen the European Research Area in maritime and marine technologies through systematic cooperation in all areas of waterborne transport. These areas consisted of offshore activity, marine resources, maritime security, biotechnologies, offshore oil and gas, hence covering the vast majority of relevant maritime and marine sectors for sustainable development in the waterborne transport sector. The proposing consortium organises and co-fund, together with the EU, a joint call for trans-national research projects on different thematic areas of Blue Growth.

6.5.3 Achievements

The main results of the MESA project were the information and knowledge produced as a result of the four thematic areas technology group. This includes the development of clustered research projects and global state-of-the-art of each technology theme, proposals for research and development roadmaps in each technology theme, reports produced in relation to market, social and regulatory trends to 2030 and several research documents. During FP5, FP6 and FP7 a large number of energy efficiency related topics were supported. Based on the available information from these projects it was concluded that substantial progress has been achieved in a number of individual areas, e.g. in ship resistance and propulsion, and engine technology. Here, European manufacturers and suppliers were identified as among world market leaders and it was concluded that at least part of this success is due to the work performed in European research projects. The developments and resulting products typically address individual solutions, as stand-alone solutions, promise substantial improvements.

During the feasibility study within the VDRConnect project a detailed market investigation for a number of initial markets was performed, with Greece (EL) having the highest market potential with over 4,700 vessels eligible for the telematics solution. It was also observed that there is currently a low, 4%, market penetration for the technology overall, although there is expected to be a 28% compound annual growth rate between 2017 and 2027. Also, a comprehensive regulatory strategy for VDRConnect has been documented, which implementation is ongoing and should be finalised before planned large-scale demonstrations in Phase 2 of the project.

PROMINENT developed e-learning modules concerning vessel stability, energy-efficient navigation and dangerous cargo. In relation to the current developments concerning modernisation and harmonisation of professional qualifications in inland waterways, PROMINENT compared the use of inland waterways ship-handling simulators to real-life situations. An e-Logbook was developed in close cooperation with the EC JRC and tested on-board 10 inland vessels. Standardised solutions for LNG have been prepared for pilot testing, including the cost-benefit analysis for the technologies applicable. The cost-benefit analyses also took account of the potential for engine right-sizing, correctly matching the engine design power to the requirements for the ship operation, and diesel-electric hybrid configurations. Various real-life pilot tests on-board vessels have been conducted during the project; including pilots in the field of energy-efficient navigation, diesel after-treatment, and LNG monitoring.

During the first period of the DocksTheFuture an online stakeholder consultation survey was set up to obtain feedback from the main stakeholders that will be impacted by the project. The results have also produced an analysis of macro trends and perspectives in the maritime sector, with a survey on the most essential macro-trends on a global level developed to obtain the most likely impacts on port of the future. It comprises an analysis economic trends, environmental trends, including energy, society trends, technological trends and governmental and political trends. For each of the thematic areas, the most essential trends have been identified and described to gain a survey about what is expected to happen until 2030.

The MarTERA project has placed emphasis on funding projects that show promise in bringing a product as close to the market as possible. Therefore, priority for funding was given for projects which include at least one industrial participant. MarTERA partners have agreed that the first one of the five priority areas of the scope of the co-funded call is 'Environmentally friendly maritime technologies' to tackle the problem of GHG emissions reduction, implementation of new technologies and fuels. Projects funded under the MarTERA project include high-performance seawater magnesium batteries for marine application (SeaMAg), under which the partners plan to improve the performance of magnesium-seawater batteries in different hydrodynamic conditions by finding the optimum combination of anode material, electrolyte additives and cathode design to achieve longevity of minimum 5 years and a capacity of 25kWh.

6.5.4 Implications for future research

The project PROMINENT had a focus on the use of LNG as a fuel for the inland waterways sector. Whilst LNG does have a lower carbon content than conventional diesel, more focus could be placed on the potential switch from LNG to bio LNG, which can offer a much greater reducing in carbon emissions than regular LNG. Future projects in this area could be more focused on the research and market of bio LNG, and the dissemination of the benefits of bio LNG over diesel, and also benefits over LNG.

The projects MESA and DocksTheFuture both developed trends and expectations of the maritime industry up to the year 2030. Future research projects could extend this time period and look towards 2050 to fit in line with the Green Deal targets to reduce total emissions by 50% in 2050 compared to 2008[37]. It is important to capture the long-term expected market trends such that the long-term decarbonisation targets can be met and adjusted accordingly.

The telematics solution developed within the VDRConnect project currently has a very low uptake across the total fleet within the markets investigated (4%). Further research could be conducted into why this is the case, and if there is a particular technological reason for the low uptake. If so, then the research could investigate how to mitigate this, and therefore if this low uptake could be increased by further developments to the technology.

6.5.5 Implications for future policy development

As mentioned above, projects have focused on looking at market trends to 2030 for the waterborne transport sector. The results of these expected industry/market trends should be reviewed to gain a clear understanding of what the market is expecting up to 2030. This of course will need to take into account the recent impacts of the COVID-19 pandemic and assess if these market changes are likely to subside in the near future, or if they are likely to have a lasting impact on the maritime market. If needed, further policies could be introduced to ensure that the 2030 decarbonisation targets are expected to be met, and that the industry is aware of what needs to be done to reach these targets. There is a risk that the industry expected trends to 2030 are not in line with the current policy targets, as such any discrepancies between the two should be addressed.

As shown through the VDRConnect project, there is currently a low market uptake of the telematics solution for the total fleet within the markets investigated. Whilst this is forecasted to increase, consideration could be given to future maritime policy around the implementation of data-driven telematics solutions by increasing the potential uptake of the technology. This would align with the recent Green Deal policy (European Commission, 2019b) to increase the digitalisation within the transport system as a whole, and aide towards the decarbonisation strategy of the maritime sector.

[37] https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-fuel-eu-maritime#:~:text=It%20seeks%20to%20reduce%20GHG,by%202050%2C%20compared%20to%202008.

7 Analysis of scientific research and patents on waterborne transport decarbonisation

7.1 Analysis of scientific research

The following exercise has as objective to mark the evolution of peer reviewed scientific publications in the area of waterborne transport in the last years, focusing on decarbonisation, and providing also a perspective beyond Europe. For the exercise, the Scopus citation database for scientific research[38] has been used. The analysis was performed in September 2020 and has been limited to journal and conference publications for the period 2010-2019.

The complete list of regular expression (REGEX) used is reported in Annex 3, while Table 18 provides the connection between the sub-themes defined in this report and some of the expressions used.

Table 18: Waterborne transport sub-themes and scientific research terms

Waterborne transport sub-theme	Expressions
Hull design	Hull design, hull structure, hull weight, bulbous bow, hull shape.
Power and propulsion	Engine, power, propulsion.
Fuels and alternative energy sources	Electric, LPG, battery, hybrid, hydrogen, methanol.
Operational measures	Navigation, GNSS, LCA, life cycle, safety, autonomous.
Coordination and support measures	Standardisation, market instrument, regulation, trading market, emission trading.

Source: TRIMIS

These analyses focus on regular expressions, representative[39] of the sub-themes defined in waterborne transport research. When looking at the overall scientific production on this specific topic, an increase of 82% in the total number of scientific publications is evident, from around 3.000 articles in 2010-2012 to 5.600 in 2018-2019. It should be noted though that in the same time span, there has been an increase of publications in the science areas in Scopus considered in this exercise. As a comparison, and with 2010 as a reference, the total number of scientific publications increased by 20% in 2016 and by 40% 2019. Considering this, still, the normalised increase of the overall scientific production on this specific topic in 2019, compared to 2010, results in little more than 30%.

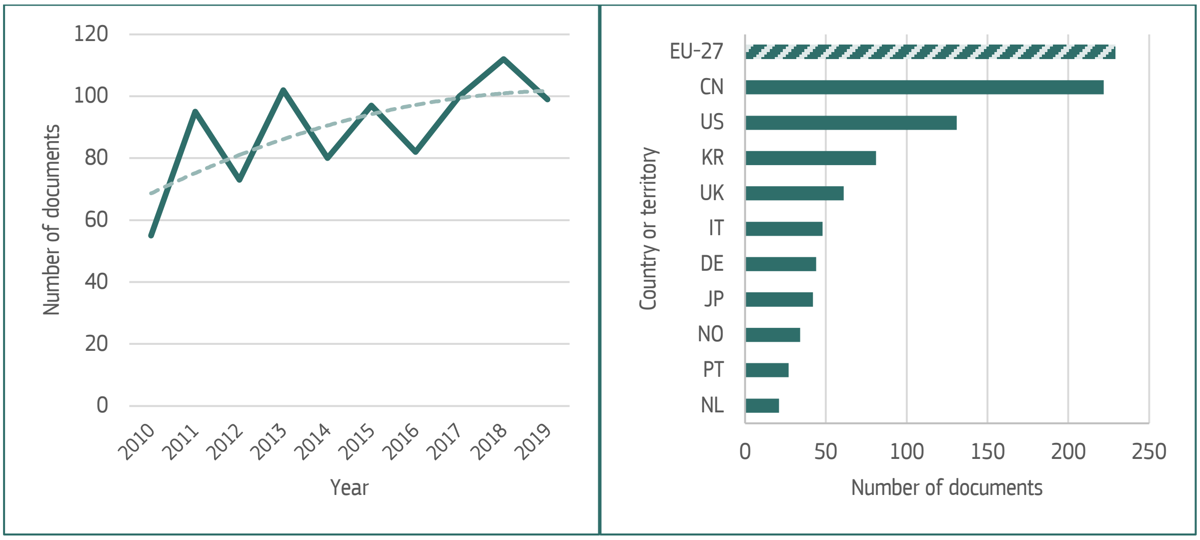
Within this analysis, it is possible to observe that some waterborne transport decarbonisation sub-themes are prevailing. The *power and propulsion sub-theme* is the one with higher number of scientific articles, ranging from 42% (2010-2012) to 38% (2018-2019) of the total articles considered; the scientific articles dealing with *operational subjects* follow, representing 32% and 37% over the total articles in 2010-2012 and 2018-2019 respectively. The articles investigating *fuels and alternative energy sources* issues are around 20% of the total scientific production, not showing any particular change during the ten years considered. The articles considering *coordination and support measures* and *hull design* aspects are relatively lower, accounting for 6% and 2% in 2010-2012 and in 2018-2019 respectively.

The figures below provide the results focusing on number of documents per year and their country of origin. A second order polynomial trend line has been added to the number of documents per year to highlight the trend. In the country of origin figures, the documents that come from the EU-27 countries have been combined in a single bar. In Annex 4 some additional results are shown on the affiliation and funding sponsor.

On the *hull design sub-theme*, as Figure 19 presents, the publication trend is positive, evolving from 55 documents in 2010 to 112 documents in 2018. China (CN) is leading in terms of research outputs, with the US and South Korea (KR) following, while Italy (IT), DE, Norway, Portugal (PT) and the Netherlands are the five EU-27 countries that make it into the top 10.

[38] www.scopus.com
[39] Regular expressions are intended to be representative of each sub-theme but not necessarily exhaustive.

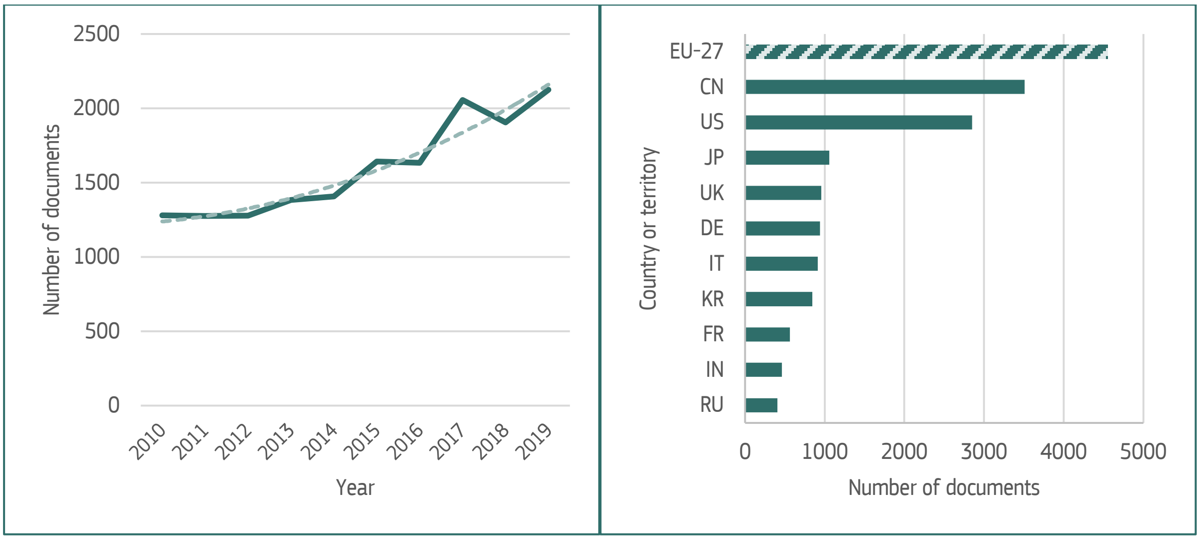
Figure 19: Research documents 2010-2019 (left) and country of origin (right) on hull design



Source: TRIMIS elaborations based on Scopus

The *power and propulsion sub-theme*, as can be seen in Figure 20, identifies a positive trend, passing from around 1280 documents in 2010 and 2012 to 2124 documents in 2019. Also, in this case, China is leading in terms of research outputs, with US and Japan (JP) following, while Germany, Italy and France (FR) are the three EU-27 countries that make it into the top 10.

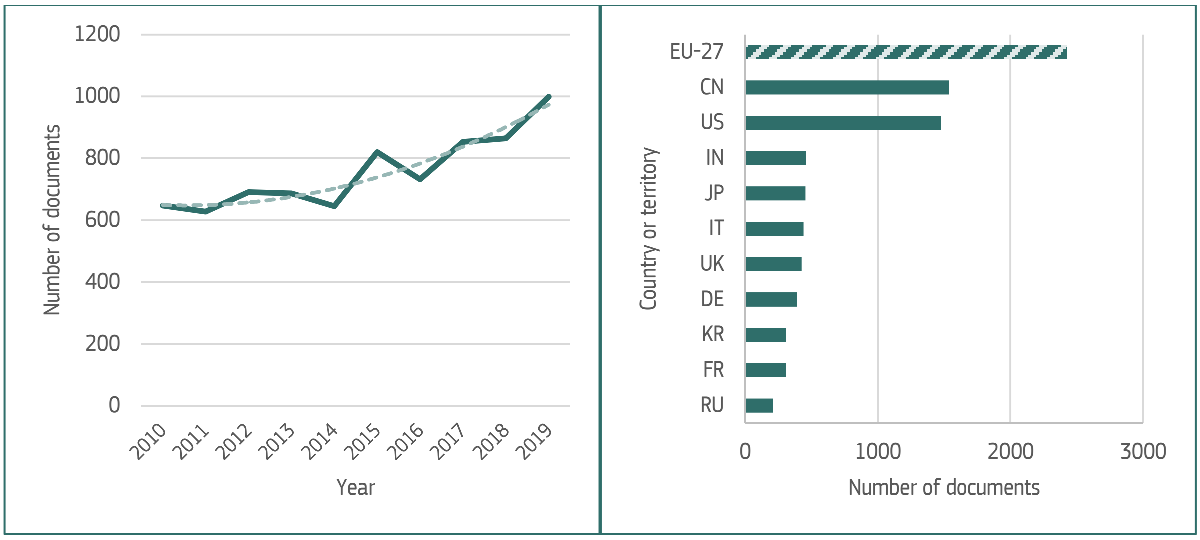
Figure 20: Research documents 2010-2019 (left) and country of origin (right) on power and propulsion



Source: TRIMIS elaborations based on Scopus

On the sub-theme *fuels and alternative energy sources*, in Figure 21, the trend is positive evolving from a low of 628 documents in 2011 to 999 documents in 2019. China is the country with the majority of publications, followed by the US. Italy, Germany and France are the three EU-27 countries that appear in the world top 10.

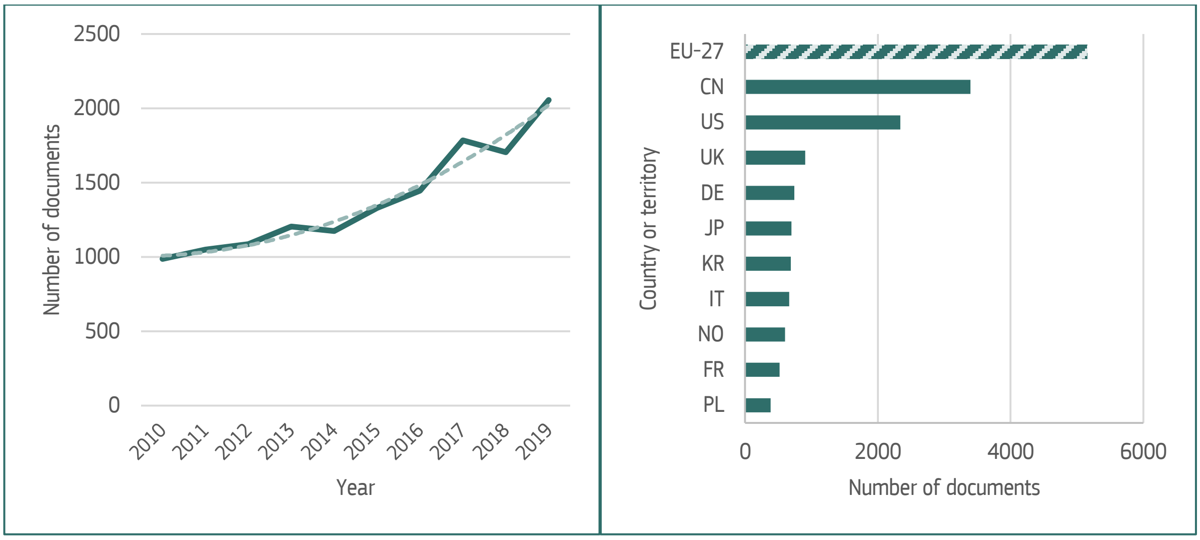
Figure 21: Research documents 2010-2019 (left) and country of origin (right) on fuels and alternative energy sources



Source: TRIMIS elaborations based on Scopus

When looking at *operational measures*, illustrated in Figure 22, a positive trend can be observed: from 987 documents in 2010 to 2056 documents in 2019. Also in this case, the majority of publications comes from: China, followed by the US and UK. Other EU countries are particularly active in *operational measures* publications, namely: Germany, Italy, Norway, France and Poland (PL).

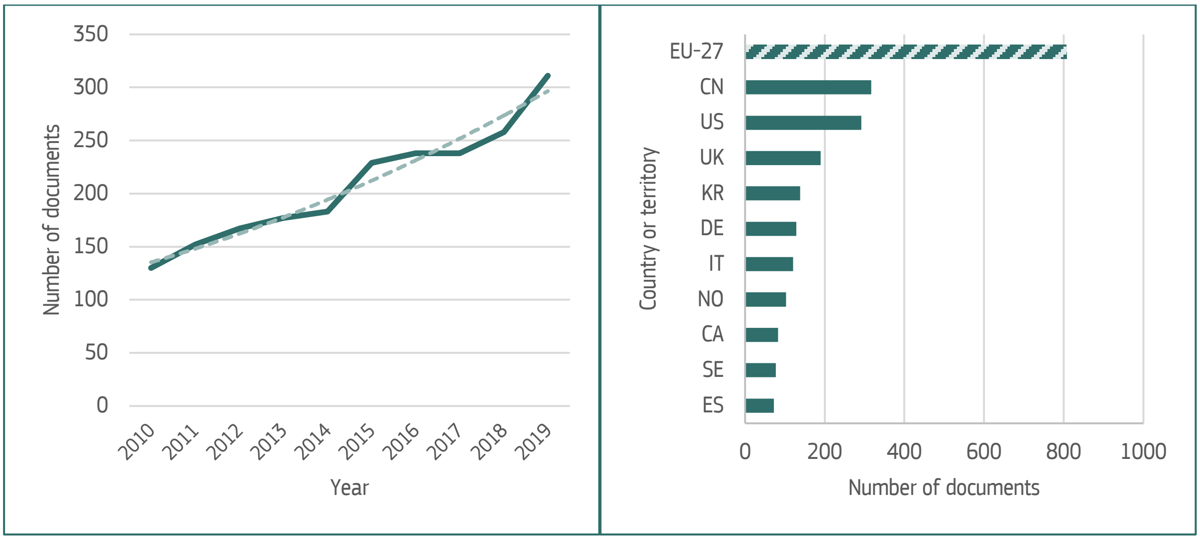
Figure 22: Research documents 2010-2019 (left) and country of origin (right) on operational measures



Source: TRIMIS elaborations based on Scopus

Finally, on the sub-theme *coordination and support measures,* including research, networking activities (**Figure 23**), the trend is positive evolving from a low of 130 documents in 2010 to 311 documents in 2019. China is again leading, closely followed by the US. Germany, Italy, Norway, Sweden (SE) and Spain (ES) are five EU-27 countries that make it into the top 10.

Figure 23: Research documents 2010-2019 (left) and country of origin (right) on coordination and support measures



Source: TRIMIS elaborations based on Scopus

From the analysis, as a general remark, China seems to dominate in waterborne transport research in the last years. However, Europe is strong with universities and research institutes being present among the top players in research. Also, if the EU-27 countries were considered all together, in all cases they would become the leading entity.

While Chinese Universities are the dominant affiliations, EU Universities and research centres, and the EC as funding sponsor appear often in the top five lists (see Annex 4).

The results provide in this section need to be read with caution as the expression chosen with REGEX may suffer from some limitation, not covering the entire themes, especially for the 5th one, which is rather broad in the issues tackled. It needs to be highlighted that the “funding sponsor” section provides fractional results since it is based on the authors’ declaration, many times not stated or divided in several sponsors that are actually the same. Nevertheless, the results provided in this section, even if with limitations, provide a meaningful analysis of research trends in waterborne transport.

7.2 Analysis of patents

Patent analysis aims to provide additional insights into private investments and research outputs related to technological topics. This assessment focuses on the analysis of international patent applications related to the waterborne transport topics and sub-topics. For this purpose, the EPO Worldwide Patent Statistical Database (PATSTAT[40]) was used, and a search using cooperative patent classification (CPC) codes, patent title and abstract was carried out.

For this exercise, the search was restricted to the CPC code “B63 - SHIPS OR OTHER WATERBORNE VESSELS; RELATED EQUIPMENT”, and the search period was 5 years (2013 to 2017). Table 19 shows the keywords used for the search for each sub-theme and Figure 24 shows the cumulative sum per year for the search period.

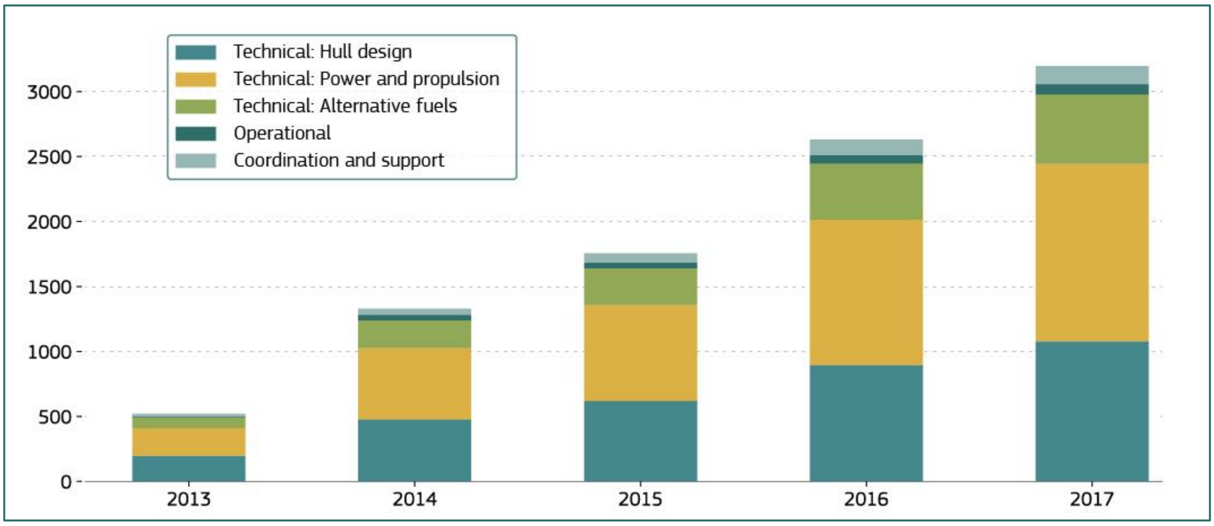
[40] https://www.epo.org/searching-for-patents/business/patstat.html

Table 19: Sub-themes and keywords used for patent search

Waterborne transport sub-theme	Keywords
Hull design	Hull design, hull dimension, hull shape, hull coating, lubrication, hull weight, bulbous bow, lightweight material, hull, material, lightweight, bulbous.
Power and propulsion	Propulsion devices, propulsion, power systems, machinery, power, power demand, on-board, on-board power demand, ballast water reduction, ballast, water reduction, waste heat recovery, heat recovery.
Fuels and alternative energy sources	Biofuel, methanol, nuclear, LNG, liquefied natural gas, sails, kites, photovoltaic cells, photovoltaic, solar panel, solar power, wind power, fuel cells, hydrogen, ammonia, synthetic fuels, electricity, hybrid propulsion, batteries, battery.
Operational measures	Shore to ship power, shore-to-ship power, shore-to-ship, shore to ship, onshore power supply, ops, onshore power, shore connection, alternative maritime power, amp cold ironing, speed reduction, slow steaming, capacity utilization, voyage optimization, voyage optimization, sailing route, voyage planning, real time data exchange, data exchange, real-time data exchange, wave condition, weather condition, network routing, trim optimisation, trim optimization.
Coordination and support measures	Monitoring, reporting, verification, MRV, market instrument, regulation, trading market, decarbonising scheme, decarbonisation scheme, emission trading scheme, emission trading.

Source: Own elaborations based on TRIMIS

Figure 24: Waterborne transport patents per sub-theme: cumulative sum between 2013 and 2017



Source: Own elaborations based on TRIMIS

From the results, it can be seen that *Power and propulsion* and *Hull design* sub-themes account for the majority of the granted patents in the search period, with an increase in the share of *Power and propulsion* in the last years. Moreover, patents within the *Alternative fuels* sub-theme show an increase over the total share of patents in the last year, while *Operational and Coordination and Support measures* ones are less present overall, also confirming the fact that these sub-topics are not directly technology oriented.

8 Conclusions

Focusing on selected EU funded projects, this report presents a comprehensive analysis of R&I in the field of waterborne transport decarbonisation in Europe. The report identifies relevant technologies, as well as operational, coordination and support measures aimed at decreasing the impact of waterborne transport over CO_2 emissions. The analysis is complemented by the findings on the evolution of international scientific publications and patents associated to waterborne transport decarbonisation technologies. Based on the assessment carried out, the main conclusions are the following:

Overview on European Waterborne Transport Decarbonisation Research funding

- Under FP7 and H2020 around €995 million has been invested in waterborne transport decarbonisation research projects. This includes €760 million of EU funds and about €239 million of own contributions by beneficiary organisations.
- Spending on waterborne transport decarbonisation research under FP7 and H2020 increased within 2012 and 2018, which are related to the concluding activities from the two framework programmes. Moreover, the percentage of decarbonisation projects related to waterborne transport changes substantially in H2020, with great increase in the budget allocated to these projects and reflecting increased attention within EU policies towards decarbonisation.
- Approximately 65% of the waterborne transport projects, in FP7 and H2020, deal with decarbonisation, with the majority of them being technical projects and practically the same number of operational and coordination and support measures projects.
- The Vehicle Design and Manufacturing STRIA roadmap is the most present for the full list of decarbonisation projects and also for technical projects. Projects dealing with operational measures belong mainly to Network and Traffic management and Connected and Automated Transport roadmaps. Coordination and support projects are more general and cross-cutting across all STRIA roadmaps.
- The technology analysis highlights that the majority of the technologies is under the initial research step.

Project related findings by sub-theme

Under the ***sub-theme on hull design***, this review has identified research projects focussed on lightweight composite materials for structural components, improved hydrodynamic hull design, reducing hull friction and innovative repair methods and hull surface protection.

- Research shows that there is interest on using composite materials for conventionally fuelled ships to make fuel savings; friction stir welding technology should allow ships built from conventional steel to be made lighter, with consequent improvements in efficiency. As some challenges have been identified in using this technology, mainly related to tooling issues, future research could investigate solutions to these problems, enabling the technology to be employed on a large scale.

- The research on the use of composite materials in ship manufacture is progressing towards implementation. However, due to fire hazards at present, IMO 'Safety of life at sea' rules limit the use of such materials to vessels of less than 500 tonnes gross weight. There may be a need to work at an international level to review and potentially revise the regulations to allow the use of advance materials in larger vessels.

- Technologies to reduce ship resistance due to fouling of the hull by barnacles without harming the environment with toxic substances, demonstrated to improve ship performance; future research in this area should focus on environment friendly coating with extended durability applicable to the full fleet.

- These technologies allow efficiency improvement, which nonetheless cannot be considered a standalone solution to meet the challenging ambition of the EU Green Deal. Therefore, future research should be focussed on combined solutions, capable of delivering significant greater reductions as well as addressing the recyclability of such materials.

The research focus of the ***sub-theme on power and propulsion***, is on topic areas such as wind assisted propulsion, increases in engine efficiency and recycling of waste heat for use elsewhere in the vessel.

- Multiple research projects have demonstrated reductions in fuel consumptions, using different propulsion concepts. As separate technologies provide fuel consumption improvements, future research should investigate how the combination of different technologies onto a single ship could enhanced such positive effects within real world conditions.

- Wind propulsion has been shown to produce savings in fuel consumption, particularly at slower speeds and certain routes. To demonstrate its benefits to ship owners and to increase its penetration in the fleet, reliability and performance must be proven at large scale within harsh marine environments, in order to underpin a full cost-benefit analysis of the technology.

- Research has demonstrated the reductions in fuel consumption that can be obtained by using waste heat from the engines to power the ship's heating and cooling systems. Future policy could encourage operators to adopt this technology to reduce their fuel consumption and emissions.

- Applications in the domain of vessel electrification has shown successful results, namely in cases of fully electric high-speed passenger ferry. Future policy could assist in increasing the range and scale of battery electric applications, as well as promoting the technology to other types of vessels operating, which benefit from zero emissions due to their proximity to urban areas such as inland waterway and urban commuter vessels which may potentially be commercialised more quickly.

Projects under the ***sub-theme on fuels and alternative energy sources***, have investigated the use of electrification, hydrogen as a fuel, and LNG/LPG as a fuel. R&I could address the elimination of the release of unburnt methane and maximising combustion efficiency so that the transitional use of such cleaner gaseous fuels can potentially contribute to GHG reduction.

- A number of alternative fuels are under consideration for decarbonising the waterborne sector. However, the ideal mix is not currently clear, as some potential sustainability, infrastructure and distribution drawbacks are associated to some of these options, as in the case of bio-fuels, bio-methane, ammonia, hydrogen or methanol. There would be benefits in investigating the advantages and disadvantages of the various alternative fuels under different waterborne applications, to support scaling up of production as well as their use in vessel engines.

- For the short-term, alternative lower-carbon fossil fuels, such as LNG, LPG and CNG are being suggested as a means to achieve a rapid reduction in pollutions from shipping, however their contribution to decarbonisation is limited depending on the engine type and release of unburnt methane. Further consideration is required as to how the transition from such fuels should be managed in order to pave the way towards low fossil carbon fuels such as bio LNG, bio-diesel, ammonia, methanol or hydrogen and if such transitional fuels may be a distraction from the development of longer-term low, or zero, carbon fuels which risks investment in infrastructure which may become stranded assets.
- Multiple projects have explored the use of battery technology for vessels, using different battery chemistries. Although this technology seems to be very efficient, the most promising applications are the ones on short distances, due the large amount of energy required. Future research could be conducted into the benefits and disadvantages of different battery chemistries for different maritime applications (including trade-offs between charge rate, energy density and cost), to assist vessel designers in choosing the optimum option for a new vessel. This would improve the capability of European battery and electrical systems to continue to lead the expanding electric shipping sector.
- The greatest impacts on decarbonisation for the transport waterborne sector are likely to come from the use of alternative energy sources, as fuels such as electricity from renewable sources or hydrogen from electrolysis can offer a pathway to net zero for the waterborne transport industry. A priority for future policy development could be to increase the necessary renewable electricity generating capacity combined with increased production and uptake of these alternative energy sources. Rapid change will be required to contribute to the achievement of Europe's ambitious decarbonisation targets. The Draft

Proposal for a European Partnership under Horizon Europe Zero-Emission Waterborne Transport[41] paper recognises that radical change will be required to meet the 2050 climate targets, as well as the necessary reduction of emissions by 2030 in line with the European Green Deal. This will require a greater emphasis on the fuels and alternative energy sources, together with efficiency improvements and non-fuel based energies to deliver the necessary decarbonisation of the waterborne sector.

Under the ***sub-theme on operational measures,*** topics such as vessel allocation systems, robotic container handling systems, improved vessel navigation and automation in shipping are being considered.

- The development of robotic container management systems has progressed to the production of design approaches for different sub-systems, fully robotic container terminals are already operational worldwide. Research should focus on the integration of such on shore automated systems with smart scheduling and potentially automated ships, integrating logistic chains and benefiting operational measures to reduce GHG emissions such as slower sailing speeds. Interoperability of technologies at different ports around the world is important. Although benefits have been identified for vessel management systems at ports, it is important that solutions that are implemented can be used by all ships and in particular to benefit those ships which apply operation GHG reduction measures. Policy could be developed for all European ports wishing to use technologies such as these, to create a standard approach to navigation and smart vessel scheduling as well as the seamless integration between port arrivals and GHG efficient hinterland connections.

- Projects have demonstrated the benefits of GNSS for automated maritime shipping and integrated logistics; building on this technology, could further improve efficiencies, and therefore reduce fuel consumption and emissions. Further research should investigate how the GNSS technologies would interact with autonomous ship technologies, could increase safety, as well as ensuring the resilience of GNSS based systems against failure or malicious intervention.

- In the domain of autonomous ships, research has been proposed on regulations, rules and standards for autonomous ships, including: the definition and the level of responsibility for the different crew members; the role of human operators on board and the allowed/needed manual operations; the management of compulsory systems, devices and procedures that would facilitate crewless vessel operation and the role and responsibilities of remote-control centres. Policy could be developed to include the safe operation of autonomous vessels, aligned across all Member States, including safe operation within complex mixed traffic, integration within logistic chains and resilience against the consequences of system failure. This would help to ensure the safety of autonomous marine and inland vessels and therefore increase the uptake of the technology across Europe and support the EU's market globally.

The ***sub-theme on coordination and support measures,*** includes research coordination and dissemination, networking activities, etc. where efforts are focused on the dissemination and consolidation of research in the waterborne transport sector, as well as planning and investigating future strategy for the sector, including both vessel and port design.

- The results of the industry/market trends to 2030 should be reviewed to consider the socio-economic impacts, such as the COVID-19 pandemic, and assess whether the impacts on the maritime market are likely to be long lasting. Further policy development may be needed to ensure that the 2030 decarbonisation targets are met, and that the industry is aware of what needs to be done to reach these targets. There is a risk that the industry expected trends to 2030 are not in line with the current policy targets; this needs addressing rapidly to reduce the risk of the targets being missed.

- Previous projects have investigated trends and expectations of the maritime industry up to the year 2030. Future research should extend this time period towards 2050 to fit in line with the Green Deal targets. It is important to capture the long-term expected market trends such that the long-term decarbonisation targets can be met and adjusted accordingly.

[41] https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf

- Research into the application of telematics solutions to maritime shipping has shown relatively low potential uptake in the markets investigated. Further research in this domain could help understanding the reasons and how to increase the uptake.

Overall, the assessment of projects finding shows that no single measure can be considered as a problem solver, rather a combination of technologies could represent the way to follow.

Scientific research and patents trends

The analysis of the evolution of peer reviewed scientific publications dealing with decarbonisation in the area of waterborne transport shows an increasing interest of the academic community. Scientific publications focus mainly on technical aspects, either linked to the power and propulsion aspect or to fuel and alternative energy sources, mostly linked to policy measures addressing more stringent environmental targets. A good part of scientific articles deals also with operational measures addressing CO_2 emissions which leads to think of business strategies supporting maritime companies. Europe has a leading role when it comes to peer reviewed publications on this topic, followed by Chines and US articles, which denote the strong maritime nature of these countries.

The assessment of international patent applications related to the waterborne transport topics and sub-topics provides interesting information on their evolution in the last years, informing about the prevalence of power and propulsion patents, together with the ones linked to hull design. It is noteworthy that during the last years the number of patents associated to fuels and alternative energy sources has increased considerably, stressing again the relevance that such topic has on the scientific, business and policy domains.

The analysis conducted in this report regards the achievement of FP7 and H2020 projects on the waterborne decarbonisation theme and the related R&I and policy recommendations naturally emerged from their main findings, hence no indications can be provided on additional or not yet explored researches on the topic. It should nonetheless be highlighted that increasing interest is given to this research area, as clearly presented in the draft proposal for the European partnership on Zero-Emission Waterborne Transport[42] under the upcoming Horizon Europe, where particular emphasis is posed on research themes such as: increasing use of sustainable alternative fuels, electrification, increasing energy-efficiency, design and retrofitting solutions for the new and existing fleet, digital green to improve efficiency and sustainable bunkering and charging solutions for climate neutral ships.

The analyses performed in this report are subject to some limitations, namely:

- TRIMIS focuses on publicly funded projects, therefore private initiatives are not fully considered. Moreover, Member States funding information is fragmented and hence has not been fully included in the report;
- waterborne transport projects loosely linked to the decarbonisation topic have not been included in this report;
- the technology assessment will be further refined;
- the methodology behind the text analysis on waterborne transport decarbonisation academic research will be further improved.

This report, by providing a comprehensive and up-to-date review of waterborne transport decarbonisation R&I across Europe, may help transport researchers, policy makers, regulators and transport companies in shaping future research, policy measures and business strategies in this domain.

[42] https://www.waterborne.eu/images/documents/201021_SRIA_Zero_Emission_Waterborne_Transport_spread.pdf

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List of abbreviations and definitions

ALT	Alternative Energy
APU	Auxiliary Power Unit
AT	Austria
BE	Belgium
BG	Bulgaria
CAT	Connected & Automated Transport
CCNR	Central Commission for the Navigation of the Rhine
CEF	Connecting Europe Facility
CH_4	Methane
CY	Cyprus
CN	China
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CORDIS	EU Community Research and Development Information Service
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CPC	Cooperative Patent Classification
CZ	Czechia
DE	Germany
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
DK	Denmark
DPF	Diesel particulate filter
DWT	Dead Weight Tonnage
EC	European Commission
ECA	Emission Control Area
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EE	Estonia
EL	Greece
ELT	Electrification
ES	Spain
ETS	Emissions Trading System
EU	European Union
EU-27	European Union of 27 Member States
EU-28	European Union of 28 Member States
FI	Finland
FP4	4th Framework Programme of European Community Activities in the Field of Research and Technological Development and Demonstration

FP5	5th Framework Programme for Research
FP6	6th Framework Programme for Research
FP7	7th Framework Programme for Research
FP	Framework Programmes
FR	France
FRP	Fibre-Reinforced Polymer
FSW	Friction Stir Welding
GDP	Gross Domestic Product
GHG	Greenhouse gas emissions
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite Systems
GTL	Gas to Liquid
H2020	Horizon 2020 Framework Programme for Research and Innovation
HFO	Heavy Fuel Oil
HR	Croatia
HSLA	High-Strength Low Alloy (steel)
HU	Hungary
ICAO	International Civil Aviation Organisation
IE	Ireland
IEA	International Energy Agency
IMO	International Maritime Organization
INF	Infrastructure
ITF	International Transport Forum
IT	Italy
JP	Japan
JRC	Joint Research Centre
KR	South Korea
LCCA	Life Cycle Cost Analysis
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LT	Lithuania
LU	Luxembourg
LV	Latvia
MARPOL	International Convention for the Prevention of Pollution from Ships
MEA	Membrane Electrode Assemblies
MRV	Monitoring, Reporting and Verification
MS	Member State
MT	Malta
NASA	National Aeronautics and Space Administration

NH_3	Ammonia
NL	The Netherlands
N_2O	Nitrous oxide
NO_x	Nitrogen oxide
NRMM	Non-Road Mobile Machinery
NTM	Network & Traffic Management
OECD	Organisation for Economic Co-operation and Development
PM	Particulate Matter
PL	Poland
PT	Portugal
REGEX	Regular Expression
R&I	Research and Innovation
RO	Romania
RO-RO	Roll on-Roll off
SCR	Selective catalytic reduction
SE	Sweden
SECAs	Sulphur Emission Control Areas
SEEMP	Ship Energy Efficiency Management Plan
SI	Slovenia
SK	Slovakia
SOLAS	Safety of life at sea
SMO	Smart Mobility
SRIA	Strategic Research & Innovation Agenda
STRIA	Strategic Transport Research and Innovation Agenda
SO_x	Sulphur Oxide
TEN-T	Trans-European Transport Network
TOS	Terminal Operating Systems
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology Readiness Level
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
US	United States
VDM	Vehicle Design & Manufacturing
VOC	Volatile Organic Compounds

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Annexes

Annex 1: List of keywords used to identify waterborne related multimodal projects

List of keywords	
Barge	Maritime
Barque	Sail
Boat	Ship
Ferry	Vessel
Inland waterways	Watercraft
IWW	Waterway

Annex 2: Project table

The following table shows all projects that were considered during the development of this report and the sub-theme(s) under which they were considered.

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
4FOLD	4FOLD Reduction of the International Transport of Empty Containers by Folding	2014 - 2015	H2020-EU.3.4				Y	
4FOLD Phase 2	4FOLD Reduction of the International Transport of Empty Containers by Folding	2016 - 2018	H2020-EU.3.4				Y	
ADAM4EVE	Adaptive and smart materials and structures for more efficient vessels	2013 - 2015	FP7-Transport	Y				
AIRCOAT	Air-Induced friction Reducing ship Coating	2018 - 2021	H2020-EU.3.4	Y				
AQUASONIC DIESEL	FUEL EFFICIENCY AND EMISSIONS REDUCTION SYSTEM FOR THE MARITIME AND ROADTRANSPORT INDUSTRIES	2018 - 2020	H2020-EU.2.1		Y			
AQUASONIC-diesel	UPSCALE OF ELECTRICAL PULSES TECHNOLOGY CAPABLE OF FRAGMENTING HYDROCARBON CHAINS IN FUEL FOR MARITIME APPLICATIONS	2015 - 2015	H2020-EU.3.4			Y		
ARIADNA	Maritime assisted volumetric navigation system	2009 - 2012	FP7-Transport				Y	
AUTOSHIP	Autonomous Shipping Initiative for European Waters	2019 - 2022	H2020-EU.3.4		Y		Y	
Auxilia	Hybrid Drive for Commercial Ships and Yachts	2017 - 2017	H2020-EU.3.4		Y	Y		
BB GREEN	Battery powered Boats, providing Greening, Resistance reduction, Electric, Efficient and Novelty	2011 - 2014	FP7-Transport		Y	Y		
BESST	Breakthrough in European Ship and	2009 - 2013	FP7-Transport	Y				Y

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
	Shipbuilding Technologies							
BIOECOMARINE	New Ultrasonic Cost-Effective Equipment as Anti-Fouling System for Vessels	2017 - 2017	H2020-EU.3.4	Y				
BOSOWS	Blue Ocean Secondary Oily Water Separator	2017 - 2018	H2020-EU.3.4		Y			
CASMARE	Coordination Action to maintain and further develop a Sustainable Maritime Research in Europe	2009 - 2012	FP7-Transport					Y
CLOUD-VAS	Cloud based Vessel Allocation Decision Support System for Vessel Chartering	2015 - 2017	H2020-EU.3.4				Y	
COFASTRANS	A Fast and Eco-Efficient Transhipment System for Ultra Large Container Vessels	2014 - 2015	H2020-EU.3.4				Y	
COFRET	Carbon footprint of freight transport	2011 - 2020	FP7-Transport					Y
COMPA	COMPA - Market Study of Composite Patch Repair for Marine Pipes A cost-efficient and durable pipe repair in urgency	2015 - 2016	H2020-EU.3.4	Y				
COMPA 2GO	COMPA 2GO Composite Repairs for Ships - Service Demonstration, Certification and Market Entry	2018 - 2020	H2020-EU.2.1	Y				
COREALIS	Capacity with a positive environmental and societal footprint: ports in the future era	2018 - 2021	H2020-EU.3.4				Y	
DEECON	Innovative After-Treatment System for Marine Diesel Engine Emission Control	2011 - 2014	FP7-Transport		Y			
Docks The Future	Developing the methodology for a coordinated approach to the clustering, monitoring and evaluation of results of actions under the Ports of the Future topic	2018 - 2020	H2020-EU.3.4					Y

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
Dtorque111	Dtorque111 – world first turbodiesel outboard engine below 100 HP	2016 - 2016	H2020-EU.3.4		Y			
ECCONET	Effects of Climate Change On the inland waterway and other transport Networks	2010 - 2012	FP7-Transport					Y
EcoHubs	Environmentally Coherent measures and environmental interventions to debottleneck HUBS of the multimodal network favoured by seamless flow of goods	2012 - 2020	FP7-Transport				Y	
E-COMPLIANCE	A European Maritime e-Compliance Cooperation Model	2013 - 2016	FP7-Transport					Y
ECO-REFITEC	Eco innovative refitting technologies and processes for shipbuilding industry promoted by European Repair Shipyards.	2011 - 2013	FP7-Transport	Y				
EEECSM-2	Energy and Environmentally Efficient Cooling System for Maritime use	2016 - 2018	H2020-EU.3.4		Y			
E-ferry	Prototype and full-scale demonstration of next generation 100% electrically powered ferry for passengers and vehicles	2015 - 2019	H2020-EU.3.4			Y		
EfficienSea 2	EfficienSea 2 - Efficient, Safe and Sustainable Traffic at Sea	2015 - 2018	H2020-EU.3.4					Y
EMAR2RES	Support Action to Initiate Cooperation between the Communities of European Marine and Maritime Research and Science	2009 - 2012	FP7-Transport					Y
ENDURUNS	Development and demonstration of a long-endurance sea surveying autonomous unmanned vehicle	2018 - 2022	H2020-EU.3.4		Y	Y		

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
	with gliding capability powered by hydrogen fuel cell							
EU-CARGOXPRESS	Greening of surface transport through an innovative and competitive CARGO-VESSEL Concept connecting marine and fluvial intermodal ports.	2009 - 2012	FP7-Transport	Y	Y			
FIBRESHIP	Engineering, production and life cycle management for the complete construction of large length FIBRE based SHIPs	2017 - 2020	H2020-EU.3.4	Y				
FLAGSHIPS	Clean waterborne transport in Europe	2019 - 2022	H2020-EU.3.4		Y	Y		
FLIpER	The first on-board automatic ship hull management cleaning system for hull fouling prevention towards maritime eco-efficiency	2017 - 2017	H2020-EU.3.4	Y				
FORCE	Future Outboards Run Conventionally and Electrically	2014 - 2015	H2020-EU.3.4		Y	Y		
FOUL-X-SPEL	Environmentally Friendly Antifouling Technology to Optimise the Energy Efficiency of Ships	2011 - 2014	FP7-Transport	Y				
FReSMe	From residual steel gasses to methanol	2016 - 2020	H2020-EU.3.3			Y		
Full Electric Boats	New full-electric propulsion system, completely submerged in water, for zero-emissions navigation	2016 - 2016	H2020-EU.3.4		Y	Y		
GASVESSEL	Compressed Natural Gas Transport System	2017 - 2021	H2020-EU.3.4	Y		Y		
General Purpose DP	A Compact Dynamic Positioning System of General Purpose for Marine Units, Crafts and Ships	2014 - 2015	H2020-EU.3.4				Y	
GEO	Green Efficient Outboards	2015 - 2016	H2020-EU.3.4		Y			

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
GFF	Green Fast Ferry - the world's first 30 knots battery powered Air Supported commuter ferry	2016 - 2018	H2020-EU.3.4	Y	Y	Y		
GHG-TRANSPORD	Reducing Greenhouse-gas Emissions of Transport Beyond 2020: Linking R&D, Transport Policies and Reduction Targets	2009 - 2020	FP7-Transport					Y
Ghost Boat	A new way to own, drive and maintain a boat	2017 - 2017	H2020-EU.3.4	Y		Y		
GMP	Green Marine Propulsion	2017 - 2017	H2020-EU.3.4		Y	Y		
GREEN EFFORTS	Green and Effective Operations at Terminals and in Ports	2012 - 2014	FP7-Transport					Y
GreenDrive	A molecular fuel modifier for ships able to reduce the costs related to fuel and maintenance for fleet operators	2016 - 2016	H2020-EU.3.4		Y	Y		
GRIP	Green Retrofitting through Improved Propulsion	2011 - 2014	FP7-Transport	Y				
H2H	EGNSS Hull-to-Hull	2017 - 2020	H2020-EU.3.4				Y	
H2MOVE	Hydrogen generator for higher fuel efficiency and lower carbon emissions in maritime transport	2017 - 2017	H2020-EU.3.4			Y		
H2OCEAN	Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy	2012 - 2014	FP7-Transport		Y	Y		
H2Ports	Implementing Fuel Cells and Hydrogen Technologies in Ports	2019 - 2022	H2020-EU.3.3, H2020-EU.3.4		Y	Y		
HCR	Market maturation of the first on-board autonomous biofouling cleaning system to keep ship's hull clean at all times	2018 - 2020	H2020-EU.2.1		Y			
HELIOS	The Development of a New Ship	2010 - 2013	FP7-Transport		Y	Y		

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
	Engine Generation							
HERCULES-2	Fuel Flexible, Near-Zero Emissions, Adaptive Performance Marine Engine	2015 - 2018	H2020-EU.3.4	Y	Y	Y		
HERCULES-B	Higher-efficiency Engine with Ultra-Low Emissions for Ships	2008 - 2011	FP7-Transport		Y			
HERCULES-C	Higher Efficiency, Reduced Emissions, Increased Reliability and Lifetime, Engines for Ships	2012 - 2014	FP7-Transport		Y			
HILDA	High Integrity Low Distortion Assembly	2012 - 2015	FP7-Transport	Y				
HOLISHIP	Holistic optimisation of SHIP design and operation for life cycle	2016 - 2020	H2020-EU.3.4				Y	
HYBRID_BOATS	An innovative hybrid propulsion and generation system for yachts	2015 - 2016	H2020-EU.3.4			Y		
HYMAR	High Efficiency Hybrid Drive Trains for Small and Medium Sized Marine Craft	2009 - 2012	FP7-Transport		Y	Y		
HyMethShip	Hydrogen-Methanol Ship propulsion system using on-board pre-combustion carbon capture	2018 - 2021	H2020-EU.3.4			Y		
HySeas III	Realising the world's first sea-going hydrogen-powered Ro-Pax ferry and a business model for European islands	2018 - 2021	H2020-EU.3.4		Y	Y		
ICARGO	ICargo - Intelligent Cargo in Efficient and Sustainable Global Logistics Operations	2011 - 2020	FP7-ICT				Y	Y
INOMANSÂ²HIP	Innovative Energy Management System for Cargo SHIP	2011 - 2014	FP7-Transport				Y	
JOULES	Joint Operation for Ultra Low Emission Shipping	2013 - 2017	FP7-Transport		Y			
KITVES	Airfoil-based Solution for Vessel On-board Energy Production	2008 - 2020	FP7-Transport		Y	Y		

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
	Destined to Traction and Auxiliary Services							
LEAF	Low Emission Anti Fouling coatings based on the novel discovered post settlement penetration triggered antifouling	2012 - 2015	FP7-Transport	Y				
LeanShips	Low Energy And Near to zero emissions Ships	2015 - 2019	H2020-EU.3.4	Y	Y			
LEANWIND	Logistic Efficiencies And Naval architecture for Wind Installations with Novel Developments	2013 - 2017	FP7-Transport			Y		
LINCOLN	Lean Innovative Connected Vessels	2016 - 2019	H2020-EU.3.2		Y	Y		
LoCOPS	Low Cost Onshore Power Supply	2015 - 2016	H2020-EU.3.4				Y	
LOGIMATIC	Tight integration of EGNSS and on-board sensors for port vehicle automation	2016 - 2019	H2020-EU.2.1				Y	
MARANDA	Marine application of a new fuel cell powertrain validated in demanding arctic conditions	2017 - 2021	H2020-EU.3.4		Y	Y		
MarketStudy-OV	Market Research for Ocean volt zero-carbon emission marine electric propulsion system	2016 - 2017	H2020-EU.3.4	Y		Y		
MARPOS	Maritime Policy Support	2008 - 2010	FP7-Transport					Y
MARTEC II	ERA-NET Maritime Technologies II	2011 - 2014	FP7-Transport					Y
MarTERA	Maritime and Marine Technologies for a New ERA	2016 - 2021	H2020-EU.3.2					Y
MESA	MESA - Maritime Europe Strategy Action - FOSTER Waterborne	2013 - 2016	FP7-Transport					Y
MOEWA	Modular Eco Waterbus ABLE TO BE DIVIDED INTO TWO IDENTICAL INDIPENDENTHYBRID UNITS ALLOWING OPERATING FLEXIBILITY IN TRANSPORTATION	2015 - 2016	H2020-EU.3.4		Y	Y		

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
MOSAIC	Materials On board: Steel Advancements and Integrated Composites	2012 - 2015	FP7-Transport	Y				
MOVE IT!	Modernisation of Vessels for Inland waterway freight Transport	2011 - 2014	FP7-Transport	Y	Y			
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks	2012 - 2015	FP7-Transport		Y		Y	
NAVAIS	New Avanced and Value-Added Innovative Ships	2018 - 2022	H2020-EU.3.4	Y				
NAVDEC	Navigational Decision Support System for Improved COLREGs Safety Management	2015 - 2015	H2020-EU.3.4				Y	
NAVTRONIC	Navigational System for Efficient Maritime Transport	2009 - 2012	FP7-Transport				Y	
NEWS	Development of a Next generation European Inland Waterway Ship and logistics system	2013 - 2015	FP7-SST	Y	Y	Y	Y	
NEXTRUST	Building sustainable logistics through trusted collaborative networks across the entire supply chain	2015 - 2018	H2020-EU.3.4				Y	Y
NOVIMAR	NOVel IWT and Maritime transport concepts	2017 - 2021	H2020-EU.3.4				Y	
OXM	A patent pending gearbox for ships that decrease fuel consumption with 25%	2016 - 2016	H2020-EU.2.3, H2020-EU.3.3		Y			
PerMarDrive	Integrated Permanent Magnet Motor-Clutch Drive for Parallel Hybrid Power MARINE Propulsion Systems	2015 - 2016	H2020-EU.3.4		Y			
PLATINA	Platform for the Implementation of NAIADES	2008 - 2012	FP7-Transport					Y
PLATINA II	Platform for the implementation of NAIADES	2013 - 2016	FP7-Transport					Y

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
PortForward	Towards a green and sustainable ecosystem for the EU Port of the Future	2018 - 2021	H2020-EU.3.4					Y
PORTOPIA	Ports Observatory for Performance Indicator Analysis	2013 - 2017	FP7-Transport					Y
POSEÂ²IDON	Power Optimised Ship for Environment with Electric Innovative Designs on Board	2009 - 2012	FP7-Transport			Y		
PROMETHEUS-5	Energy efficient and environmentally friendly multi-fuel power system with CHP capability, for stand-alone applications.	2016 - 2019	H2020-EU.2.1, H2020-EU.2.3, H2020-EU.3.3		Y	Y		
Prominent	Promoting Innovation in the Inland Waterways Transport Sector	2015 - 2018	H2020-EU.3.4					Y
PURE	Development of Auxiliary Power Unit for Recreational yachts	2013 - 2016	FP7-JTI			Y		
RAMEMBER STATESES	Realisation and Demonstration of Advanced Material Solutions for Sustainable and Efficient Ships	2017 - 2021	H2020-EU.3.4	Y				
RCMS	Rethinking Container Management Systems	2015 - 2017	H2020-EU.3.4				Y	
REFRESH	Green Retrofitting of Existing Ships	2012 - 2015	FP7-Transport	Y	Y			Y
RETROFIT	Retrofitting ships with new technologies for improved overall environmental footprint	2011 - 2015	FP7-Transport	Y				Y
RISING	RIS Services for Improving the Integration of Inland Waterway Transports into Intermodal Chains	2009 - 2012	FP7-SST				Y	
RotorDEMO	Norsepower Rotor Sail Solution demonstration project	2017 - 2018	H2020-EU.3.4		Y	Y		
S.D.S.	an innovative system for building hulls for recreational and work boats	2016 - 2016	H2020-EU.3.4	Y				
SCIPPER	SHIPPING CONTRIBUTIONS TO	2019 - 2022	H2020-EU.3.4					Y

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
	INLAND POLLUTION PUSH FOR THE ENFORCEMENT OF REGULATIONS							
SCOUT	Smart Monitoring Control and User interactive ecosystem for improving energy efficiency and economic maintenance of Medium-Weight Ships	2017 - 2018	H2020-EU.3.4					Y
SeaBubble	Fast-Forwarding to the Future of On-Demand Urban Water Transportation	2017 - 2017	H2020-EU.3.4			Y		
SeagateSail	20% fuel saving for commercial vessels through a hybrid wind plus motor cruise mode	2014 - 2015	H2020-EU.3.4			Y		
SEAHUB	Real-time Fleet Performance Center (FPC) to optimize energy efficiency in Maritime Transport to reduce fuel consumption and harmful emissions	2016 - 2017	H2020-EU.3.4				Y	
ShipHullSHM	Bespoke Acoustic Emission System for real-time ship hull monitoring for all weather conditions	2015 - 2016	H2020-EU.3.4	Y				
SHIPLYS	Ship Lifecycle Software Solutions	2016 - 2019	H2020-EU.3.4				Y	
SPLASH	Sail Plan service for energy efficient Shipping (SPLASH) - innovative and revolutionary sail planning	2016 - 2017	H2020-EU.3.4				Y	
STEERER	STRUCTURING TOWARDS ZERO EMISSION WATERBORNE TRANSPORT	2019 - 2022	H2020-EU.3.4					Y
STREAMLINE	Strategic Research For Innovative Marine Propulsion Concepts	2010 - 2014	FP7-Transport	Y	Y			
SYNCHRO-NET	Synchro-modal Supply Chain Eco-Net	2015 - 2018	H2020-EU.3.4				Y	
SUPERGREEN (SG)	Construction of 3 Electric Commuter Vessels	2019 - 2022	CEF			Y		

Project acronym	Project name	Project duration	Source of funding	Hull design	Power and propulsion	Fuels and alternative energy sources	Operational measures	Coordination and support measures
TARGETS	Targeted Advanced Research for Global Efficiency of Transportation Shipping	2010 - 2014	FP7-Transport		Y			
TEFLES	Technologies and Scenarios For Low Emissions Shipping	2011 - 2014	FP7-Transport		Y			
THROUGHLIFE	Development and proof of new approaches for through-life asset management based on next generation of materials and production technology	2011 - 2014	FP7-Transport	Y				
TrAM	Transport: Advanced and Modular	2018 - 2022	H2020-EU.3.4	Y		Y		
TRANSPHORM	Transport related Air Pollution and Health impacts? Integrated Methodologies for Assessing Particulate Matter	2010 - 2014	FP7-Environment					Y
TRILO-BWTS	Disruptive and patented microfluidic technology purification for ship ballast water, being maintenance free, eliminating clogging of filters and providing significant life-cycle cost savings	2016 - 2016	H2020-EU.3.4		Y			
TRIPOD	Triple Energy Saving by Use of CRP, CLT and PODded Propulsion	2010 - 2013	FP7-Transport		Y			
ULTRABOAT	Ultrasonic System for Antifouling Protection of Ships	2014 - 2015	H2020-EU.3.4	Y				
ULYSSES	Ultra Slow Ships	2011 - 2013	FP7-Transport		Y	Y	Y	
VDRConnect	VDRConnect: VDR-based vessel telematics solution	2016 - 2016	H2020-EU.3.4					Y
VEZ	VEZ	2014 - 2015	H2020-EU.3.4	Y		Y		
VIRTUAL-FCS	VIRTUAL & physical platform for Fuel Cell System development	2020 - 2022	H2020		Y	Y		
Zbox	ZBOX: THE NEXT GENERATION OF FOLDABLE CONTAINERS	2018 - 2018	H2020-EU.3.4				Y	

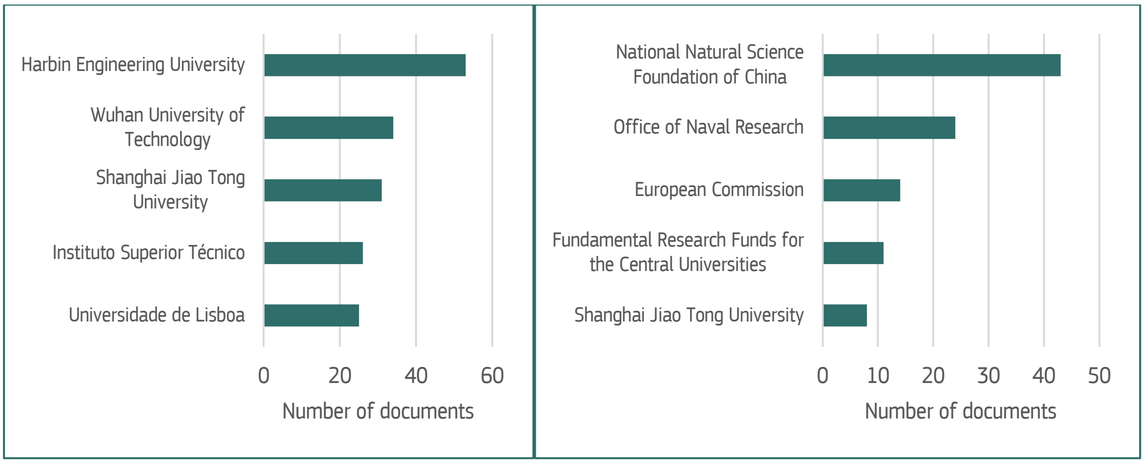
Annex 3: Scopus database regular expression analysis keywords

REGEX (documents retrieved on September 2020)

Waterborne transport sub-theme	Regular Expressions
Hull design	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS (("hull design" or "hull structure" or "Hull weight" or "Bulbous bow" or "Hull shape") and (boat or ship or ferry or vessel) and not "electric field") AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Power and propulsion	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS(engine or power or propulsion and (boat or ship or ferry or vessel)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Fuels and alternative energy sources	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS ((electric or lpg or batter* or hybrid or hydrogen or methanol) and (boat or ship or ferry or vessel) and not "electric field" and not "pressure vessel" and not "spherical vessel") AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Operational measures	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS ((electric or lpg or batter* or hybrid or hydrogen or methanol) and (boat or ship or ferry or vessel) and not "electric field" and not "pressure vessel" and not "spherical vessel") AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))
Coordination and support measures	((DOCTYPE(ar) or DOCTYPE(cp)) and TITLE-ABS(standardization or "Market instrument" or Regulation or "Trading market" or "Emission Trading" and (boat or ship or ferry)) AND PUBYEAR > 2009 AND PUBYEAR < 2020 and not SUBJAREA(MEDI OR NURS OR VETE OR DENT OR HEAL OR MULT))

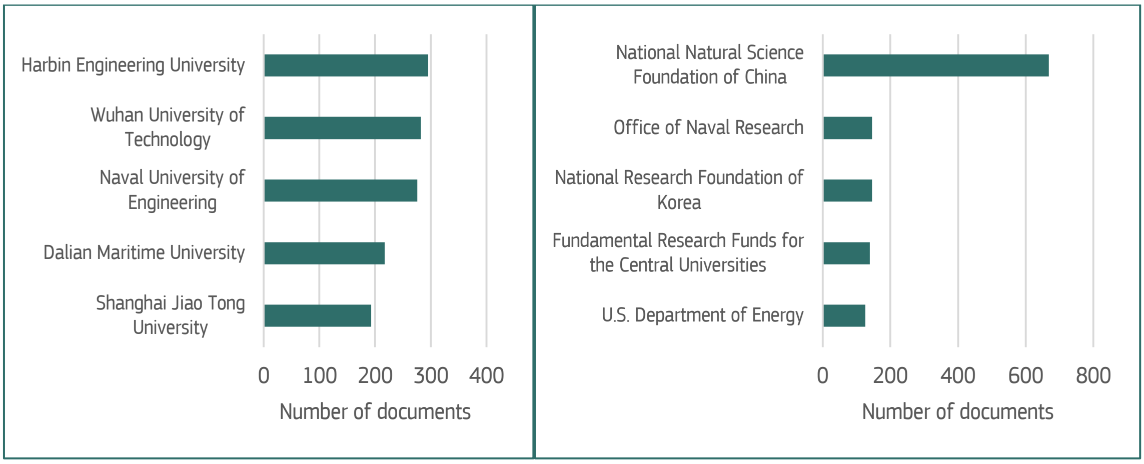
Annex 4: Affiliation and funding sponsor for the scientific research analysis

Affiliation (left) and funding sponsor (right) on hull design



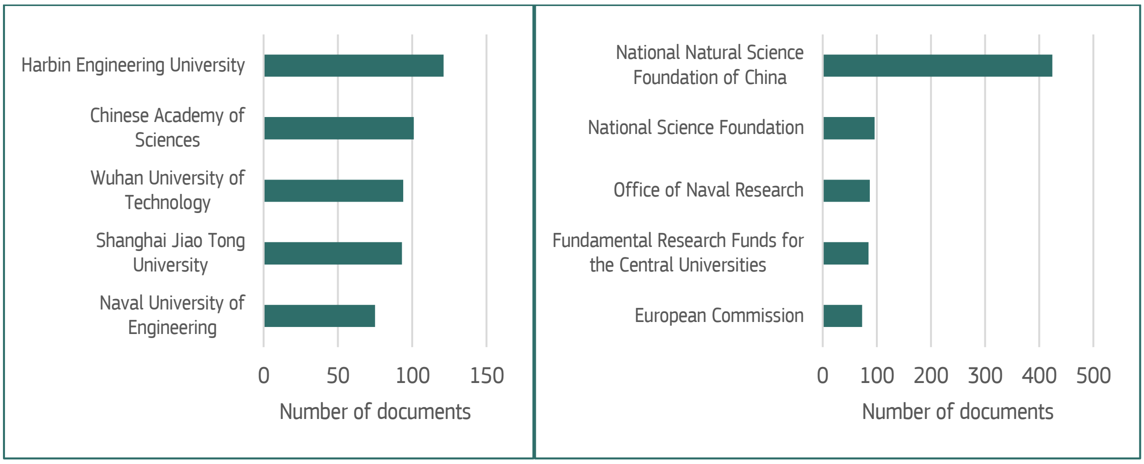
Source: TRIMIS elaborations based on Scopus.

Affiliation (left) and funding sponsor (right) on power and propulsion



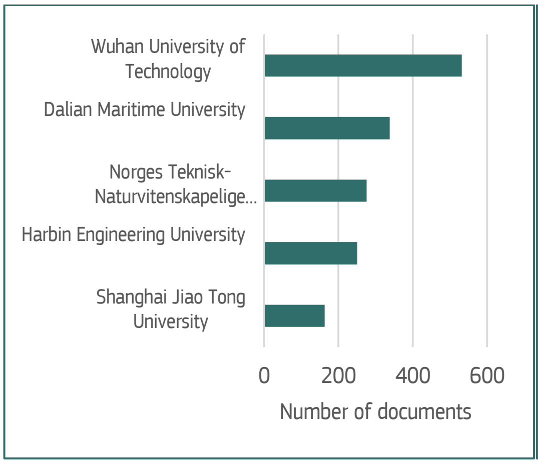
Source: TRIMIS elaborations based on Scopus.

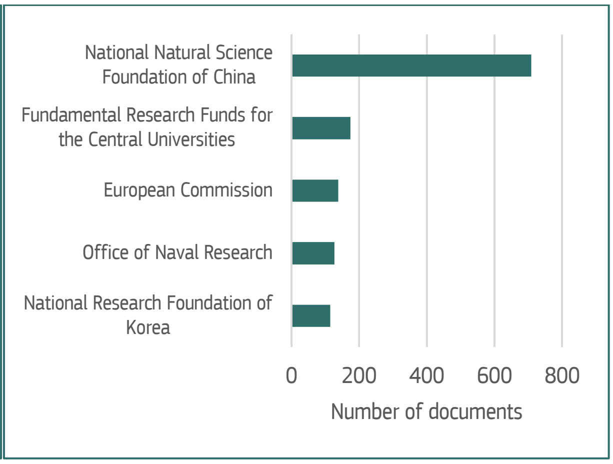
Affiliation (left) and funding sponsor (right) on fuels and alternative energy sources



Source: TRIMIS elaborations based on Scopus.

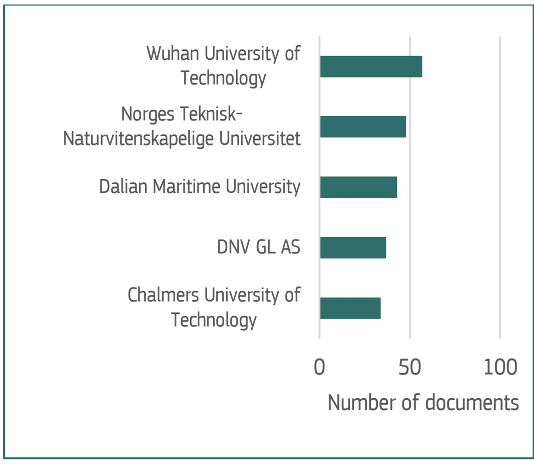
Affiliation (left) and funding sponsor (right) on operational measures

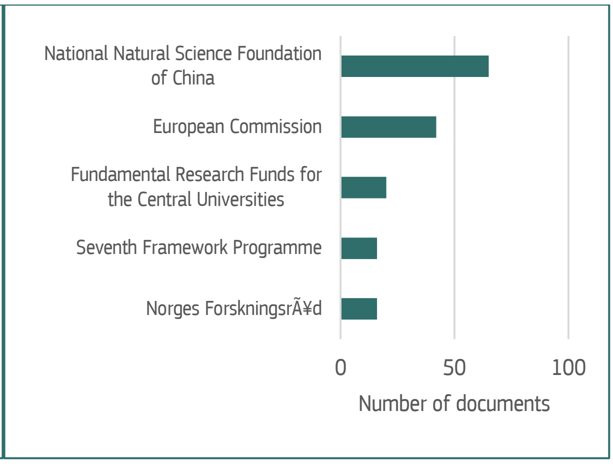




Source: TRIMIS elaborations based on Scopus.

Affiliation (left) and funding sponsor (right) on coordination and support measures





Source: TRIMIS elaborations based on Scopus.

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