Review study on the Recreational Craft Directive 2013/53/EU

Final Report

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Contents

Executive Summary

The Recreational Craft Directive (RCD) 94/25/EC, harmonising the provisions related to recreational craft, was adopted by the European Parliament and the Council in June 1994 and was applied from June 1996. Directive 2003/44/EC amended the Recreational Craft Directive in 2003 and introduced a set of exhaust and sound emission requirements as well as added the provisions for post-construction assessment. Directive 2013/53/EU replaced the Directive 94/25/EC in 2013. The review clause set out in Article 52 of the Directive 2013/53/EU requires the European Commission (EC) to submit a report to the European Parliament and the Council to address the feasibility for further reducing exhaust emissions from marine propulsion engines, feasibility to introduce requirements for evaporative emissions and the evaluation of the impact of current structure of watercraft design categories on manufacturers and consumers as well as the evaluation of whether they require additional specifications or subdivisions.

To collect information to draft the report required by Article 52 of Directive 2013/53/EU, a study was performed by a Consortium consisting of Panteia (NL, lead), TNO (NL) and Emisia (GR). As a part of the approach, an in-depth data analysis was performed and a detailed consultation strategy was applied, consisting of a Public Consultation and supplementing targeted consultations and interviews.

Due to the nature of the research questions concerning the Review clause, this study focuses on three areas: exhaust emissions, evaporative emission and watercraft design categories.

The contributions of emissions of recreational craft are generally very small when compared to the transport sector and when also compared to all other sectors together. For Carbon Dioxide, these are 0,4% and 0,1% respectively. For particulate matter, the figures are 0,5% and 0,1% and for Nitrogen Oxides 0,6% and 0,3%. Finally, for Hydrocarbons it is 4% and 0,3%. Only Carbon Monoxide makes a more significant contribution, with 11% and 2,4% respectively. Emissions of Nitrogen Oxides and Carbon Dioxide have the greatest economic impact in monetary terms.

The three areas of focus are discussed further below.

Exhaust emissions

The technologies that have been identified for reducing exhaust emissions are mature technologies that are already being applied in other markets (non-road mobile machinery, heavy-duty automotive but also marine applications). Both technologies that aim to reduce pollutant gases (air quality) and technologies that reduce greenhouse gas emission are in principle applicable also to recreational craft. However, the application of technologies that strongly reduce nitrogen oxides emissions may be accompanied with challenges to match the associated size increase with existing packaging constraints, as well as with the need to adapt the exhaust system so that temperature targets are met. They may also require the availability of ultra-low-sulphur diesel and, in the case of catalytic aftertreatment to reduce nitrogen oxide exhaust emissions, on-board storage of a urea-water mixture.

Three scenarios for reducing exhaust emissions were investigated: the application with outboard and personal watercraft spark ignited engines of cleanest technology currently in use with these engines and further harmonisation with US legislation, in particular on Not-To-Exceed requirements and on emission limits for compression ignition engines below 37 kW (scenario 1); in addition to scenario 1 and for power levels above 75 kW the application of three-way catalytic aftertreatment to outboard and personal watercraft spark ignited engines and of best available non-aftertreatment technology to compression ignition engines (scenario 2); and finally, in addition to scenario 1 and for all engines above 75 kW, the application of best available catalytic aftertreatment technology for maximum reduction of pollutant emissions (scenario 3).

Electrification and/or hybridization can also be applied to some classes of craft. Especially with electrification this would result in a further considerable reduction of emissions. Various ways can be identified to stimulate this. However, the biggest driver for electrification will be the expected further improvement in battery technology: lower cost, higher energy and power density.

Off all scenario's investigated, scenario 2 gives the biggest difference between (discounted) monetised environmental benefits and costs, but the other scenarios score only 6 % lower. Scenario 1 has by far the highest benefit to cost ratio and the shortest payback period (9 years, compared to 16 years and 20 years for scenario 2 and 3 respectively). Furthermore, in scenario 1 there is the least uncertainty: there is no dependency on the wide availability of low-sulphur diesel fuel and there are no concerns regarding possible size constraints when applying to recreational craft. Scenario 3 scores best on monetized environmental benefits but it has the lowest benefit to cost ratio. Finally, the development effort and corresponding costs corresponding to scenario 2 and scenario 3 could make the production of these engines no longer economically viable for some smaller, non-OEM manufacturers.

The proposed scenarios for exhaust emission reduction apply to newly produced craft. To further reduce emissions of the recreational craft sector, it is recommended to investigate the possibilities of emission reduction of older engines, which have relatively high emissions compared to newer ones. It should be noted that it will take at least another 20 years before the last engines that were built in the period before Directive 2003/44/EC are phased out. Also, it is recommended to further study uncertainties regarding the wide availability of low-sulphur diesel fuel and urea-water mixture and to further detail the implications of technologies on volume limitations of crafts.

Evaporative emissions

Evaporative emissions are an important source of Non-methane volatile organic compound emissions, which are at comparable levels, but lower than, exhaust emissions. Permeation from fuel tanks, hoses and lines are responsible for about 80% of total evaporative emissions, whereas diurnal emissions contribute another 20%. Hot soak and running losses are rather insignificant, being responsible for about 1% of the total evaporative emissions.

The technologies for reducing evaporative emissions are already mature and are successfully implemented in the road transport sector, such as in cars, mopeds and motorcycles. The same technologies, with proper sizing and adjustments, are also applicable in the recreational craft sector. Carbon canisters, pressurized fuel tanks, low-permeability (multi-layer) fuel tanks and fuel hoses are already used in the recreational craft sector in the US (EPA 40 CFR Part 1060), where emission limits apply for diurnal, fuel tank and fuel hoses emissions. Three scenarios for controlling evaporative emissions are examined in the present study: measures aimed at reducing diurnal emissions (scenario 1), fuel tank permeation (scenario 2), and fuel hoses permeation (scenario 3). A fourth scenario, combining all the above emissions controls, has also been assessed. In view of a possible harmonisation of emission limits with other jurisdictions, the respective emission limits already applied in the US have been considered for the above scenarios.

All scenarios deliver benefits. From the perspective of benefits versus costs, controlling permeation emissions from fuel hoses and lines will deliver the highest benefits within the shortest amount of time. In the longer range, scenario 4 scores best regarding the benefits versus costs. Setting a permeation emissions limit of 15 $g/m^2/day$ for fuel hoses and lines proves the most cost-beneficial option for reducing evaporative emissions from the recreational craft sector. This scenario has the shortest payback time (17 years) from all other policy options considered. All other options have a payback time of more than 20 years, making them less appealing compared to permeation control. An emissions limit of 1,5 $g/m^2/day$ for fuel tank permeation is the second most cost-beneficial option, with a payback time of 23 years. The payback time increases considerably for diurnal emissions control, for which an emissions limit of 1,5 g/lt/day has been considered.

Watercraft design categories

All stakeholders are satisfied with the current RCD design categories and did not criticise either the number or the range of them. Moreover, based on the experience of five years of implementation since the last amendment of the Directive, they confirmed that the main strength of the current set-up is that the market is running smooth with a high degree of familiarity and consensus. On the other hand, the main weakness of the design categories is the unequal and large gaps of wave heights and disproportionate range of physical forces induced by the wind forces between categories. Another weakness is the unequal distribution of the market share, since category C encompasses more than two thirds of the market.

Although no proposals were presented by the stakeholders, four scenarios for additional subdivisions or specifications were developed for assessment in the present study: subdivision of category D with increase of upper limit of significant wave height up to 1,5 m (scenario 1), subdivision of category C within its initial range (scenario 2), subdivision of category C and specification of new ranges in all categories in order to improve scientific soundness through reduction of the steps in Beaufort scale and through alignment of significant wave heights with the World Meteorological Organization sea states coding since these are the sea states broadcasted by the marine forecasts (scenario 3) and the existing categories remain with transposition of EN ISO 12217-1 category A upper limits (scenario 4).

An assessment of the first two scenarios resulted in incurring costs without any benefits. Scenario 3 presents an improved distribution of the design categories, rectifying the weakness of the unequal distribution to a certain extent, but incurs more than a billion in costs whereas no tangible benefits can be substantiated in terms of safety (reduced casualties) or advanced stability or advanced watercraft strength.

Scenario 4 is the most beneficial from a cost perspective, since it implies that leaving the current status unchanged can be combined with the minor modification of transposing EN ISO 12217-1:2017 upper limit values for the A category and the addition of technical information concerning wind speed, gusts and maximum wave height in the form of explanatory notes. In that case, it incurs no cost and delivers the qualitative benefits of clarity of information for the end-user aiming at safer use of the watercraft, legal certainty for the manufacturers and full harmonisation with the international standard ISO 12217-1,2,3: 2015.

1 Introduction

This chapter describes the background of this study (section 1.1), the specific objectives and overall approach (section 1.2 and 1.3 respectively) and a reader's guide (section 1.4), providing an overview of the content of this report.

1.1 Background

The Recreational Craft Directive (RCD) 94/25/EC, harmonising the provisions related to recreational craft, was adopted by the European Parliament and the Council in June 1994 and was applied from June 1996. Directive 2003/44/EC amended the Recreational Craft Directive in 2003 and introduced a set of exhaust and sound emission requirements as well as added the provisions for post-construction assessment. Directive 2013/53/EU replaced the Directive 94/25/EC in 2013.

The review clause set out in Article 52 of the Directive 2013/53/EU requires the European Commission (EC) to submit a report to the European Parliament and the Council by 18 January 2022. The report shall address:

- The technical feasibility for further reducing of exhaust emissions from marine propulsion engines.
- The feasibility to introduce requirements for evaporative emissions.
- The cost efficiency of technologies.
- The need to agree globally harmonised values for the sector.
- The evaluation of the impact of current structure of boat design categories on manufacturers and consumers, with a possibility to suggest additional specifications and sub-categories of boat design categories.

The Consortium, consisting of Panteia (NL, lead), TNO (NL) and Emisia (GR) (from now on called the "Consortium"), has been selected to carry out a study with the aim of collecting information in order to draft the report required by Article 52 of the Directive 2013/53/EU.

1.2 Objectives of the study

The specific objectives of the study are:

- To quantify the share of exhaust emissions produced by recreational marine engines in the EU comparing to exhaust emissions produced in related sectors in the EU.
- To find out if it is technically feasible and cost-beneficial to further reduce the emissions of pollutants from marine propulsion engines (nitrogen oxides NO_x, hydrocarbons HC, particulates PT and carbon monoxide CO). The cost efficiency of approaches and/or technologies and the need to agree globally harmonised values for the sector have to be taken into account.
- To find out if other engine testing procedures than listed in the Directive 2013/53/EU would be more appropriate for the recreational marine propulsion engines, including hybrid installations as well as if these procedures would better contribute to reduction of pollutants' emissions.
- To list the possible options of further reduction of exhaust emissions from recreational marine propulsion engines.
- To assess the possibility to set out requirements on evaporative emissions and fuel systems. To list possible options and accompany them by cost/benefit analysis.
- To assess the adequacy and impact of the current specification of watercraft design categories (based on combination of resistance to wind force and to significant wave height) on manufacturers and end-users.
- To assess the need to introduce further specifications, eventually to introduce further subdivision of the current design categories. Potential options to modify current specification of watercraft design categories are accompanied by cost/benefit analysis.

1.3 Overall approach

In this study, the overall approach is focused on combining the extensive knowledge and experience of experts in the field of emissions and watercraft design, market research, cost benefits analysis and legal and regulatory frameworks with an elaborate stakeholder consultation strategy. This approach makes it possible to develop economically, legally and regulatory feasible proposals related to further reduction of emissions and watercraft design categories and assess the support for these proposals within the sector.

As addition to the available expertise and experience by the Consortium, data is collected via (1) desk research and a literature review and (2) a stakeholder consultation, consisting of interviews with experts in the field, a public consultation and a targeted stakeholder consultation.
It should be noted that the data collected in the desk research, literature review and stakeholder consultation is used as base for the results of this study, including the proposals presented for exhaust emissions, evaporative emissions and design categories.

Based on the data collection, the Consortium has estimated the emission levels of the EU recreational craft sector (Chapter 2), has defined proposals for exhaust emissions, evaporative emissions and design categories (respectively Chapters 4, 5 and 6) and has carried out a Cost-Benefit Analysis of the proposals (Chapter 7), to obtain insight in the economic performance of the proposals compared to a base case.

Literature review

A literature review was carried out. A list of the literature studied is included in the Reference Chapter of this report. The results were used in the further course of the study.

Stakeholder consultation

An extensive stakeholder consultation was carried out via the public consultation and via interviews. The information obtained in the stakeholder consultation is used in the further course of the study. The following parties were interviewed via online meetings:

- ICOMIA
    - Many telcons (including two video conferences on exhaust emissions and hybridization) have been organised with Icomia experts (Udo Kleinitz, Patrick Hemp, Jeff Wasil, Richard Payne, Emil Hasl, M. Magnussion, Tjeerd Piket, Jason Stimmel, Klaus Roeder, Stefano Pagani).
    - ICOMIA/IMEC RCD Review 2022 (Part 1).
    - ICOMIA/IMEC RCD Review 2022-Evaporative emissions (Part 2).
    - ICOMIA/IMEC/EUROMOT RCD Review 2022-Evaporative emissions (Part 3).
    - Many telecons on design categories.
- IMEC
    - Many telcons have been organised with IMEC experts
- EBI
    - A number of telcons were organised with Philip Easthill and other EBI experts.
    - Two video conferences were organized with EBI on the topic of exhaust emissions and hybridization (attendance of Philip Easthill, Giovanni Franzini, Alberto Carmagnani, Stefano Pagani, Jose Luis Fayos, Sébastien Milendau, Ulrich Heineman, Tony Burie, Giel Tettelaar).
    - RCD Review Expert Interview: evaporative emissions.
    - Second Videoconference EBI on evaporative emissions.
    - Call with the owner of CAN-SB (fuel tank manufacturer)
- EBA
    - A telcon was organised with Stuart Carruthers
- DI2S
    - An interview with Pierre Duret (CEO) on state-of-the art OB engine technology.
- SECAPLAS (Association of Greek Manufacturers of FRP boats) - EU/GR
    - Interview with the president Giorgos Kranitis on design categories.

- SITESAP (Hellenic Professional Yacht Owners Bareboat Association, end-users association) - EU/GR
    - Interview with the president Paris Loutriotis on design categories.
- MEKY (Small crafts Research Center) - EU/GR
    - Interview with the owner and Naval Architect Antonis Mantouvalos on design categories.
- EMCI (Notified Body in Netherlands)
    - Telcon with the chairman Giel Tettelaar on design categories.
- Compass Boats (Recreational crafts manufacturer in Greece)
    - Interview with the co-owner George Samouhos on design categories
- ErgoSymbouleutiki (Recreational crafts Design Office in Greece)
    - Interview with the owner and Naval Architect Stratis Efstratiou
- Hellenic Ministry of Development and Investments / General Secretariat of Industry (Greek Surveillance Authority)
    - Interview with Ms Vassiliki Xroni on design categories
- IMCI (Notified Body based in Belgium)
    - Interview with the Managing Director Ulrich Heinemann on design categories.
- Maritime Administration of France / Leisure Boats (French Surveillance Authority for the implementation of RCD)
    - Interview with Pierre Forges on design categories
- Marine Mentors (consulting in small craft technology in Finland)
    - Interview with Markku Hentinen on design categories
- ICNN (Notified Body in France)
    - Interview with Director Alexandre Cocheril on design categories.
- AdCo
    - An interview (telcon) was organised with Natasja Kamp, the former chair of the related Administrative Cooperation Group (AdCo).
- Interview of a boat owner active in CI inboard diesel engine development, (early stage) interview on recreational crafting and possibility for emission reduction.
- Traficom (Finnish Transport and Communications Agency/Watercraft and Registers)
    - Communication with Senior Inspector Juhani Pappila on design categories.

In addition, the targeted stakeholder consultation, in the form of a questionnaire, took place amongst the institutes of all member states who have prepared the Informative Inventory Reports and National Informative Reports, to obtain missing data.

1.4 Reader's guide

This report includes the following:

- Introduction (Chapter 1, this chapter), includes a description on the background of this initiative (1.1), the specific objectives and questions of this study (section 1.2), the overall approach applied (section 1.3) and the reader's guide (1.4).
- Emission levels (Chapter 2) presents the methodologies used to estimate exhaust- and evaporative emissions levels of recreational craft within the EU (section 2.1), an overview of the assumptions used for this related to the EU fleet and activity data (section 2.2), information on emission levels (section 2.3) and how the order of magnitude of the estimated emissions relate to other sectors within the EU.
- Exhaust emission proposals (Chapter 3) presents an introduction in which the different propulsion systems of recreational craft causing exhaust emissions are described (section 3.1), followed by an overview of the current regulations on exhaust emissions and a discussion on the introduction of greenhouse gas emission regulation for exhaust emissions (section 3.2). Then, the results of the technical feasibility study for emission reduction are presented (section 3.3), per type of propulsion system. This is followed by a proposal of candidate scenarios (section 3.4) and a unit cost estimate (3.5).
- Evaporative emission proposals (Chapter 4) provides an introduction to evaporative emissions (section 4.1), followed by an overview of the evaporative emissions for recreational craft in the US and proposed evaporative emission limits for the EU recreational craft sector (section 4.2), the technical feasibility of related evaporative emission reduction technologies (section 4.3), the presentation of four candidate scenarios (section 4.4) and a cost estimate of the proposed changes (4.5).
- Design categories proposals (Chapter 5) provides an overview on the discussions and views on changing the watercraft design categories (section 5.1),

elaborates on the specifications of the regulation for design categories, presents identified possibilities for improvements for the legislation in literature and discusses related (watercraft design categories) regulation in other nations such as the US and reflects on the related ISO standards (section 5.2). Then, four candidate scenarios for changes are proposed (section 5.3), followed by a cost estimate of the proposed changes (section 5.4).

- Economic impact of scenarios (Chapter 6) presents the results of the impact analysis of the scenarios proposed, showing the economic implications of each of the scenarios. First, the methodology and input assumptions are presented (section 6.1), followed by the presentation of the qualitative- and quantitative economic impact (compared to a base case) of exhaust emission scenarios (section 6.2), evaporative emissions (section 6.3) and watercraft design categories (section 6.4). In the last section (section 6.5), a comparison of the impact assessment results of the proposed scenarios is presented.
- Conclusions and recommendations (Chapter 7) presents the answers to the question of this study, as mentioned in the Terms of Reference, as well as the conclusions and recommendations for exhaust emissions (section 7.1), evaporative emissions (section 7.2) and design categories (section 7.3).
- References provides an overview of the sources used for this study.
- Annex provides details on the Public Consultation (Annex 1) and input assumptions used for the evaporative emissions parts (Annex 2).

2 Emission Levels

This chapter presents the methodologies used to estimate exhaust- and evaporative emissions levels of recreational craft within the EU (section 2.1), an overview of the assumptions used for this, including an assumption of the EU fleet and related activity data (section 2.2), information on emission levels (section 2.3) and how the order of magnitude of the estimated emissions relate to other sectors within the EU.

2.1 Methodologies for calculating emissions and emission factors

This section deals with the mechanisms underlying the emissions and how we can quantify them. In turn, we deal with emissions as a result of exhaust of combustion gasses and emissions due to fuel evaporation.

2.1.1 Exhaust emissions

Emissions of recreational craft are not included in the databases of Eurostat (EC, 2021), in which data of the European Environmental Agency (EEA) is presented. The data is also lacking in the Informative Inventory Reports (IIR) and National Inventory Reports (NIR) at the member state level. In the search for available emission data of recreational craft, institutes who have prepared the IIR and NIR reports have been contacted with a request for information. However, this so called "top-down approach" of collecting emission data did not result in sufficient input required for the comparison of emissions at an EU level.

To obtain insight into the magnitude of recreational craft emissions at an EU level, to be used as input of the comparison with other sectors and as input for the Cost Benefit Analysis, a bottom-up estimation of the emission is made. For this, the Tier 3 method for estimated emissions of the EMEP/EEA guidebook 2019 is used (Part B, 1.A Combustion, 1.A.3.d Navigation (shipping)), which provides guidelines how to estimate emissions of recreational craft (EEA, 2019), as presented in Equation 2-1:

Equation 2-1 Equation used for calculating exhaust emissions of recreational craft

$$E_{i,m} = \sum_b \sum_e \sum_z \left(N_{b,e,z} * T_{b,e,z} * P_{b,e,z} * LF_{b,e,z} * EF_{b,e,z}\right)$$

In which:

- E = emissions by crafts per year
- N = number of crafts (# crafts)
- T = average duration of operation of each craft per year (hours/craft)
- P = nominal engine power (kW)
- LF = engine load factor (%)
- EF = emission factor (g/kWh)
- b = craft type (yawl, cabin boat, sailing boat, etc.)
- e = engine type (inboard, outboard, 2-stroke, 4-stroke)
- i = pollutant or fuel consumption (NO_x, PM, HC (NMVOC))
- m = fuel type (petrol, diesel)
- z = technology layer (conventional, aligned with 2003/44/EC)

Emission factors used are as recommended by the EMEP/EEA guidebook, table 3-11, for recreational craft, and are specified for:

- The type of craft: yawls and cabin boats, speed boats, water scooters, motor sailors, motor boats (<27 ft., 27-34 ft. and >34 ft.), sailing boats (<26 ft. and > 26ft), and other boats (<20 ft.)
- The type of fuel: petrol and diesel
- The type of engine: inboard or outboard
- Type of drive: 2-stroke or 4-stroke
- The type of substance - NO_x, PM, NMVOC, fuel required (g/kWh)
- Alignment with the 2003/44/EC directive and "conventional" emission factors, showing higher values

Emission factors of CO were lacking for the Tier 3 method. Therefore, the Tier 2 CO emission factors for recreational craft are used of the same EMEP/EEA guidebook, as presented in table 3-5, which are specified per type of fuel, engine, drive and technology layer. CO_2 emission factors are based on a study of TNO and CBS on CO_2 emission factors of petrol and diesel (Swertz, et al., 2017). For CO_2 emission factors to account for the production of electricity used by electric- and hybrid crafts, an emission factor of Well-To-Wheel (WTW) emissions[1] of 475 g/kWh is assumed (International Energy Agency, 2019), based on an unknown source of the production (assuming a combination of different types of grey- and green electricity).
The conventional emission factors of the EMEP/EEA guidebook are applied to the estimated part of the fleet which was produced before the 2003/44/EC directive was in force. The emission factors of the 2003/44/EC are applied when the related Directive was in force (EU, 2003), so before the period 2013/53/EU was in force (EC, 2013). Emission factors aligned with the latest Directive are not available in the EMEP/EEA guidebook. Therefore, for the use of emission factors on the part of the fleet produced in 2016 and later on (when the 2013/53/EU became in force), the emission factors for 2003/44/EC are corrected with the differences in emission limits as presented for different engines in the 2013/53/EU- and 2003/44/EC Directives.

The total installed nominal power of the engines per craft, type of fuel, type of engine(s) and drive is also assumed based on the values presented in the EMEP/EEA guidebook, as shown in table 3-11 of the guidebook. The values are assumed as installed nominal power per craft, so assuming 1 engine per craft. For water scooters (assumed 75 kW in this study) and speedboats (assumed 125 kW), higher values are assumed than presented in the EMEP/EEA guidebook, following information obtained of ICOMIA regarding water scooters and observed higher values of installed power of speedboats in the market.
For the estimation of exhaust emissions in this study, a simplification and assumption is made that the lifetime of the engine is equal to the lifetime of the craft. The average marine petrol engine runs approximately 1500 hours and the average diesel en (National Marine Manufacturers Association, 2021). Assuming the 1500 hours and 35 engine hours a year (as presented in the next section), this would theoretically mean over 40 years, equally to the assumed lifetime of a craft running on petrol (and theoretically, diesel engines would last longer). However, in practice, engines could be replaced sooner than the lifetime of the craft. Engine replacement before craft dismantling is not accounted for in this study, leading to an "upper estimate" of the exhaust emission levels.

2.1.2 *Evaporative emissions*

Evaporative emissions refer to the sum of all fuel related NMVOC emissions not deriving from fuel combustion. Specifically, evaporative emissions of VOCs emanate from the fuel supply system of petrol-powered crafts. Evaporative emissions from diesel-powered crafts are negligible due to the presence of heavier hydrocarbons and the low vapour pressure of diesel fuel and therefore can be neglected in calculations (Mellios & Ntziaxristos, 2019).

In order to make an assessment on the likely emission levels of the sector, the relevant methodology used in the road sector (passenger cars and L-category vehicles) properly adapted, and the methodology used by the US EPA are combined. The applied methodology is based on the different sources of evaporative emissions as described below and carried out for each EU member state by month because of the temperature and fuel volatility variations.

The different sources of evaporative emissions taken into consideration for the assessment include:

- **Diurnal emissions** are due to temperature variation throughout the day. An increase in ambient temperature results in thermal expansion of the fuel and vapour in the tank.

[1] Well-To-Wheel emissions are the sum of Tank-To-Wheel (TTW) emissions, the emissions resulting from the production of electricity by a power plant, and Well-To-Tank (WTT) emissions, the emissions resulting from the production of the energy carriers the power plant is using.

For diurnal emission estimates, the Reddy equation describes and provides the amount of NMVOCs emitted per day as a function of fuel volatility, temperature variation, fuel tank size and fill level (EPA, 2010). With proper adjustments, Equation 2-2 provides the annual grams of diurnal emissions.

Equation 2-2 Reddy equation used for diurnal emissions estimation

$$Diurnal = \sum_{s} Ds \times \sum_{j} Nj \times \left[\left(1 - \frac{h}{100}\right) \times vtank, j \times \left(0{,}025 \times e^{0{,}0205 \times vp} \times \left(e^{0{,}0716 \times Tmax} - e^{0{,}0716 \times Tmin}\right)\right)\right]$$

Where:

- Diurnal: annual diurnal emissions [g]
- Ds: number of days for which craft are in operation
- j: fuel tank category (portable plastic, installed plastic/metal (stored in water), installed plastic/metal (stored on trailer))
- N_j: number of craft in category j
- h: fuel tank fill level [%]
- vtank: fuel tank volume [lt]
- vp: fuel vapour pressure (DVPE) [kPa]
- Tmax: monthly maximum tank temperature [°C]
- Tmin: monthly minimum tank temperature [°C]

The fuel tank fill level is determined as the volume of fuel in the tank divided by the fuel tank capacity. For the present estimations, a 50% of fuel tank fill is assumed. In addition, typical fuel tank volumes are assumed for each craft type.

Dry vapour pressure equivalent (DVPE) is a common measure of petrol volatility which defines its evaporation characteristics. During both the summer and winter months, petrol evaporates at different rates depending on the ambient temperature. Fuel with a lower DVPE evaporates slower while higher DVPE fuel evaporates faster. In the EU, winter blends need to have a higher DVPE (90 kPa) for engines to start and operate properly during cold weather. During summer, lower DVPE fuels (60 kPa) are used to prevent unnecessary evaporation due to rising temperatures (Appendix 2, Table A 2) illustrates the DVPE values used for each member state.

As diurnal emissions are affected by the ambient temperature variations, average values of minimum and maximum temperatures for each member state have been collected (Appendix 2, Table A 3).

A temperature correction is required in order to avoid overestimations during the winter season. To account for this, winter diurnal emissions are adjusted by including a minimum temperature of 4,4 °C. The model checks both Tmin, Tmax input values to identify if either is below the limit of 4,4°C. If both are below 4,4°C, then diurnal emissions are set to zero. If just Tmin is below 4,4°C, but Tmax is above 4,4°C, Tmin is adjusted to 4,4°C. For example, if Tmin is -6,6°C and Tmax is 10°C, the model calculates diurnal emissions for the 4,4°C to 10°C range (EPA, 2010).

Additional temperature adjustments are applied to factor in the boat storing (in the water, on trailer), as described below:

- A 50% temperature swing reduction for crafts with installed (plastic or metal) tanks stored on trailers.
- An 80% temperature swing reduction for crafts with installed (plastic or metal) tanks stored in water.
- A 0% temperature swing reduction for crafts with portable plastic tanks. These are exposed to the ambient air and, as a result, there no temperature swing adjustment is applied (EPA, 2008).

The corrected Tmin, Tmax input values arising from each temperature swing are calculated presented in Equation 2-3:

Equation 2-3 Equations for temperature correction due to temperature swing.

$$Temperature\ swing = Tmax - Tmin$$

$$Taverage = \frac{Temperature}{2}$$

$$Tmin, corrected = Taverage - \frac{Temperature\ swing}{2}$$

$$Tmax, corrected = Taverage + \frac{Temperature\ swing}{2}$$

To avoid overestimations related to the methodology and the activity, two correction factors are applied. The first is a correction of 0,78, derived from the comparison of US non-road test results with the theoretical results of Equation 1-2 (EPA, 2010). The second correction is related to the use of portable fuel tanks and a value of 0,5 is assumed to account for tanks out of use.

- Fuel tank permeation/leakage occurs when fuel escapes through the permeable walls of the fuel tank. The outer surfaces of the tanks are exposed to ambient air, so the petrol molecules permeate through them and are emitted directly into the atmosphere. Permeation is most common through plastic fuel tanks.

Fuel tank permeation emissions are estimated using Equation 2-4 :

Equation 2-4 Equation used for the estimation of the NMVOCs emitted through permeation from the fuel tank

$$fuel\ tank\ permeation = \sum_{s} Ds \times \sum_{j} Nj \times \left[EF_j \times fuel\ tank\ surface\ area_j \times TCF, tank\right]$$

Where:

- Fuel tank permeation: annual fuel tank permeation emissions [g]
- Ds: number of days for which craft are in operation
- j: fuel tank category (portable plastic, installed plastic/metal (stored in water), installed plastic/metal (store on trailer))
- Nj: number of craft in category j
- EF_j: fuel tank permeation emission factor [g/m²/day]
- Fuel tank surface area,$_j$ [m²]
- TCF,tank is the temperature correction factor

As permeation is very sensitive to temperature, Arrhenius' relationship is applied to adjust the emission factors by temperatures, where the constants reflect the properties of materials used in fuel tanks and lines. The temperature adjustment is applied from the average temperature for the scenario. Since the emission factors are typically provided at a temperature of 29°C, the temperature adjustment reduces emissions by 50% for each 10°C reduction from 29°C (EPA, 2010). The temperature adjustment is calculated using Equation 2-5:

Equation 2-5 Temperature correction factor for fuel tank permeation

$$TCF, tank = 0{,}03788519 \times e^{0{,}03850818 \times (32 + 1{,}8 \times Taverage)}$$

The fuel tank surface area is calculated by Equation 2-6. This expression relates fuel tank volume (lt) to surface area (m²).

Equation 2-6 Fuel tank surface area equation

$$fuel\ tank\ surface\ area\ = 0{,}15 \times \sqrt{\frac{(0{,}219969 \times tank\ volume + 2)^2}{4} - 1}$$

Permeation emissions are proportional to the fuel tank surface area. As the surface to volume ratio of a fuel tank changes with capacity and geometry of the tank, two similar shaped tanks of different volumes or two different shaped tanks of the same volume could have different permeation rates even if they were made of the same material and used the same emission control technology. For this reason, the emission factors, are based on g/m²/day and are function on the fuel tank type. As presented in Table 2-1 and Table 2-2 , the fuel tank permeation emission factors are aligned to fuel tank specifications (manufacturing process and construction material) for both uncontrolled and controlled craft.

Portable fuel tanks and some small, higher production-volume installed tanks are generally blow-molded using high-density polyethylene (HDPE). Installed plastic marine fuel tanks are often produced in many shapes and sizes to fit the needs of specific craft designs. These fuel tanks are generally rotationally-molded out of cross-link polyethylene (EPA, 2008).

Table 2-1 Emission factors for fuel tank permeation of uncontrolled[2] crafts

Fuel tank permeation baseline emission factors at 29°C [g/m2/day]	
Fuel tank type	petrol (E10)
HDPE plastic tanks	10,9
cross-link plastic tanks	8,8

Table 2-2 Emission factors for fuel tank permeation of controlled[3] crafts

Fuel tank permeation control emission factors at 29°C [g/m2/day]	
Fuel tank type	petrol (E10)
All	1,5

Metal tanks are assumed to have zero permeation, so the metal tanks are not included in the calculation of emissions.
A correction of 0,5 related to the use of portable fuel tanks is assumed to account for tanks out of use.

- Hose permeation emissions concern the fuel hoses, and their emissions generation mechanism is similar to that of fuel tank permeation.

Hose permeation emissions from recreational craft include all emissions from supply/return, fill neck and vent line hoses. Hose permeation emissions are estimated using Equation 2-7:

Equation 2-7 Equation used for the estimation of the NMVOCs emitted through permeation from the fuel hoses

$$hosepermeation = \sum_{s} Ds \times \sum_{j} Nj \times \left[EF_{j,a} \times fuel\ hose\ surface\ area_{j} \times TCF, hose\right]$$

Where:

- Hose permeation: annual hose permeation emissions [g]
- Ds: number of days for which craft are in operation
- j: fuel tank category (portable plastic, installed plastic/metal (stored in water) installed plastic/metal (store on trailer))
- N_j: number of craft in category j
- a: craft category (according EEA classification)
- $EF_{j,a}$: hose permeation emission factor [g/m²/day]
- Fuel hose surface area,$_j$ [m²]
- TCF,hose is the temperature correction factor

As mentioned in the case of fuel tank permeation, permeation is very sensitive to temperature and thus, a similar TCF is applied for hose permeation. Emission factors are given for a reference temperature of 23°C, the adjustment therefore reduces emissions by 50% for each 10°C reduction from 23°C (EPA, 2010). The temperature adjustment is calculated using Equation 2-8:

[2] uncontrolled crafts: crafts without emission control device (typical of the current EU situation).
[3] controlled crafts: crafts with emission control devices.

Equation 2-8 Temperature correction factor for hose permeation.

$$TCF, hose = 0{,}06013899 \times e^{0{,}03850818 \times (32+1{,}8 \times Taverage)}$$

The fuel hose surface area is calculated by Equation 2-9:

Equation 2-9 Fuel hose surface area equation

$$fuel\ hose\ surface\ area\ = \pi \times hose\ length\ \times inside\ hose\ diameter$$

Hose permeation is a function of fuel hose surface area and thus, the emission factors are based on g/m²/day. As presented in Table 2-3 and Table 2-4, the hose permeation emission factors are aligned to engine specifications (engine size and fuel tank type) for both uncontrolled and controlled craft.

Table 2-3 Emission factors for fuel hose permeation of uncontrolled crafts

Supply/return hose permeation baseline emission factors at 23°C [g/m2/day]		
Craft type	Engine size (kW)	
portable/2-str outboard	<=18,6	222
installed/2-str outboard	>18,6	125
installed/4-str outboard	All	40
installed/2-str PWC[4]	All	125
Fill neck & vent line hose permeation baseline emission factors at 23°C [g/m2/day]		
Craft type	Engine size (kW)	
All	All	4,9

Table 2-4 Emission factors for fuel hose permeation of controlled crafts

Supply/return hose permeation control emission factors at 23°C [g/m2/day]		
All	All	7,5

Metal hoses are assumed to have zero permeation, so the metal fuel lines are not included in the calculation of emissions.

- Hot soak emissions are the emissions caused when a hot engine is turned off. Heat from the engine and exhaust system increases the temperature of the fuel in the system (which is no longer flowing).

Hot soak emissions are estimated using Equation 2-10:

Equation 2-10 Equation used for the estimation of the NMVOCs due to hot soak.

$$hotsoak\ = \sum_{a} N_a \times [EF \times engine\ starts_a \times activity\ hours_a]$$

Where:

- Hot soak: annual hot soak emissions [g]
- a: craft type
- N_a: number of craft in category a
- EF: hot soak emission factor in [g/start]
- Engine starts,$_a$: Number of engine starts by craft type in [start/h]
- Activity hours,$_a$: activity hours by craft type in [h/year]

[4] Personal watercraft

Based on Equation 2-10, engine starts are equivalent to the engine being turned off when a hot soak occurs. Hot soak emissions are independent of the temperature and thus, no temperature correction is applied.

Table 2-5 Engine starts per hour[5]

Craft type	*activity [start/hour]*
Sailing boats (<26 ft.)	0,5
Yawls and cabin boats	0,5
Speedboats (outboard)	0,2
Speedboats (inboard)	0,2
Water scooters	3
Other boats (<20 ft.)	0,5

Table 2-6 Activity hours per year[6]

Craft type	*activity [hour/year]*
Sailing boats (<26 ft.)	45
Yawls and cabin boats	35
Speedboats (outboard)	35
Speedboats (inboard)	45
Water scooters	75
Other boats (<20 ft.)	35

The hot soak emission factor is 3 g/start and is applied to all recreational craft, except those using portable fuel tanks (i.e., outboard engines <=18 Kw). This value is based on US-EPA data for non-road equipment (EPA, 2010).

- Running loss emissions are the result of vapour generated in the fuel tank during vessel operation.

Running loss emissions are estimated using Equation 2-11:

Equation 2-11 Equation used for the estimation of the NMVOCs due to running losses

$$running\ loss\ = \sum_{a} N_a \times [EF \times activity\ hours_a]$$

Where:

- Running loss: annual running loss emissions [g]
- a: craft category
- N_a: number of craft in category a
- EF: running loss emission factor in [g/h]
- Activity $hours_{,a}$: activity hours by craft type in [h/year]

Running loss emissions are independent of the ambient temperature, so no temperature adjustment is necessary. Running loss emissions are not a significant source of evaporation for:

- Crafts with outboard engines.
- Crafts with larger fuel tanks, as the fuel tank is mounted away from the engine and is not significantly affected by engine heating.

As a result, crafts with either outboard engines, or larger fuel tanks have no emission factor. For the remaining boat categories (smaller inboard/ sterndrive engines and water

[5] Based on our assumptions.
[6] Based on data received from interviews with stakeholders.

scooters), an emission factor of 2,86 g/h is applied, based on US-EPA data for non-road equipment (EPA, 2010).

2.2 Fleet and activity data

Two aspects are important in order to determine emissions from recreational boating. Firstly, we need to understand the mechanisms underlying these emissions and how we can quantify them. We discussed this in the previous section. On the other hand, we need to understand the size of the recreational fleet and the characteristics of the various components of this fleet. This section deals with this aspect in turn.

As input for the emission estimations, numbers on the fleet size and activity data (including engine hours/year, load factor) are required.
For the estimation of exhaust emission levels, a specification of numbers is required in the EMEP/EEA craft classification (EEA, 2019), as presented in section 2.1, since available emission factors apply to the crafts in this specific classification: speed boats, water scooters, motor sailors, yawls and cabin boats (mostly outboard cabin boats and very limited yawls, generally reported "sailing boats" are classified within the sailing boats categories), motor boats (<27 ft., 27-34 ft. and >34 ft.), sailing boats (<26 ft. and > 26ft), and other boats (<20 ft.).

Fleet statistics and specifications are collected from recreational craft associations, including ICOMIA and EBI. Furthermore, statistics are collected from the IIR and NIR reports. In addition, a targeted stakeholder consultation is held amongst all member states, specifically amongst the institutes who have prepared the emission inventories, to obtain (additional) fleet data.

Numbers of crafts and specifications of the types- and engines are incomplete at the EU level. However, for most member states, the order of magnitude of the current recreational craft fleet is known. For approximately two-third of the member states, information on the types of craft within the fleet is available, however, the member states use different craft classifications. For very few countries, specific statistics are available on engine-level (for Denmark, detailed data in the EMEP/EEA classification is available).

In summary of the above, there is a lack of fleet data in a consistent (EMEP/EEA) classification and with a lack of detail. Therefore, making an estimation of the fleet size, types of craft and engine specifications within the EMEP/EEA classification of the complete EU fleet is unavoidable.
As part of the estimation, available data of fleet statistics are assumed within the EMEP/EEA classification (e.g. sailing boats, motor boats, water scooters). The order of magnitude of the fleet size and craft types per member state of which data is lacking, are estimated based on the fleet statistics of a comparable member state, based on the population ratio. A comparable member state of a member state with missing data is selected based on geographical location, aerial size and if the country is land-locked or located adjacent to the sea. For example, for the estimation of the fleet size and craft types of Latvia, the fleet size- and craft types of Estonia are assumed, corrected with the population ratio of both countries.
Then, additional engine specifications (the distribution 2-stroke and 4-stroke petrol engines per craft type, share using diesel or petrol per craft type, the distribution sizes of sailboats and motor boats) are appointed to the craft types assumed, based on the detailed reference dataset of recreational craft available (as presented in the IIR of Denmark 2019). Regarding the age of the fleet, a lifetime of 40 years per craft is assumed, in line with the EU publication "Assessment of impact of business development improvements around nautical tourism" (EU, 2016).
Based on the economic attractiveness of electric engines with lower power levels (especially below 5 kW, reference to Chapter 3 for an elaboration), it is assumed that in the period relevant to this study (from the "current" situation, since the implementation of RCDII in 2016 to 2040) on average 50% of the category "other boats <20 ft.", 50% of the "Sailing boats <26 ft." and a smaller part (assumed 15%) of the "Sailing boats >26 ft." produced are electric. It should be noted that this is an optimistic assumption. Hybridization is most likely for inboard engines and therefore, it is assumed a part of these crafts with inboard engines produced (assumed 10%) are hybrid. The authors are aware that these numbers are expectations and strongly dependent on expected future cost and volume/weight reductions of batteries.

For the Cost Benefit Analysis, a projection of the fleet development is required, to assess the economic impact of the various scenarios considered. First, the fleet size and composition is estimated for the "base year" 2020. Fleet data of member states which were not from this base year (but e.g. from 2019) are updated with a correction factor, in line with the population growth as presented in the Eurostat data, series DEMO_GIND (EC, 2021). Population growth is used as indicator for fleet growth, based on the observed correlation between population growth and fleet size in the past few years (of the few member states of which data is available). Since a projection of the EU fleet is unavailable, this same indicator (series PROJ_19NP) is used for the projection of the EU fleet size up to 2040, which is required as input for the cost benefit analysis (EC, 2021). In line with the assumption of a craft lifetime of 40 years and an assumption of an equal distribution regarding age of the 2020 fleet (no sufficient data source stating otherwise), the number of crafts per production period and so per legislation period are estimated. It is assumed older crafts (produced when the 94/25/EC was in force) are dismantled before dismantling newer crafts (more recent legislation).
Furthermore, for the projection, it is assumed all petrol crafts produced after 2020 are 4-stroke (2-stroke engines are being out phased).

The 2020 composition and projection of the EU recreational craft fleet is presented in Figure 2-1 and Figure 2-2. It should be noted that the total fleet size seems constant in the figure in a first view, but the numbers show a very small increase in the next few years followed by a very small decrease during the time period, in line with the population projections series of Eurostat.

Figure 2-1 Assumption of EU fleet size and composition per type of craft 2020-2040 for the purpose of this study (electric- and hybrid crafts assumptions not specified)

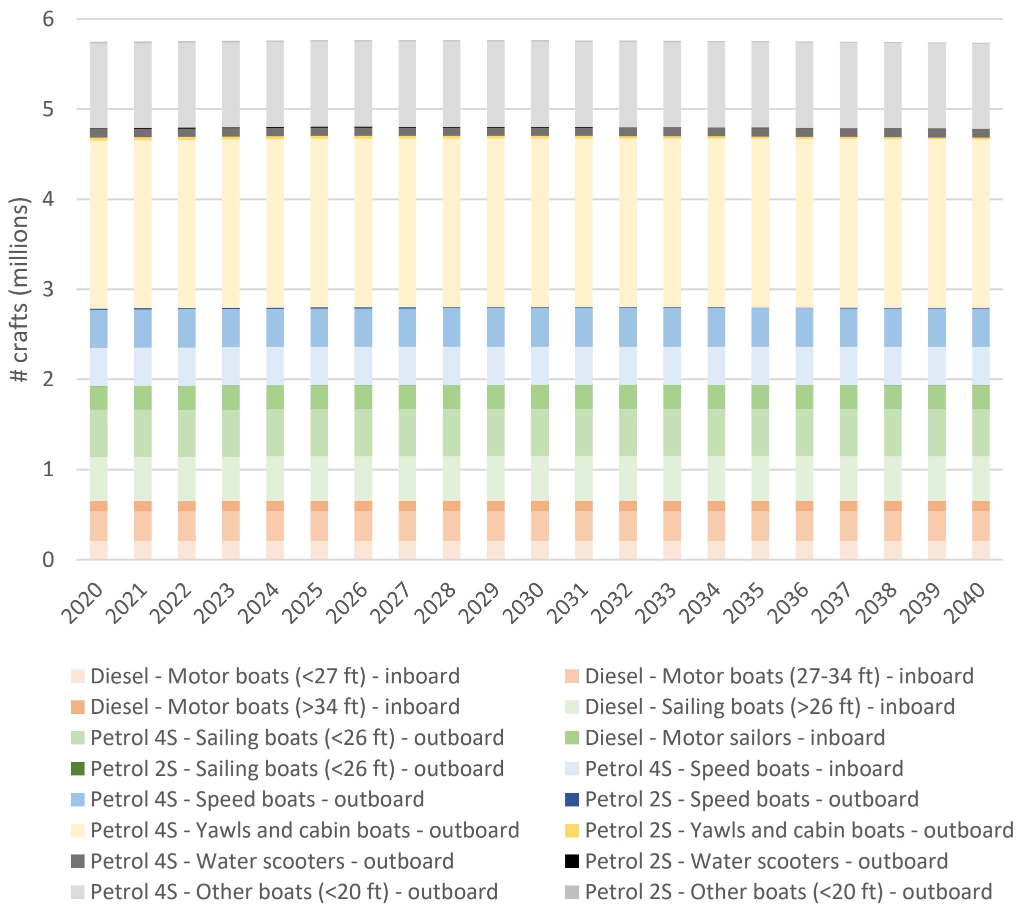
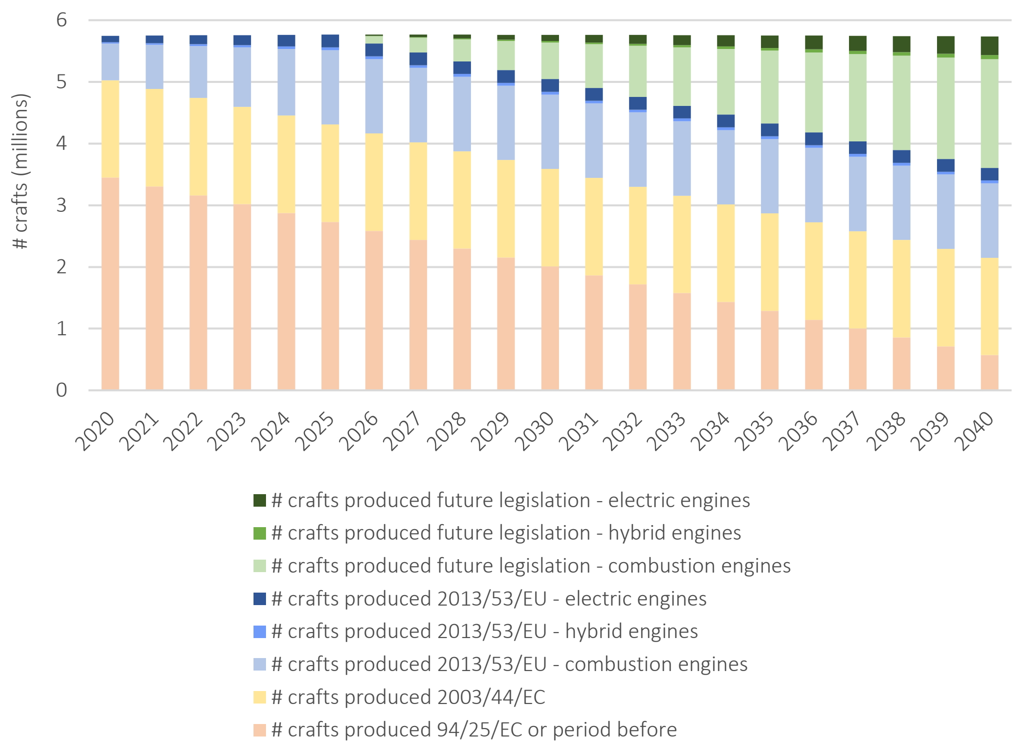


Figure 2-2 Assumption of the EU fleet and breakdown based on production period and engine specification combustion-, hybrid- or electric



In Table 2-7, the assumed activity hours- and engine load factors assumed for the various craft types are presented, based on interviews with EBI and ICOMIA, as well as engine-specific numbers found in literature, based on a study of the California Air Resources Board (CARB, 2014).

Table 2-7 Assumptions of engine hours / year and load factors

Craft type	*Assumption engine hours / year*	*Load factor*
Diesel - Motor boats (27-34 ft.)	35	0,21
Diesel - Motor boats (<27 ft.)	35	0,21
Diesel - Sailing boats (>26 ft.)	45	0,35
Diesel - Motor boats (>34 ft.)	35	0,21
Diesel - Motor sailors	35	0,21
Gasoline 4S - Sailing boats (<26 ft.)	45	0,32
Gasoline 4S - Yawls and cabin boats	35	0,32
Gasoline 4S - Speed boats (outboard eng.)	35	0,32
Gasoline 4S - Speed boats (inboard eng.)	45	0,21
Gasoline 4S - Water scooters	75	0,4
Gasoline 4S - Other boats (<20 ft.)	35	0,32
Gasoline 2S - Sailing boats (<26 ft.)	45	0,32
Gasoline 2S - Yawls and cabin boats	35	0,32
Gasoline 2S - Speed boats	35	0,32
Gasoline 2S - Water scooters	75	0,4
Gasoline 2S - Other boats (<20 ft.)	35	0,32

For the evaporative emissions assessment, an additional number of assumptions has been made, as presented below:

- Assumption of the allocation of fuel tank types per craft type (Table 2-8)
- Engine starts per hour (Table 2-5)

Table 2-8 Allocation of fuel tank types per craft type

Craft type	*Portable plastic fuel tank*	*Installed plastic in trailerable*	*Installed metal in trailerable*	*Installed plastic in non-trailerable*	*Installed metal in non-trailerable*
Sailing boats (<26 ft.)	0	0,6	0	0,2	0,2
Yawls and cabin boats	0	0,6	0	0,2	0,2
Speed boats (outboard)	0,45	0,3	0	0,25	0
Speed boats (inboard)	0	0,4	0,15	0,2	0,25
Water scooters	0	1	0	0	0
Other boats (<20 ft.)	0,6	0,3	0	0,1	0

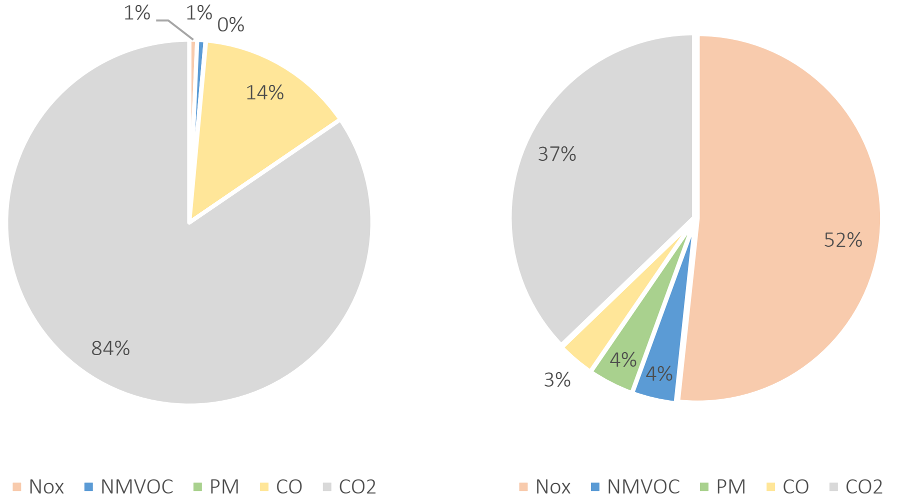
2.3 Exhaust emissions

Based on our estimates regarding the size of the recreational fleet and the emission characteristics of the various components of this fleet (section 2.2) and the methodology described for estimating exhaust emissions (2.1), we determined the total of exhaust emissions of recreational craft for the EU.

2.3.1 Estimated emission levels

EU emission levels for 2021 are presented in this sub section. The share of the emission levels per substance of the total emissions of recreational craft, in tonnes (left pie chart) and monetized values (right pie chart), are shown in the pie charts below. From the left chart, it becomes clear CO_2 has the largest share of emission levels (84% of all tonnes emitted by recreational craft are CO_2). From the right pie chart can be concluded that the largest environmental cost is a consequence of NO_x emission (52% of all environmental costs), followed by CO_2 (37% of all environmental costs).

Figure 2-3 Per substance, the share of emissions of the total in tonnes (left) and environmental cost (right)



Exhaust emission levels for recreational craft in 2021 for NO_x, NMVOC, PM, CO and CO_2 are respectively estimated at ~28000 tonnes, ~29000 tonnes, ~1600 tonnes, ~558000 tonnes and ~3,38 million tonnes. If monetizing these values by using the assumed 2021 environmental prices based on the Handbook on the external cost of transport 2019 (reference to chapter 6 on the economic impact and explanations of this assumptions), NO_x and CO_2 have the largest environmental cost (almost €900 million together in 2021), followed by relatively smaller environmental cost for PM and NMVOC (each ~€40 million in 2021) and CO (~€30 million in 2021).

2.3.2 *Largest contributors*

It is noted that for 2021 generally most emissions are emitted by older engines of crafts produced when the 94/25/EC and the 2003/44/EC directive was in force, following the related EMEP/EEA emission factors for engines produced in these periods (which assume higher emission factors for the period when the 2003/44/EC was in force).

It is estimated that just over one third of the NO_x emissions is caused by diesel combustion and two third by petrol combustion. NO_x is mostly emitted by inboard and outboard petrol speed boats and inboard diesel motor boats, followed by diesel- and petrol sailing boats, motor sailors and outboard petrol yawls and cabin boats.

Roughly 75% of the CO_2 is emitted by petrol engines. The largest contributors are outboard and inboard petrol speed boats, inboard diesel motor boats, outboard petrol yawls and cabin boats and sailing boats, followed by water scooters.

Over 60% of the recreational craft PM emissions are resulting from diesel combustion. PM is mostly emitted by diesel motor boats, followed by diesel sailing boats and motor sailors. Most petrol contributions to PM come from 2-stroke engines. Noted it is assumed 2-stroke engines will be out phased in the future.

Almost 95% of the HC (NMVOC) is emitted by petrol engines. The largest contributors are outboard petrol speed boats, followed by outboard yawls and cabin boats, water scooters and inboard speed boats.

Almost all of the CO emissions are emitted by petrol engines, specifically speed boats, yawls and cabin boats and water scooters.

2.3.3 *Share of emissions*

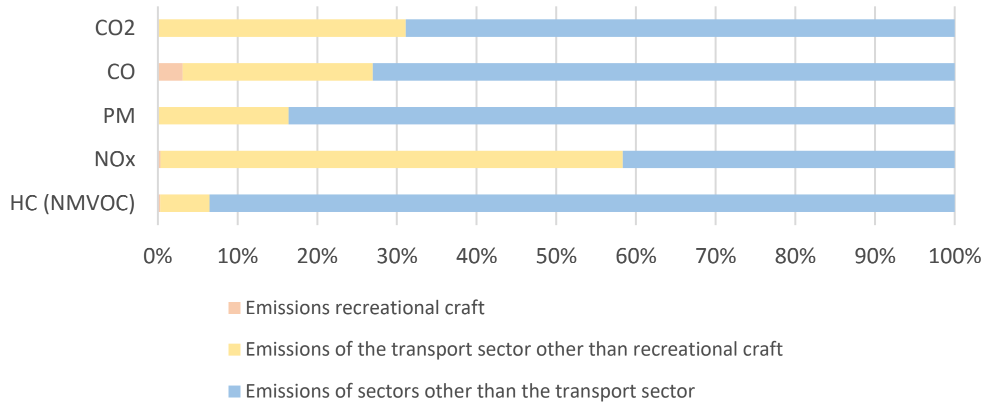
The air emission inventories as presented by Eurostat are used as for the comparison of recreational craft pollutant emissions with shipping- and transport emissions at the EU level (EC, 2021). The emission inventories provide key input for policies on air quality and climate change and are collected by the EEA, which uses them to compile EU aggregates on behalf of the European Commission.

The EEA emission values of CO_2 emissions are extracted from Eurostat (EC, 2021), series Greenhouse gas emissions by source sector (ENV_AIR_GGE), of which the data source is the European Environment Agency. The emission values of pollutants PM, NO_x and HC (NMVOC) are extracted from the same source Eurostat as well (EC, 2021), from the series ENV_AIR_EMIS. The data of the pollutants of CO are not included in the ENV_AIR_EMIS series of Eurostat and are therefore extracted of the data sources of emission inventories of the EEA directly (EEA, 2021).

The share of recreational craft of the transport sector- and all other EU sectors is presented in Figure 2-4. It is noted that the most recent numbers available and collected for the comparison are of the years 2018-2019, whilst the estimation of the recreational craft emissions are based on the estimated current fleet size. However, no large changes are expected in a year or two and therefore no major changes in the results are expected.

In line with the methodology section on exhaust emissions (section 2.1) the estimation of recreational craft emissions is an *upper estimate*. In other words, the shares presented in this section are maximum expected shares.

Figure 2-4 Emissions of recreational craft compared to the EU transport sector and all other EU sectors



The share of CO_2 of recreational craft (estimated just over 3 million tonnes per year) of the EU transport sector (0,4%) is very small, just as the share of all EU sectors together (0,1%). Total emissions of the EU transport sector, including recreational craft, are estimated over 800 million tonnes. Emissions of all EU sectors together in this year are over 2,5 billion tonnes for the same year.

With just over 1600 tonnes emissions, also the share of PM (0,5% of the transport sector and 0,1% of all EU sectors) is very small. Total PM emissions of the EU transport sector are ~330000 tonnes and all EU sectors together have emitted almost 2 million tonnes. The large majority of PM emissions in the transport sector are emitted by the road transport sector and by international shipping. The transport sector only contributes marginally to the PM emissions of the EU: the largest contributors are the residential, commercial and institutional sector.

With an estimated 28000 tonnes NO_x, the share of emissions of the EU transport sector (ca. 5 million tonnes/year) is estimated at 0,6%. Most NO_x within the EU transport sector is emitted by passenger cars, heavy duty vehicles, buses and international shipping. The share of all EU sectors (ca. 8,5 million tonnes/year) is 0,3%. The transport sector is the sector with the largest share in NO_x emissions.

The estimated share of HC (ca. 29000 tonnes) in the form of NMVOC is just over 4% of the total EU transport sector (ca. 670000 tonnes/year). More than half of the EU transport NMVOC emissions are caused by passenger cars, mopeds and motorcycles (with petrol engines, just as of recreational craft). Compared to all EU sectors, the share of recreational craft is 0,3%: the transport sector has a limited contribution to NMVOC emissions of the EU (total more than 10 million tonnes/year). The largest contributing sector is the manufacturing and extractive industry.

The CO emissions, with ~550000 tonnes for recreational craft, have a share of over 11% of the total transport sector (~5 million tonnes/year) and a share of 2,4% of the total EU CO emissions. Most CO within the transport sector is emitted by passenger cars, followed by mopeds and motorcycles. The largest contributing sectors to CO emissions in the EU are the residential, commercial and institutional sector, the transport sector and the construction and manufacturing sector. It is worth pointing out that most recreational craft engines run on petrol and have very high specific CO emissions levels (going up to typically 350 g/kWh for the smaller versions without catalyst). These high values originate with the rich fuel-air ratio calibration strategies of these engines. Rich operating is sometimes also applied at the highest loads with passenger cars, but these operating points have a lower weight in the emission tests. Diesel engines have even much lower levels (with values usually well below 2 g/kWh).

Although a check of the estimations of recreational craft is difficult due to the limited available data on emissions of the sector, the large share (of a relatively small sector such as recreational craft) of CO emissions of the transport sector and all sectors together is in line with the few publications available. In the Netherlands, the share of recreational craft CO emissions of all sectors is approximately 3,3% (which is higher than the estimated 2,4% in this study for the EU) and the share of the transport sector is larger than the share of other substances as well (similar to the estimations on an EU level in this study), estimated at 6-7%. The Informative Inventory Report of the Netherlands (Wever, et al., 2021), states recreational crafts are one of the *key sources of CO emissions*, together with passenger cars, mopeds, motorcycles (which mainly have petrol engines, just as most recreational crafts), the manufacturing and construction industry, households and gardening. It should be noted that inland shipping and international shipping (in which generally no petrol is used) are *not* mentioned as key source of CO in the Netherlands (however, inland- and international shipping are key sources of NO_x and PM). At the same time, it is stated that recreational crafts are only a small emission source of substances other than CO (e.g. NO_x, PM). In line with this statement of recreational craft being a large contributor to CO emissions, the institute that prepared the Informative Inventory Report of Italy (following the targeted stakeholder consultation) states recreational craft emissions of Italy to be just over 50000 tonnes/year – this is in the order of 10% of the total estimated CO emissions on an EU level (as estimated in this study), aligning with the fleet size of Italy as share of the estimated EU fleet, which is also in the order of 10%.

Comparing the emissions of the recreational craft with emissions of the shipping sector accurately is challenging. This is due to the fact that emissions of recreational craft are generally not calculated by the Member States separately for the emission inventories, but recreational craft emissions are included integrally by accounting for them in the national fuel consumption numbers, which are considered in the emission inventories. This information is obtained during the targeted stakeholder consultation in the form of a survey, in which institutes of EU member states were contacted that have prepared the national emission calculations, as input for the inventory reports. The respondents in the survey also stated that the fuel consumption of recreational craft is allocated to different NFR[7] categories: 1A3D (navigation), 1A5B (Other: Mobile (including military, land based and recreational boats) or 1A3B (road transport). Whilst most of the institutes of EU member states stated to have allocated the fuel consumption to 1A3D (navigation), it was also stated a part of the fuel, the petrol-part specifically, is allocated to the road transport category. In most cases however, diesel emissions of recreational craft are allocated to category 1A3D.

In other words, it is unknown to what extent the petrol emissions of recreational craft are allocated to the NFR category corresponding to the shipping sector and therefore a proper comparison of the petrol emissions of the recreational craft- and shipping sector cannot be made. However, the "what-if" scenario of diesel emissions being allocated in 1A3D and the petrol emissions in NFR 1A3B (and therefore adding up the petrol emissions of recreational craft to 1A3D for the comparison), results in a share of recreational craft emissions the shipping sector of approximately 24,1%, 1,5%, 1,3%, 56,5% and 2,2% for respectively HC (NMVOC), NO_x, PM, CO and CO_2. Depending on the proportion of petrol emissions allocated to 1A3D (which is unknown), the share would more or less remain the same for the emissions of NO_x, PM and CO_2 (the substances with the largest economic impact) but the share of HC (NMVOC) would increase. Also, in particular the share of CO would increase, as CO is mainly emitted by petrol (EEA, 2019), (EEA, 2019), in which it is recommended to use emission values for petrol engines up to 851 kg CO/tonne fuel and up to 791 g fuel/kWh (used for the oldest engines, newer engines have lower emission factors), whilst for diesel emission factors of 18,6-19,8 kg CO/tonne fuel and 275-281 g fuel/kWh are presented (many times more CO per kWh emitted by recreational crafts with petrol engines compared to recreational crafts with diesel engines). In addition, the emission factors for marine diesel oil and marine gas oil are much smaller than the ones recommended for recreational craft in the EMEP/EEA guidebook (resulting in relatively very small CO emissions per kWh compared to recreational crafts with petrol engines).

2.4 Evaporative emissions

Similar to the previous section, here the total of evaporative emissions for the EU is determined.

2.4.1 *Estimated emission levels*

Based on the evaporative emissions methodology described in section 2.1.2, the emission levels have been calculated and are presented in Figure 2-5. Fuel tank

[7] Nomenclature For Reporting (NFR) is the classification used to report data to the Convention on Long-Range Transboundary Air Pollution (CLRTAP).

permeation emissions have the highest contribution of all emissions sources with about 43%, while hose permeation and diurnal follow with 37% and 19%, respectively. Running loss and hot soak emissions are rather insignificant, being responsible for about 1% of the total evaporative emissions.

Figure 2-5 Share of evaporative emission sources (%)

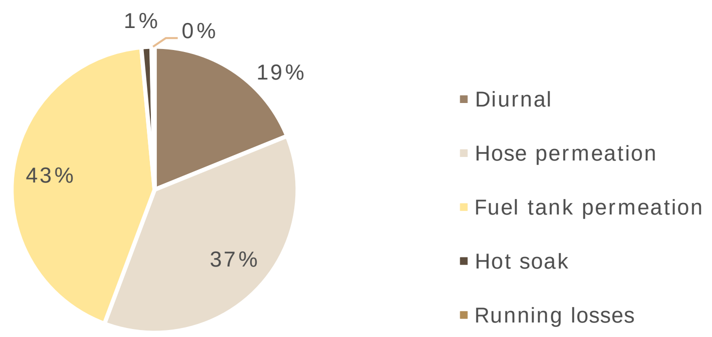
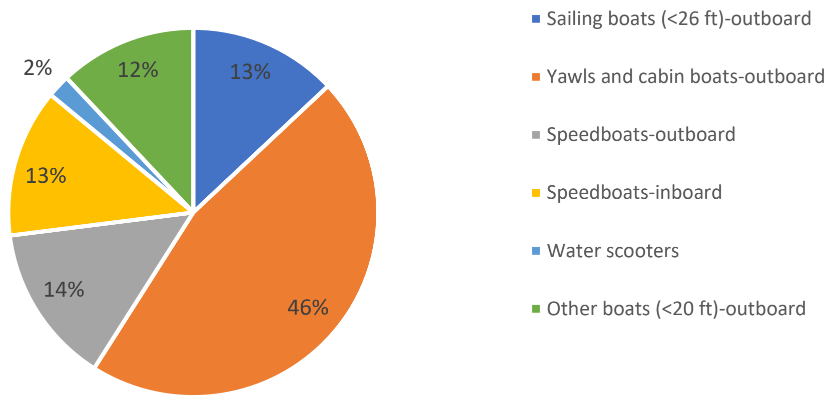


Table 2-9 Evaporative emission levels by emission source in 2020.

Evaporative emissions source	*Emission level [tonnes]*
Diurnal	3085
Hose permeation	6021
Fuel tank permeation	6997
Running losses	56
Hot soak	187
Total	16346

2.4.2 Largest contributors

Figure 2-6 Evaporative emissions contribution by craft type (%) in the EU



The evaporative emission contribution by craft type is shown in Figure 2-6. Yawls and cabin boats with outboard engines are the largest contributors of evaporative emissions (46%), followed by speed boats-outboard (14%), sailing boats (13%), speedboats-inboard (13%), other boats-outboard (12%) and water scooters (2%). The high emissions share of yawls and cabin boats is attributed to both their prevalence in the fleet (about 32%), as well as the high permeation emission factors due to the larger size of their fuel system (fuel hoses length and fuel tank capacity).

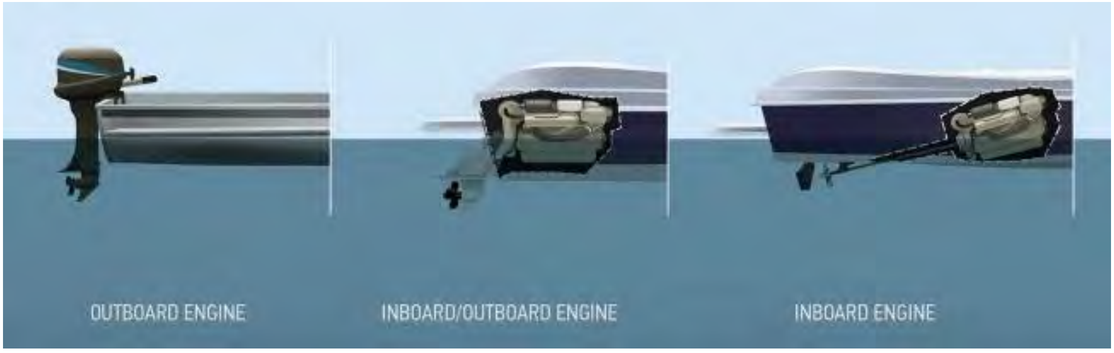
3 Exhaust emission proposals

This chapter provides an introduction to the different propulsion systems of recreational craft causing exhaust emissions (section 3.1), followed by an overview of the current regulations on exhaust emissions and a discussion on the introduction of greenhouse gas emission regulation for exhaust emissions (section 3.2).
Then, the results of the technical feasibility study for emission reduction is presented (section 3.3), per type of propulsion system: spark ignition (SI) outboard and personal watercraft (PWC) propulsion systems, SI inboard and jet boat propulsion systems, compression ignition (CI) inboard propulsion systems, hybrid- and electric propulsion systems.
This is followed by a proposal of candidate scenarios (section 3.4) and a unit cost estimate (3.5) per scenario and per type of propulsion system.

3.1 Context

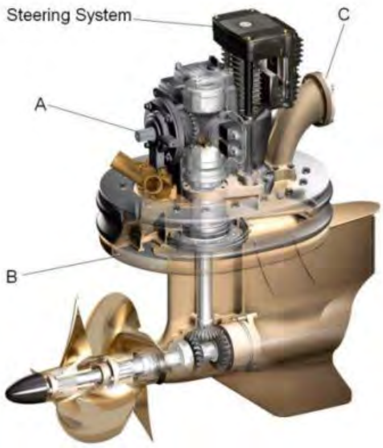
In recreational craft, combustion engines are used in a wide range of different driveline configurations. Some of these configurations are illustrated in Figure 3-1.

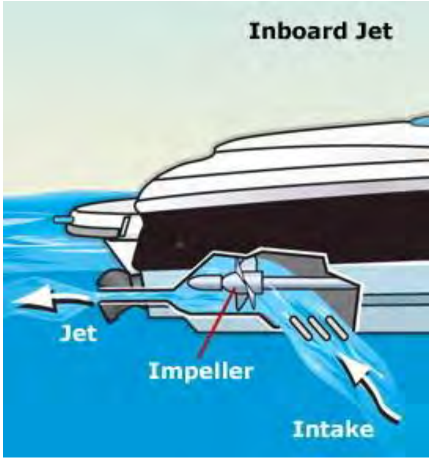
Figure 3-1 Different recreational craft propulsion systems (Anon., 2021)



In outboard propulsion systems the engine is a separate unit that can be attached to the rear (the transom) of the recreational craft. This outboard (OB) unit is then connected to the on-board fuel tank. In all other solutions the propulsion system is built around an engine that is positioned inside the craft. These are called inboard (IB) engines. The classical inboard driveline has an engine that is connected with an angled shaft to the propeller. This configuration is shown on the right of Figure 3-1. In the middle of this figure a so-called Z-drive or sterndrive configuration is shown. This configuration has the advantage of a horizontal propeller position (which is more efficient in delivering thrust power).
In the specification of the propulsion system of a recreational craft, the EU certification document distinguishes between the following inboard solutions: inboard with angled shafts, sterndrives (with or without integrated exhaust system), sail-drives and pods. Figure 3-2 (left) illustrates the lay-out of a pod driveline.
Finally also jet-drives exist. Here the engine is not connected to a propeller but to a powerful rotating pump. This pump takes in water and spews it out at great speed, thus generating opposing thrust for the craft as illustrated in Figure 3-2 (right). These propulsion systems are typically used in personal water craft (i.e. for the propulsion of so-called water-scooters). They are also used for propulsion of boats. These boats are then called jet boats.

Figure 3-2 Pod driveline lay-out (Volvo Penta) (left) and operating principle of inboard jet drive (Anon., 2021) (right)





Recently, two other types of propulsion systems have appeared on the market: pure electric propulsion systems (where the sole source of energy supply is an electric battery that feeds an electric motor) and hybrid (electric) propulsion systems where a combustion engine works together with an electric motor (with energy stored both in a fuel tank and a battery). Furthermore, recently also outboard propulsion systems driven by a diesel engine have appeared on the market. These – relatively high powered - engines have been developed for commercial applications (e.g. patrol boats, ribs) where the number of hours of operation per year are much larger than usual with recreational craft. The lower fuel consumption of these engines (compared to equivalent petrol outboards) more than compensates their higher initial investment costs, making it an economically viable solution in commercial applications, but not viable at present in recreational craft applications.

Table 3-1 presents an overview of the different driveline/engine technologies currently being applied to recreational craft. The combinations marked in grey are the ones that are currently considered in the RCD regulation.

Table 3-1 Overview of different propulsion systems for recreational craft

	Spark ignition (SI) internal combustion engine (petrol[8])	Compression Ignition (CI) internal combustion engine (diesel)	Electric engine	ICE and electric engine (hybrid)
Outboard				
Inboard				

In the next section, the current status of recreational craft emission regulation will be discussed. In section 3.3 the technical feasibility of emissions reduction will be discussed separately for the following relevant propulsion system types:

- SI outboard engines / Personal Water Craft (PWC)
- SI inboard engines (including jet boat engines)
- CI inboard engines
- Electric propulsion systems
- Hybrid propulsion systems

Although personal water craft use inboard engines, they have traditionally been treated together with SI outboard engines. This is because, in the past, both applications were using SI two-stroke engines for propulsion[9], given the lower weight to power ratio of

[8] A small number of SI engines will run on LPG or CNG
[9] In addition to four stroke engines.

these engines. Inboard engines have been almost exclusively four-stroke engines for a considerable number of years.

3.2 Emission regulation

3.2.1 *Current status of pollutant emissions regulation*

Emissions of recreational craft are presently regulated on different levels:

- Emissions can be regulated on a local level (e.g. by imposing speed limits or zero-emission technology).
- Sometimes emission limitations are imposed on a regional/state level (e.g. the Bodensee regulation in Europe or CARB emission regulations in the US).
- Regulations on (inter-)national level.

This study reviews the latter level of emission regulation.

The US and EU fleets for recreational craft are the most important ones in the world and in the last decades their regulations have set the pace for emission reduction in this market. With other areas adopting the same regulations within a few years. The current pollutant emission regulation in the EU and in the US consists of test procedures and of emission limit values. Traditionally this regulation has focused on combustion engine driven propulsion systems. Furthermore it has, until now, been different for SI engines and for CI engines.
Table 3-2 presents the main characteristics for both these regulations for SI engines.

Table 3-2 Overview of SI exhaust emission limits in EU and US (EPA, 2008) (EC, 2013)

Regulation		EU RCD II maximum emission levels [g/kWh] (2013)			US EPA maximum emission levels [g/kWh] (2008)		
Application date		18/01/2016			2010+/		
Type of engine	Power range[10] [kW]	CO	NO_x + HC	PM	CO	NO_x + HC	PM
Outboard engines and PWC engines	$P \leq 4{,}3$	$500 - 5 \cdot P$	30	-	$500 - 5.P$	30	-
	$4{,}3 < P \leq 40$		$15{,}7 + \frac{50}{P^{0{,}9}}$	-		$15{,}7 + \frac{50}{P^{0{,}9}}$	-
	$40 < P$	300		-	300		-
Stern-drive and inboard engines	$P \leq 373$	75	5	-	75	5	-
	$373 < P \leq 485$	350	16	-	350	16	-
	$485 < P$	350	22	-	350	22	-

Limit values for SI IB engines are below those of OB engines up to 373 kW. For P > 373 kW (so-called high performance recreational engines) they are in line with OB limits.

Both regulations consider limiting of CO and combined emission of NO_x+HC. They do not consider the emission of methane or N_2O. They also do not impose particulate matter (PM) mass emission limits to SI engines. The latter is in line with the fact that at the time of development of these regulations the vast majority of these engines were multipoint port fuelled injection (MPFI) engines with typically low particulate matter formation. Of course, for these same reasons, they also do not consider particulate number limitations.
Further both regulations apply the same emissions test cycle: the so-called E4 test cycle (see Figure 3-3 for details). The use of such a steady-state cycle implies the assumption that acceleration (and transient behaviour in general) is not having a significant impact on emissions. Furthermore, this approach implies that the impact of (cold) starting is also negligible.
Obviously a high level of harmonisation has been reached between both regulations. There are however still a number of differences remaining:

- The E4-test cycle requires testing of the engine in 5 test-points only (situated along a virtual propeller curve). In practice, engines will be used in many more operating points. Therefore, in the US, additional not-to-exceed (NTE) levels have defined that

[10] Unless mentioned otherwise, power refers to power measured at the engine crankshaft.

apply to a larger part of the engine operating range. A similar limitation has not been introduced yet in the EU.

- For high performance engines, US regulation allows to replace the idle speed testing point with another operating point: 15% torque at idle speed.
- The EPA requires that manufacturers provide deterioration factors for the emissions performance of the engines that they supply to the market.

Similarly, Table 3-3 presents the main characteristics in both of these regulations for CI engines.

Table 3-3 Overview of CI exhaust emission limits in EU and US (EPA, 2004) (EC, 2013)

Regulation		EU RCD II maximum emission levels [g/kWh] (2013)					EPA Tier 3 maximum emission levels [g/kWh] (2008)		
Application date		2016+					Between 2009 and 2014		
Displacement volume SV (per cylinder)	Power range [kW]	CO	HC	NO_x	NO_x + HC	PM	CO	NO_x + HC	PM
SV < 0,9	P < 8	5	$1,5 + 2/\sqrt{P}$	9,8	-	1	8	7,5	0,4
	8 ≤ P < 19						6,6		
	19 ≤ P < 37						5	4,7[11]	0,3
	37 ≤ P < 75		-	-	4,7[12]	0,3	5	4,7[13]	0,3
	75 ≤ P < 3700		-	-	5,8	0,15	5	5,8	0,15
0,9 ≤ SV < 1,2	P < 3700[14]		-	-	5,8	0,14	P-dependent as for SV < 0,9	5,8	0,14
1,2 ≤ SV < 2,5			-	-	5,8	0,12	5	5,8	0,14
2,5 ≤ SV < 3,5			-	-	5,8	0,12	5	5,8	0,12
3,5 ≤ SV < 7,0					5,8	0,11	5	5,8	0,11

Both regulations consider the same pollutant gases. None of them consider limitation of N2O, CH4 or PN. As to PM emission, no difference is made between PM10 and PM 2.5 (as is presently standard practice with on-road applications).
In the EU for CI engines test cycle ISO 8178 E1 or ISO 8178 E5 can be applied. Or alternatively, above 130 kW, test cycle ISO 8178 E3 may be applied. Details of these test cycles are shown in Figure 3-3. The E5-cycle includes the emissions at idle and is weighted more heavily towards lower power levels. The E3-cycle uses the same engine operating points (or modi), apart from the idle operating point, but attributes more weight to the higher power points. This cycle is used primarily for emission certification of commercial marine diesel engines that are applied for inland waterway propulsion and is supposedly more representative of the operation of these engines. The E1-cycle is completely different (and is − according to ICOMIA/IMEC − rarely used). The US requires the E5 cycle for recreational diesel engines.

[11] Alternatively 5,8 g/kWh in combination with 0,20 g/kWh on PM
[12] Alternatively 5,8 g/kWh in combination with 0,20 g/kWh on PM
[13] Alternatively 5,8 g/kWh in combination with 0,20 g/kWh on PM
[14] In the US also P > 3700 kW is considered. For these recreational marine engines the limits apply as for engines with displacement between 3,5 and 7 liter per cylinder.

Figure 3-3 Details of ISO 8178 steady-state test cycles used for CI engine certification (EC, 2013)

Cycle E1, Mode number	1	2	3		4	5
Speed	Rated speed		Intermediate speed			Low-idle speed
Torque, %	100	75	75		50	0
Weighting factor	0,08	0,11	0,19		0,32	0,3
Speed	Rated speed		Intermediate speed			Low-idle speed
Cycle E3, Mode number	1		2	3	4	
Speed, %	100		91	80	63	
Power, %	100		75	50	25	
Weighting factor	0,2		0,5	0,15	0,15	
Cycle E4, Mode number	1		2	3	4	5
Speed, %	100		80	60	40	Idle
Torque, %	100		71,6	46,5	25,3	0
Weighting factor	0,06		0,14	0,15	0,25	0,40
Cycle E5, Mode number	1		2	3	4	5
Speed, %	100		91	80	63	Idle
Power, %	100		75	50	25	0
Weighting factor	0,08		0,13	0,17	0,32	0,3

Again a high level of harmonisation is visible when comparing both regulations. But as with the SI engine regulation there are however still a number of differences remaining:

- From the table above it is clear that there a high similarity in the limit values. The main differences are that in the US stricter limits on NO_x+HC and PM emission are imposed for engines with P < 37 kW. This is somewhat balanced by less stringent CO limitations.
- Furthermore there is a small difference in the PM-limits for engines with 1,2 < SV < 2,5.
- The EU allows different test-cycles to be applied for CI recreational engines, in the US only the E5-cycle is used.
- In the US, additional not-to-exceed levels have defined that apply to a larger part of the engine operating range. A similar limitation has not been introduced yet in the EU.

These regulations do not consider the application of hybrid propulsion systems. They also do not consider limiting GHG emissions.

3.2.2 *Introducing greenhouse gas emission regulation*

At this moment there is no regulation of greenhouse emissions of recreational craft, not in the US and not in the EU. In principle, such regulation could take different forms.

Introducing new fleet average emission levels

This would be similar to the current practice in the automotive passenger car market. Similar to the automotive market, these targets would be imposed on the boat manufacturers. It is expected that such regulation would, for instance, increase the uptake of electric alternatives in the outboard propulsion system market. As well as the uptake of hybrid drivelines in the larger boat segment of the recreational craft market.

Imposing fleet-average CO_2-emission limits is however expected to be difficult to achieve.

To start with, there is no test procedure to determine a representative value for the greenhouse emission of a boat. Measuring the greenhouse emission of the engine that is implemented in that boat in the current ISO test cycles (that were defined for emissions testing) would not really be a substitute. This is because greenhouse gas emission is determined only in part by engine performance. It is to a large extent determined by other aspects such as propeller design, boat shape, positioning of propeller(s) and of course handling of the boat. Furthermore, the representativeness of the test cycles for real-world operation of a particular boat class can be questioned.

To come up with a greenhouse emission value of a boat, a VECTO-like[15] calculation tool could be developed. Such a tool would combine info on the engine level (i.e. on its efficiency, in het form of a speed/torque map) with information on the rest of the driveline and on the design of the boat plus a definition of a number of use cases (boat weight as well as speed profile). The latter info would then originate from the boat developer. This would improve the level of information / knowledge on recreational craft greenhouse gas emissions.

At the same time it is important to point out that the recreational boating industry is not vertically integrated as are the automotive passenger or truck market or the market of generator sets or excavators. Many boat manufacturers do not build their own engines and depend on the developments by the engine supplier. The R&D roadmap of such a supplier will (especially for inboard engines) be determined by developments in other markets. To illustrate this: Stage V IWP (Inland Waterway Propulsion) emission targets have been introduced in the EU in 2016, but until now only a few of such engines have become available on the market.

To make matters even more complicated: recreational craft that are aimed for application of outboard engines are produced without an engine. The customer decides separately from the boat manufacturer on the outboard engine he will buy.

Furthermore, production numbers of a certain boat type tend to be low. Determining the value of the boat design parameters required for a VECTO-like calculation would further increase the development cost.

Regulation on engine level (GHG emission per kWh)

This could be a first step towards achieving some kind of greenhouse emission reduction. It would be sufficient to require that also GHG levels are determined and communicated (with the regulator and also with the potential customers).

However, the emissions reduction on engine level that is expected to be achievable will most likely remain very limited. The biggest step could be when an engine would be combined with battery and an electric motor. The resulting hybrid driveline would however be much more expensive and fuel consumption savings on average also limited (as explained later in the report). Other measures could have a larger impact. As an illustration: a recent study (Burke, 2021) suggests that hull shape design optimization could lead to a 30% reduction in fuel consumption (and corresponding emissions)[16]. This re-emphasizes the fact that greenhouse emission reduction preferably should be targeted on boat level.

Regulating fuel quality

A lot of stakeholders that were contacted mentioned that they considered the introduction of renewable fuels for recreational craft as a more efficient means of reducing greenhouse gas emissions than setting tailpipe CO_2 emission limits. This would however require regulating (and monitoring) the fuel quality used in these engines.

3.3 Technical feasibility for emissions reduction

This section discusses the technical feasibility for emission reduction per type of propulsion system.

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[15] Vehicle Energy Consumption Calculation Tool (VECTO)

[16] In fact some companies (for instance Greenline) already apply such hull shape improvement as a means to increase the attractiveness of their electric recreational craft.

3.3.1 SI outboard and PWC propulsion systems

For SI outboard and PWC propulsion systems the following is discussed:

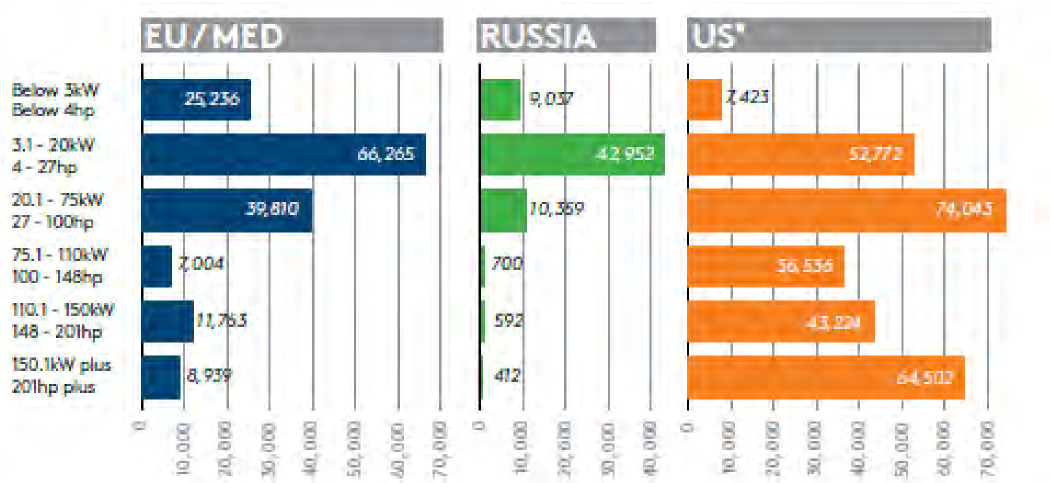
- The market description
- The state-of-the art technologies and changes since the introduction of the last Directive
- Candidate emission reduction technologies
- The impact on volume and weight
- The impact on durability and maintenance
- The impact on fuel consumption and greenhouse gas emissions
- Specific PWC observations

SI outboard market description

Outboard SI engines have been very popular (amongst others) because of their lower weight and volume. And because they do not take up space inside the craft. This has resulted in high sales numbers, even if these engines were more expensive than in-board competitors that derived from mass produced automotive engines.

Figure 3-4 shows the 2018 outboard engine sales numbers per region and per power. From this it is clear that most SI outboards in Europe have a power below 75 kW, with the majority in the 3,1 – 20 kW range. In the US, sales numbers are much higher and also typical powers are much higher.

Figure 3-4 Sales numbers of outboard motor sales (ICOMIA, sd)



The same database shows that the numbers of outboard engines sold in the range 100 – 150 kW is increasing steadily. This seems to be the result of emission legislation. In the EPA 2008 emission legislation the outboard emission limits that were retained did not demand for the implementation of catalytic aftertreatment (as with SI inboard engines). This was because it was felt that the cost impact on the outboard manufacturing business would be too large.
As the recreational market collapsed in 2008 no initiative has been taken until now to change this. As a result of this the cost of outboard engines has become comparable with those of inboard engines. This has resulted in a decline in the SI-inboard engines sales numbers and a corresponding increase in application of one or multiple outboard engines as an alternative propulsion solution. This is illustrated in Figure 3-5.

Figure 3-5 Market outlook trends by product category (net balance score), 2013-2018 (ICOMIA, sd)

Product Category	2013	2014	2015	2016	2017	2018
Sailboats (excluding dinghies)	-5%	20%	20%	29%	8%	11%
Sailing dinghies	-18%	-9%	13%	17%	12%	0%
Trailerable boats	0%	4%	22%	38%	23%	11%
Used boat market	52%	29%	40%	29%	31%	21%
Motorboats: Sterndrive/Inboard boats	-8%	-4%	-4%	25%	-4%	-14%
Motorboats: Outboard boats	34%	36%	36%	54%	54%	25%
Motorboats: Inflatable/RIB Boats	21%	-13%	21%	50%	23%	31%
PWCs	13%	17%	40%	50%	38%	26%
Accessories	14%	38%	33%	57%	46%	32%
Engines: Outboards	35%	36%	44%	63%	27%	42%
Engines: Inboard/Sterndrive Diesel Engine	5%	-17%	-8%	13%	12%	-15%
Engines: Inboard/Sterndrive Petrol Engine	-31%	-30%	-17%	-17%	-12%	-23%

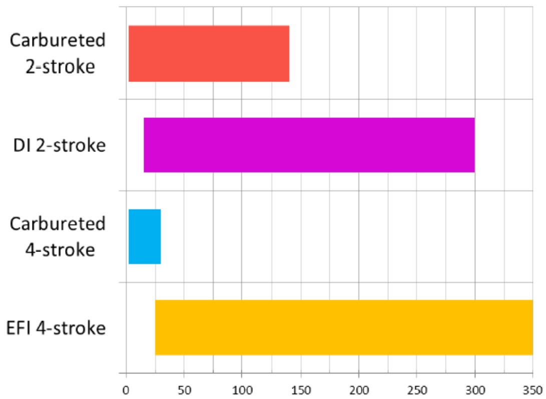
The impact of this shift on the market is of course a smaller than envisaged emission reduction resulting from the EPA-2008 and EU-RCDII regulations.

Current production of these engines is dominated by a limited number of large companies from Japan (Yamaha, Nissan, Tohatsu, Suzuki, Honda) and from the US (Mariner, Mercury). In Europe, Selva is selling (re-branded) Yamaha SI outboard four-stroke engines.

State-of-the art technology with OB engines and changes since the introduction of RCD II

Traditionally outboard SI engines have been a mix of two-stroke engines and four-stroke engines. Until 2008 (introduction of latest EPA regulation) different fuel supply systems were being applied: from very simple and cheap carburetted systems (that do not rely on battery powered fuelling control) to electronically controlled fuel injection (EFI), to direct injection (DI) fuel injection systems. Figure 3-6 gives an overview of the most relevant combinations in 2019.

Figure 3-6 Overview of SI outboard engine power range for different engine technology packs (Duret, 2021)



At this moment, two-stroke outboard engines have almost disappeared from the market. This is also illustrated in the numbers sold in France in recent years with only some 900 2-stroke engines sold compared to almost 16000 4-stroke units. And with very few 2-stroke engines sold above 45 kW (ICOMIA, sd).
Evinrude, part of Canadian company Bombardier Recreational Products (BRP), has decided to stop production of its two stroke engines (in the 3,5 < P(HP) <350 range, including its E-TEC and ETEC-G2 engines) in the beginning of 2020. Mercury Marine still produces a two-stroke engine, but this engine (a 200 HP/ 137 kW Sport Jet Optimax) is intended for use in outboard jet drives. Similarly, production of small 2-stroke marine engines has been stopped by Selva Marine and Tohatsu in February of 2020. Selva Marine had gone into production with an IAPAC injection system. However, this has been stopped because of the low interest in the market. With these small engines there is an additional issue: implementing modern electronic injection systems requires a battery, adding to the weight and cost of these propulsion systems.

According to Pierre Duret (Duret, 2021), two stroke engine expert, the most important reasons for the demise of the 2-stroke outboard engine were twofold. First, it was conceived by the general public as an engine that was more polluting than its four-stroke counterpart. Secondly, the dealers in general preferred to sell four-stroke engines:

- Because of the larger sales numbers, dealers could get a larger discount than when they ordered a 2-stroke engine.
- Four-stroke engines require more maintenance, resulting in more aftermarket income for dealers.

In line with these observations, only four-stroke engine technology is retained as the starting point for this study. The emissions performance of 4-stroke outboard engines that have appeared recently on the market are shown in
Figure 3-7. None of these engines have a catalytic exhaust aftertreatment system (EAS) and the power of most of these engines ranges between 7,3 and 350 kW. Only one OB engine was found that has a power that exceeds 350 kW.

Figure 3-7 Emissions performance of recent outboard four-stroke engines (EAS) (EPA, 2021)

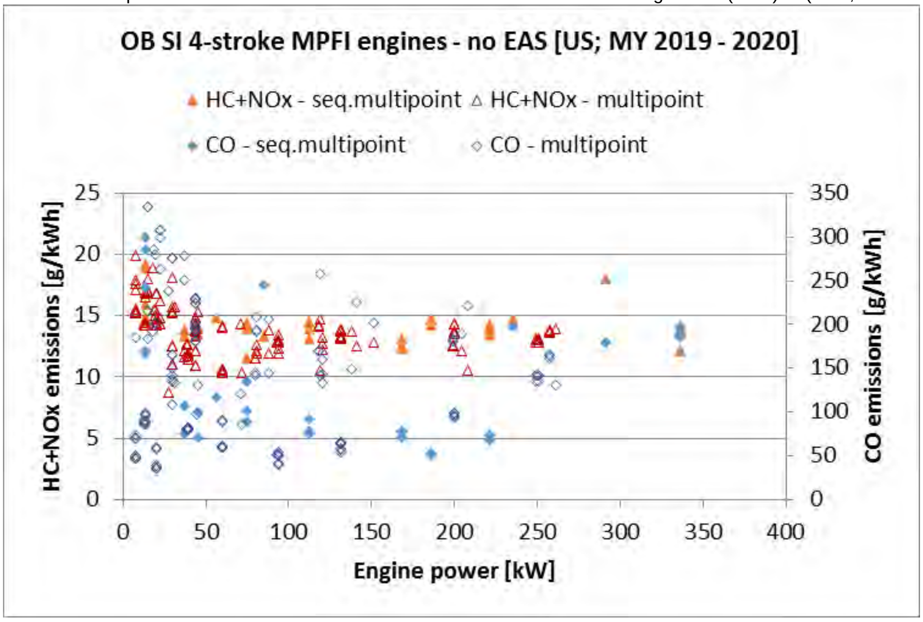


Figure 3-8 Emissions performance of recent PWC engines (EPA, 2021)

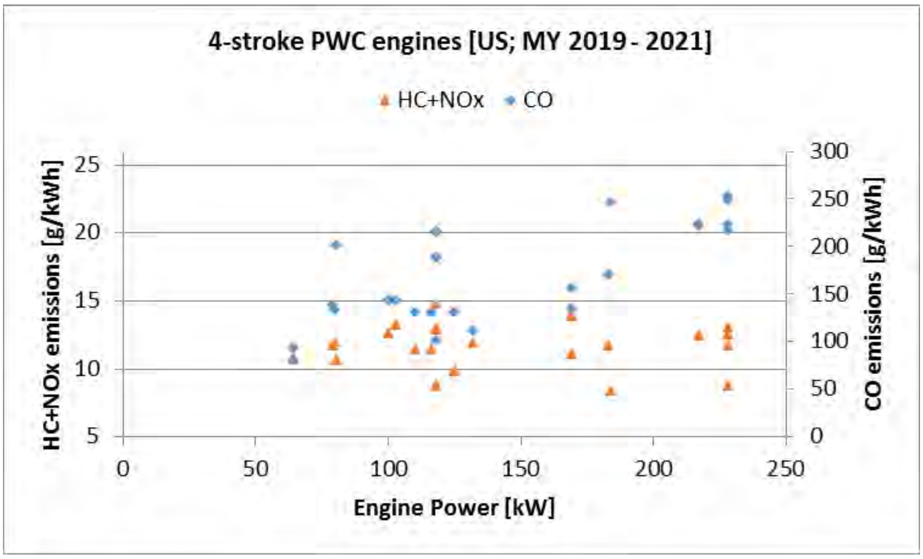


Figure 3-8 gives a similar overview for the personal watercraft engines. Personal water craft have a power in the range 60 – 250 kW. Only 4-stroke PWC SI engines are shown. Only one manufacturer (MSR engines) has certified a 2-stroke solution in 2019 resp. 2020. Emissions of PWC are comparable to those of other 4-stroke OB engines (in line with the current emission regulations).

Candidate OB emission reduction technologies

As shown in Figure 3-7 and Figure 3-8, the certification values for CO of current engines are well below the limit values. Best-in-class engines (i.e. the cleanest engines across the power range) also have NO_x+HC levels that are significantly lower than the limit values. This indicates that with electronically controlled (sequential) multi-point injection technology application a further emissions reduction is possibly, especially at lower powers.

The most obvious candidate for a further significant reduction of the emissions of 4-stroke outboard engines is the application of catalytic aftertreatment. This was already stated in the EPA 2008 regulation impact study as well as in previous EU-sponsored studies (Rijkeboer, et al., 2004), (ECNI, 2006) and (ECNI, 2006).

In 2010, Mercury Marine performed a feasibility study into the implementation of 3-way catalytic aftertreatment technology on two of their outboard engines – with 44,8 kW (60 SAE HP) respectively 149 kW (200 SAE HP) – towards meeting a 5 g/kWh NO_x+HC limit respectively a 75 g/kWh CO limit (tested in the E4-cycle) (Broman, 2012). This study demonstrated that these limit levels are feasible with implementation of closed loop fuel control and a catalytic convertor.

At the same time this study indicated several challenges for equipping outboard engines with catalytic systems. The principal challenges are summarized below:

- With many outboard engines the exhaust system is an integral part of the cylinder head respectively of the cylinder block. Implementing catalyst systems would requiring redesigning these parts and would result in considerable cost-increase.
- Of course, also thermal management of the exhaust system would need some adaptation.
- The top cover (cowl) of the small outboard engines would probably increase.
- Durability of oxygen sensors and catalyst was a concern.
- There was a concern about a reduction in power-to-weight ratio (which is more critical with outboard engines than with SD/IB engines.
- Development times would be in the order of 2 to 3 years per engine family; to adapt all engines a proportional time would be needed.

Alternatively, catalyst technology could be introduced that further reduces CO emission (to safeguard the boat owner from CO intoxication). But there is no indication that current CO limitations are not sufficient. Furthermore such technology would only oxidize CO into CO_2 with no reduction in fuel consumption. For this reason the assessment of such technology was not retained in this study.

Impact on volume and weight

Applying a 3-way catalytic aftertreatment system is expected to result in a 3 – 4% weight increase. This level of weight increase should not pose a limit on the implementation of this technology. For smaller engines the volume of the propulsion system would also increase (top cowl).

Impact on durability and maintenance

A concern was raised that the marine environment would negatively impact the durability of the catalytic system (oxygen sensors and catalyst block). Experience with catalysed SD/IB engines indicates that there is only a limited durability impact, as long as water can be kept away from these components.
Manufacturers of outboard engines point out that the water level is much closer to the engine with their product than with inboard engines. This difference is however not that big for the larger engines. Furthermore, a concise patent study has indicated that many outboard manufacturers have patented different solutions to implement catalysts in their engines in such a way that the water level is kept away of this catalyst. An example

is patent US10876459 applied by BRP (Wasil & Broughton, 2020). Similar patent applications were found by Honda, Yamaha, Suzuki.
Of course, maintenance costs are expected to increase somewhat and to come in line with those of SD/IB engines.

Impact on fuel consumption and greenhouse gas emissions

Based on the EPA certification database, it is expected that the implementation of a catalytic system will result in a 10% decrease in fuel consumption (as rich operating areas are reduced). There will however be no significant decrease in CO_2 emissions, because the 3-way catalyst (when operating in stoichiometric conditions) will turn most of the fuel in CO_2 (and not partly into CO as with most not-catalysed engines). The remaining CO-emission will result mainly from operating the engine rich at highest loads (in order to avoid excessive thermal loads on the engine).

PWC observations

Personal watercraft propulsion systems demand a high power density (similar to outboard engines). In these systems similar technologies are applied to outboard propulsion systems. Personal water craft have therefore until now been subject to the same regulations as outboard propulsion systems. However, they are positioned inside the hull of the craft. One could argue that they should be subject to the same regulations as other SD/IB engines. The main manufacturers of engines for this type of craft are BRP-ROTAX, Yamaha and Kawasaki (the latter company is not active in the outboard engine market).

3.3.2 SI Inboard and jet boat propulsion systems

For SI inboard and jet boat propulsion systems the following is discussed:

- The market description
- The state-of-the art technologies and changes since the introduction of the last Directive
- Candidate emission reduction technologies
- The impact on volume and weight
- The impact on durability and maintenance
- The impact on fuel consumption and greenhouse gas emissions

SI Inboard market description

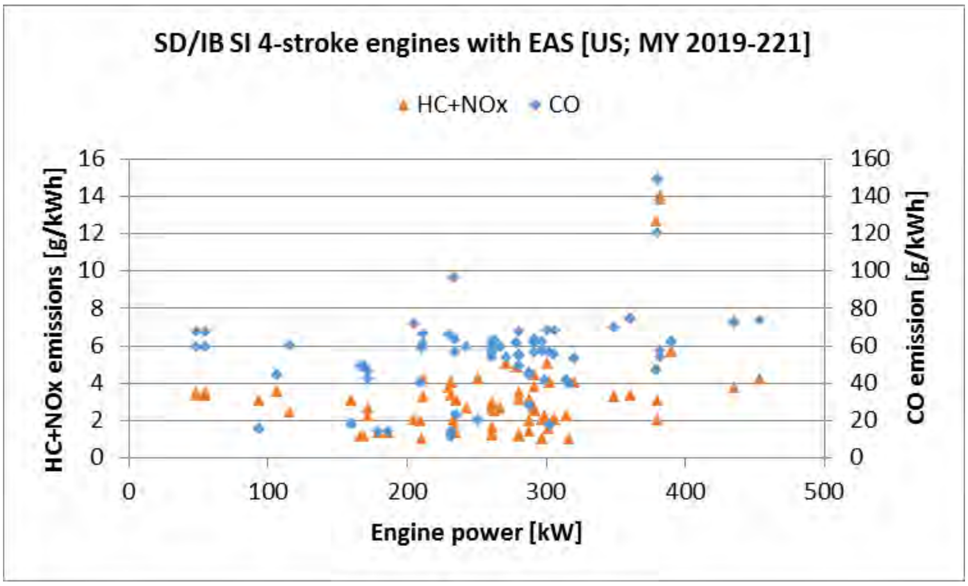
Many modern SD/IB propulsions systems rely on current production (Ford, GM, BMW) automotive engines. An exception to this is Mercruiser, who produce their own engines. The main manufacturers are Volvo Penta, Mercury and KEM equipment with some smaller players such as Indmar, Ilmor, BMW Marine, Textron.
Similar engines (e.g. by BRP-ROTAX and by Yamaha) are aimed at application in personal watercraft and in jet boats[17].

State-of-the art technology and changes since the introduction of RCD II

Current SD/IB engines that are applied for recreational craft are all 4-stroke engines. They apply advanced per-cylinder fuel injection in combination with electronical lambda control and 3-way catalytic aftertreatment. Aftertreatment was introduced in response to the 5 g/kWh NO_x+HC emission limit by CARB in 2008 and by EPA in 2010. This resulted in a considerable emissions performance improvement.
This is illustrated in Figure 3-9. This figure shows all SD/IB engines with aftertreatment that were recently certified in the US. These engines are produced in the power range 55 < P[kW] < 453, with the majority above 150 kW. All engines up to 374 kW have NO_x+HC levels well below 5 g/kWh, with lowest values at 1 g/kWh. CO emissions are in line with the 75 g/kWh cap. Some engines above 374 kW (so-called performance engines) have higher emissions.

[17] As a matter of fact they have to follow OB emission legislation when used in PWC, but IB emission legislation when used in jet boats.

Figure 3-9 Emissions performance of recent SD/IB 4-stroke engines with catalytic aftertreatment (EPA, 2021)



A significant number of these engines comply with the (stricter) Bodensee regulation. This regulation introduces a reference number IKZ (from the German word 'EmissionsKennZahl'). The definition of this reference number is presented in Equation 3-1:

Equation 3-1 Definition reference number

$$EKZ = 0{,}00305 \cdot \left(1{,}3 \cdot CO + 8{,}2 \cdot (HC + NOx)\right) \cdot P_{nom}$$

Where CO, HC and NO_x are emissions in g/kWh and P_{nom} represents rate engine power in kW. EKZ should not exceed a level of 58 g/h.

Candidate emission reduction technologies

Most of the emissions remaining with current SD/IB engines originate with the highest load operating points. In especially with the 100% torque operating point in the E4-test cycle. At nominal speed and max torque the brake mean effective pressure[18] (bmep) in these engines varies between 8 and 16 bar. Exhaust gas temperatures of stoichiometric mixtures at high bmep levels tend to exceed 800 or even 950 ºC. These temperatures are not compatible with typical materials used for exhaust valves and for the turbocharger turbine. To reduce the engine out temperature in this operating point, the mixture ratio is changed from stoichiometric to rich.

To further reduce SD/IB emissions it is therefore necessary to avoid this need for such fuel enrichment calibration. This is possible by applying other (more expensive alloys) for valves and turbine. Alternatively, this can also be achieved by limiting the maximum bmep of these engines. To retain the same rate power, this will require to increase the total displacement volume of these engines correspondingly (in the order of 20%).

Impact durability and maintenance

This is not really an issue due to the proven technology.

Impact on volume and weight

If the limit values would be further reduced and if − in response to these lower limit values − the maximum bmep value would be reduced, then the volume and weight of the engine would (have to) increase accordingly.

[18] Brake mean effective pressure is proportional to the ratio of engine torque and engine total displacement volume.

Impact on fuel consumption and greenhouse gas emissions

If the maximum bmep level is decreased, friction losses will have more impact and fuel efficiency will be reduced.

3.3.3 CI Inboard propulsion systems

For CI inboard propulsion systems the following is discussed:

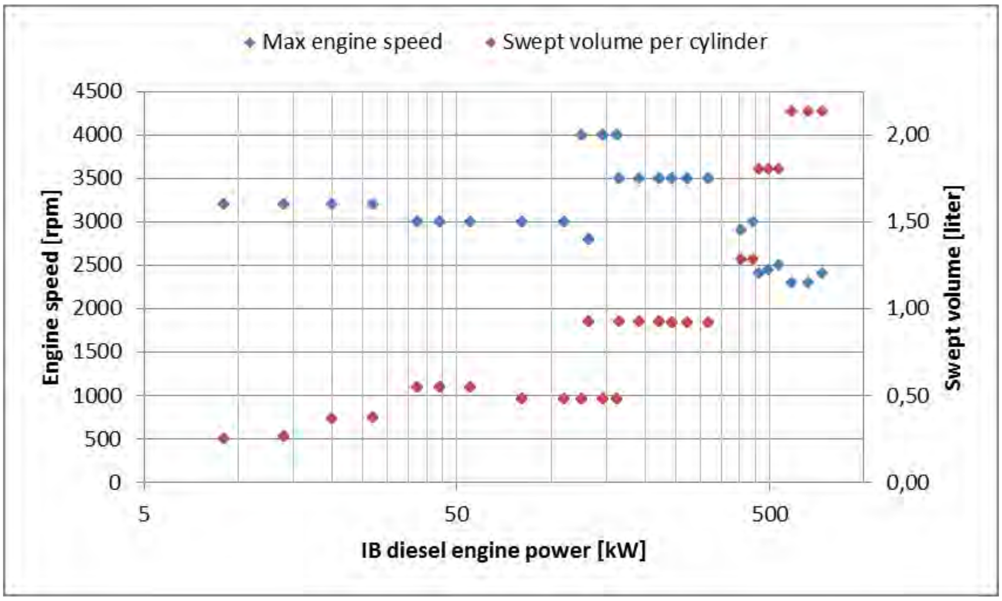
- The market description
- The state-of-the art technologies and changes since the introduction of the last Directive
- Candidate emission reduction technologies
- The impact on volume and weight
- The impact on durability and maintenance
- The impact on fuel consumption and greenhouse gas emissions

CI Inboard market description

Compression ignition engines are used for the propulsion of a variety of recreational craft: for sailing boats (e.g. sail-drive units, typically with a power not exceeding 55 kW) but also for motor boats (canal boats, cabin cruisers, small fishing boats, speed boats and yachts). The recreational craft directive, however, only applies to craft with a hull length that is not exceeding 24 m. Maximum power of these boats typically will go up to 750 kW. For large, powerful boats even bigger engines or multiple engines are used. Sterndrive propulsion units typically have a power up to 290 kW.

Companies producing these boats can be divided into two groups. Some producers produce these engines from scratch (sometimes as subdivision of a larger group active also in on-road heavy-duty engine and off-road mobile machinery). They are referred to as OEM's (original equipment manufacturers). Examples of such manufacturers are Volvo Penta (Sweden), FPT/Iveco (Italy), Yanmar (Japan) and Mercury Marine (US).
The second group buys basic engine parts from manufacturers of non-road mobile machinery and adapt (or marinize) these engines to meet with recreational marine engine requirements. Typical examples of the latter group of companies are Nanni (France), Solé (Spain), and Vetus (The Netherlands)[19].

Figure 3-10 Overview of Volvo Penta CI SD/IB production range – max engine speed and swept volume versus max power (2019 data)

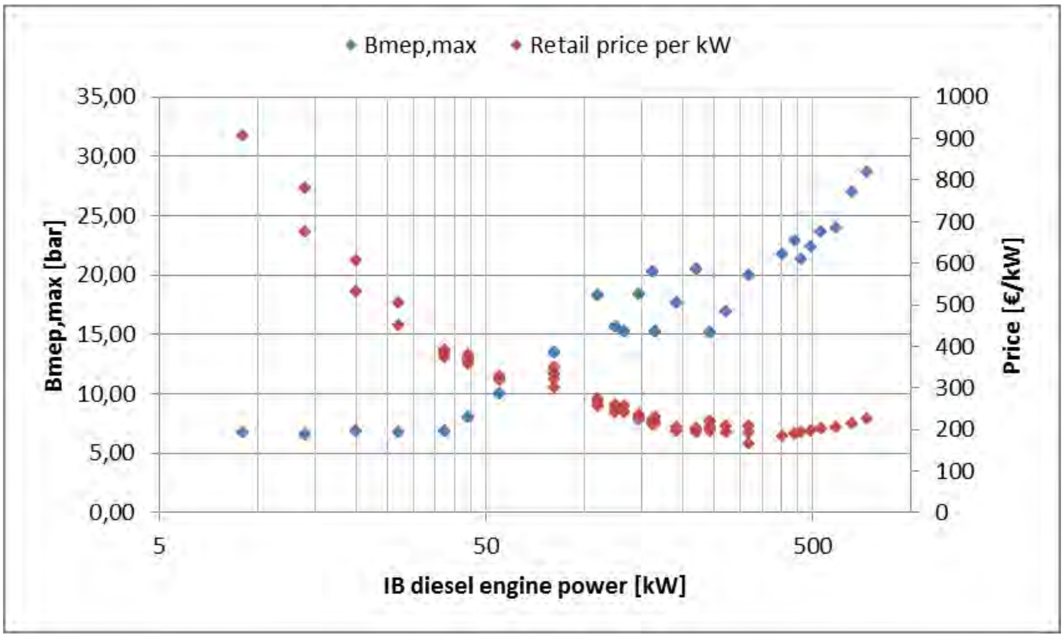


[19] This list is illustrative only and not exhaustive.

CI inboard propulsion systems are much more popular in Europe, and consequently there are more European manufacturers.

Figure 3-10 and Figure 3-11 show how the main characteristics of these engines change with engine power for the 2019 production line of one manufacturer. Below 30 kW these engines have a small displacement volume (typical of small generator sets / industrial engines) and a relative high rated engine speed. Their low bmep-values indicate that they are typically naturally aspirating engines. These are relatively high cost engines (in €/kW installed power).
Between 30 and 157 kW, the engines have a displacement and speed range typical of light-duty automotive diesel engines. Above 157 kW up to 350 kW the design resembles that of medium duty automotive engines (with typically 0,9 l/cylinder). Only for the most powerful engines, the specifications resemble that of heavy-duty diesel engines (with bmep above 20 bar and rated speed below 2500 rpm.

Figure 3-11 Overview of Volvo Penta CI SD/IB production range – max bmep levels and retail price (per kW, incl. VAT) versus max power (2019 data)



The same segmentation is observed in the product portfolio of Nanni, a major marinizer:

- In the 7,36 < P[kW] < 84,6 range, Nanni products are marinized versions of a Kubota industrial engine, with turbocharging applied only for P > 37 kW.
- Nanni further produces marinized Toyota automotive engines in the 147 – 272 kW range.
- Somewhat overlapping are marinized versions of John Deere (lower speed) engines with a power ranging from 112 to 559 kW.
- For engines that exceed 472 kW (up to 882 kW) their base engines are heavy-duty diesel engines from Scania (or MAN).

State-of-the art technology and changes since the introduction of RCD II

To comply with RCDII, diesel engines had to reduce their NO_x+HC emission levels as well as limit their PM emission. However, all of these new target levels could be achieved without having to apply exhaust gas recirculation or exhaust gas aftertreatment.

For the smaller engines (below 37 kW) it has meant mainly the retarding of fuel injection. Additional measures typically would be: higher injection pressures, low sac volume nozzles, more sophisticated control of fuel injection.

For engines with an output exceeding 37 kW, the NO_x+HC-limit was set at 5,8 g/kWh (with further reduction of PM under 0,20 g/kWh, see Table 3-3)[20]. Experience with diesel

[20] Or, for 37 ≤ P[kW] < 75 even a lower limit of 4,7 g/kWh (but allowing for higher PM emission).

engine development in other markets (i.e. the development of Euro III engines for the HD market, where similar target emission levels were imposed (Krishnan, et al., 2008)) had shown that these levels could indeed be achieved with a mix of the following measures.

- 4-valve per cylinder engine technology
- After-cooling of intake charge with turbocharged engines
- Central bowl in piston design and central injector
- Intake flow (swirl) pattern optimization
- Reduced crevices in the combustion chamber
- Retarded fuel injection, electronically controlled as a function of speed and load
- High injection pressure
- Reduced compression ratio

Combinations of these technologies have been applied to recreational marine CI SD/IB engines in recent years to meet the legislative requirements. As an illustration: in response to the 2014+ EPA-Tier 3 regulations in the US and the 2016+ RCDII regulations in the EU, Yanmar introduced Common Rail technology to its engines for engines with a power output exceeding > 30 kW (Nuta, 2016). Similar to Yanmar, some small recreational marine CI SD/IB engines already comply with the more stringent EPA 2014.

Until now, none of these engines has applied more advanced technologies for NO_x reduction such as exhaust gas recirculation (EGR) or SCR (selective catalytic reduction) exhaust gas aftertreatment:

- With recirculation of (part of the exhaust gas) the oxygen concentration in the combustion reaction zones is reduced, this in turns reduces the reaction temperatures and because of this also the NO formation is also reduced. Cooling the recirculated gas further reduces the NO-formation.
- With SCR-aftertreatment technology a urea-water mixture is injected into and mixed with the exhaust gas (in the automotive field this mixture is marketed as Adblue). This mixture releases ammonia (NH_3). When this exhaust gas flows through a SCR catalyst, and temperatures are kept in the 280 – 500 ºC range, NO and NO_2 will preferentially react with this NH_3 to form nitrogen and water.

Typical NO_x-reduction levels that are achieved with EGR and SCR in other (heavy-duty or NRMM[21] markets) are 50% respectively 85% or more.

Candidate emission reduction technologies

For making an overview of possible emission reduction technologies for recreational craft engines, a comparison has been made with the emissions target levels of engines with the same basic design and power rating in the NRMM and marine market. As a reference for recreational craft, the EPA Tier3 2014+ emission levels have been used. As mentioned before, these are already below RCDII levels. The resulting overview is shown in Table 3-4.

From this table a number of observations can be made:

1. Target levels change considerably with the power rating of these engines. Target emission levels become lower as the engine power increase. This is because:
    a. the fact that engines with low power tend to suffer a relatively larger additional cost when they have to meet a lower emission level (this would apply to engines with P < 19 kW), e.g. because of lower sales numbers,
    b. the overall contribution of this market segment to the total emission is relatively small (this could apply to engines with P < 19 kW and/or engines with P > 560 kW).
2. At the same time, there are considerable differences in this classification. Within this study it has not been possible to check the background of these differences.
3. Regulations for recreational craft make a difference in target levels depending on swept volume (SV). A similar split is not in the NRMM legislation, notwithstanding the similarity in the design of the engines operating in this market.

[21] NRMM = Non-Road Mobile Machinery

Table 3-4 Overview of emission regulations in different markets relevant to CI SD/IB engines

<table>
<tr><td colspan="2">Regulation maximum emisson levels [g/kWh]</td><td colspan="3">EPA Tier 3 (2008)</td><td colspan="3">Stage V IWP[22]</td><td colspan="3">EU Stage V NRMM</td></tr>
<tr><td colspan="2">Application date</td><td colspan="3">2009 - 2014</td><td colspan="3">2016+</td><td colspan="3">2017+</td></tr>
<tr><td>Displ.vol. SV (per cylinder)</td><td>Power range [kW]</td><td>CO</td><td>NO_x + HC</td><td>PM</td><td>CO</td><td>NO_x + HC</td><td>PM</td><td>CO</td><td>NO_x + HC</td><td>PM</td></tr>
<tr><td rowspan="9">SV < 0,9</td><td>P < 8</td><td>8</td><td rowspan="2">7,5</td><td rowspan="2">0,4</td><td colspan="3" rowspan="2">Not considered</td><td>8</td><td rowspan="2">7,5</td><td rowspan="2">0,4</td></tr>
<tr><td>8 ≤ P < 19</td><td>6,6</td><td>6,6</td></tr>
<tr><td>19 ≤ P < 37</td><td rowspan="7">5</td><td rowspan="3">4,7 (5,8)</td><td rowspan="3">0,3 (0,2)</td><td rowspan="4">5</td><td rowspan="3">4,7</td><td rowspan="3">0,3</td><td rowspan="4">5</td><td rowspan="2">4,7</td><td rowspan="6">0,015</td></tr>
<tr><td>37 ≤ P < 56</td></tr>
<tr><td>56 ≤ P < 75</td><td rowspan="4">0,4+0,19</td></tr>
<tr><td>75 ≤ P < 130</td><td rowspan="4">5,8</td><td rowspan="4">0,15</td><td>5,4</td><td>0,14</td></tr>
<tr><td>130 ≤ P < 300</td><td rowspan="3">3,5</td><td>2,1+1</td><td>0,1</td><td rowspan="3">3,5</td></tr>
<tr><td>300 ≤ P < 560</td><td rowspan="2">1,8+ 0,19</td><td rowspan="2">0,015</td></tr>
<tr><td>560 ≤ P < 3700</td><td>3,5+0,19</td><td>0,045</td></tr>
<tr><td>0,9 ≤ SV < 1,2</td><td rowspan="4">P < 3700[23]</td><td>as SV < 0,9</td><td>5,8</td><td>0,14</td><td colspan="3" rowspan="4">As SV < 0,9</td><td colspan="3" rowspan="4">As SV < 0,9</td></tr>
<tr><td>1,2 ≤ SV < 2,5</td><td>5</td><td>5,8</td><td>0,14</td></tr>
<tr><td>2,5 ≤ SV < 3,5</td><td>5</td><td>5,8</td><td>0,12</td></tr>
<tr><td>3,5 ≤ SV < 7,0</td><td>5</td><td>5,8</td><td>0,11</td></tr>
</table>

Based on Table 3-4, the following major groups are considered:

- small naturally aspirated engines with a power below 19 kW
- engines with a power between 19 and 37 kW
- engines between 37 kW and 75 kW, and finally
- engines with a power exceeding 75 kW

This classification is very close to the one presently used in recreational craft power classification. In the remainder of this paragraph these groups will be treated separately.

CI SD/IB engines with rated power P < 19 kW

These engines are all naturally aspirated engines. They apply indirect fuel injection or else simple mechanical DI fuel injection systems. According to RCDII regulations they are allowed to emit NO_x+HC levels that exceed 10 g/kWh and PM up to 1 g/kWh. At the same time, recent Stage V levels of NOx+HC have been demonstrated by NRMM-products in that same power range from companies like Kubota (Japan), Yanmar (Japan), Hatz (Germany) and Kohler((Italy) (Gioria, et al., 2019). These levels were met without the need for electronic fuel injection, exhaust gas recirculation (EGR) or aftertreatment technology. Obviously, the same combustion system optimization is feasible for recreational marine application.

CI SD/IB engines with rated power 37 ≤ P[kW] < 75

Emission limits in this power range are similar for RCDII, EPA Tier 3 and Stage V NRMM (see Table 3-4). RCDII engines in this power range are a mix of naturally aspirated (at

[22] IWP = Inland Waterway Propulsion
[23] In the US also P > 3700 kW is considered. For these recreational marine engines the limits apply as for engines with displacement between 3.5 and 7 liter per cylinder.

lower power) and turbocharged engines. Both DI mechanical FIE[24] is used (with smaller displacement engines) as well as common rail DII FIE with electronic control of injection timing[25].
To achieve RCDII emission levels of 4,7 (or 5,8) g/kWh NO_x+HC and 0,3 (or 0,2) g/kWh PM, the combustion system was further optimized, similar as has been performed before with the larger automotive engines (Nuta, 2016). To improve the trade-off between emissions and fuel consumption, cooled EGR has been applied in NRMM engines in that same power range.
For lower NO_x+HC emission levels more complicated EGR systems would be required and/or the application of SCR exhaust aftertreatment technology.
Similarly, to further significantly reduce PM emissions would require DOC[26] and/or DPF[27] technology.

CI SD/IB engines with rated power 19 ≤ P < 37 kW

RCDII engines in this power range are naturally aspirated engines with similar design (and current RCDII emission targets) as the engines with P < 19 kW described before. They tend to use IDI or DI mechanical FIE.
To meet with the lower EPA Tier 3 emission levels (5,8 g/kWh NO_x and 0,2 g/kWh PM) for its 3JH40 engine (29,7 kW), Yanmar introduced CR technology to this engine in 2018. Alternatively, cooled EGR could be applied for meeting these emission levels (when combined with simpler FIE).

CI SD/IB engines with rated power above 75 kW

RCDII engines in this range are turbocharged engines and they typically already apply high pressure Common Rail (electronically controlled) fuel injection. With this technology it is possible to reduce NO_x+HC emissions to 4,7 g/kWh (possibly by also applying internal EGR). This will however result in some increase in fuel consumption. Alternatively, the bmep-level could be reduced. The latter strategy is presently applied in some RCDII engines that are developed to comply with Bodensee regulations.
To go towards even lower in emission levels (as in Stage V NRMM engines), the same technologies can be applied as mentioned before: cooled EGR and/or SCR[28] exhaust gas aftertreatment for NO_x-reduction and DOC+DPF for PM reduction.

Impact on durability and maintenance

Applying changes to the combustion system have little or no impact on the durability and maintenance of these engines. This situation changes when applying EGR and SCR.

Durability issues when applying EGR-technology: corrosion and fouling

Until now, recreational marine engines are designed for operating with so-called marine distillate oil or MDO. This fuel can contain up to 1000 ppm of Sulphur (or 0,1%). When used in combustion engines the exhaust gas will therefore contain SO_2 and H_2O. These exhaust gas components will combine into sulphurous (H_2SO_3) and/or sulphuric (H_2SO_4) acid. The condensate of these substances will corrode most metal parts. Such condensation is for instance to be expected in the heat exchanger that is used to cool the recirculating exhaust gas. For this reason, 500 ppm Sulphur is considered the maximum level for applying this technology in commercial marine engine application[29].
A second durability issue is that of EGR-circuit and intake system fouling. With EGR, any particulate matter formed that is present in the exhaust gases will be recirculated and mixed with the intake charge. This will result in some level of fouling of the corresponding circuits and/or sticking of valves. This can be avoided by taking exhaust gas from the exhaust after the turbocharger and DOC/DPF and feeding it into the intake before the compressor (so-called low pressure or LP[30] EGR circuit). In a high-pressure EGR circuit (HP EGR), exhaust gas is tapped off before the inlet of the turbocharger and

[24] Fuel Injection Equipment
[25] With CR technology higher injection pressures are possible, resulting in faster combustion with lower in-cylinder particulate formation. As a result of this, injection can be retarded and NO_x reduced. Electronic control allows to optimize timing across the full engine operating range.
[26] Diesel Oxidation Catalyst
[27] Diesel Particulate Filter
[28] Selective Catalytic Reduction
[29] These are guidelines for applications where the lifetime far exceeds that considered for recreational marine engines.
[30] Low Pressure

fed into the intake just before the intake manifold. Both versions can be combined; such a hybrid system is shown in Figure 3-12.
EGR fouling tends to be higher when heat exchanger walls are cooler. Further (of course) fouling increases when PM and HC concentration are higher. Experience in the automotive field suggests that acceptable operating times are possible before problems occur. After that period, components should be dismantled and cleaned. Occasionally this may result in higher maintenance costs.

Durability issues when applying SCR-technology: catalyst deactivation, plugging and corrosion

In SCR-exhaust systems, the NH3 that is fed into the exhaust will react with H_2SO_4 to form ammonium sulphate salts $(NH_4)_2SO_4$ and $(NH_4)HSO_4$. This reaction occurs at temperatures below 280 ºC. Deposition of these salts in the catalyst cause catalyst deactivation as well as partial blocking of small passages in the catalyst brick (plugging/ blocking).
Because of its lower sensitivity to S-poisoning, marine diesel engines apply so-called Vanadium-based SCR-catalysts (where TiO_2, WO_3 and V_2O_5 are active components) instead of the Cu/Fe-zeolite SCR-catalysts that are typically used in automotive applications. And because of the intense use of these engines also larger cell sizes are used.
Further, a DOC catalyst prior to the SCR cat (to turn NO into more reactive NO_2) will turn SO_2 into SO_3, hence such a DOC is typically avoided in marine applications.
To avoid these durability issues, 1000 ppm MDO could be replaced by so-called ultra-low-sulphur diesel (ULSD) with less than 15 ppm Sulphur content. This is also the S-level that is found in EN-590 diesel fuel that is applied in the automotive and NRMM market. This fuel can be applied with no problem to recreational marine engines (TNO, 2007). A shift to ULSD fuel would also enable the application of Cu/Fe-zeolite SCR-catalysts (that demonstrate better efficiency over a wider temperature range).

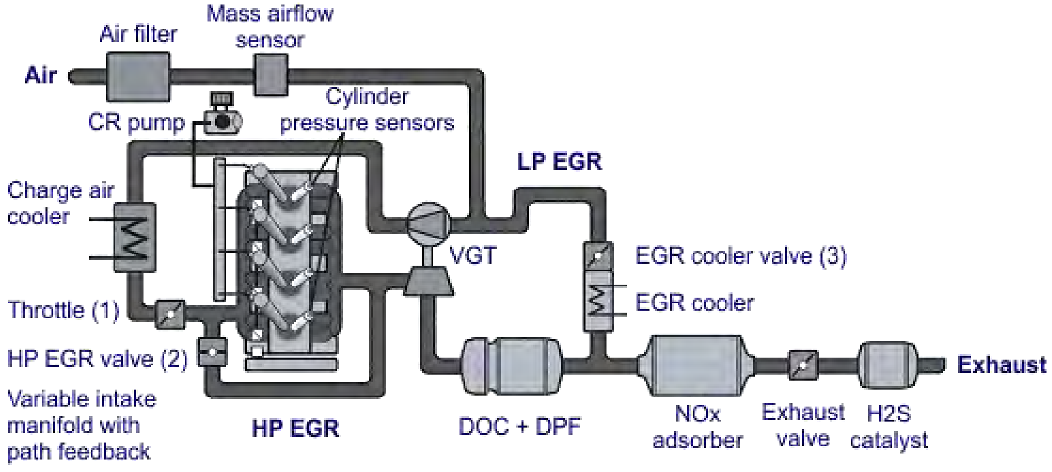
Impact on volume and weight

Applying cooled external EGR and or SCR-aftertreatment will impact volume and weight.

EGR system impact

Applied cooled EGR requires a separate circuit for tapping off part of the exhaust, cooling this gas, and feeding it back to the engine. Both low pressure EGR-circuits and high pressure EGR-circuits are in use with automotive engines, both in the light-duty as well as in the heavy-duty market. The EGR-circuit (with its valves and sensors) and the corresponding extra cooling circuit will take up more volume.
This is illustrated in Figure 3-12.

Figure 3-12 Volkswagen light-duty hybrid EGR system developed for US EPA Tier 2 Bin 5 diesel application (Jääskeläinen & Khair, 2021)



Although there is a volume increase, it seems that this increase is limited. In fact, the volume of NRMM engines that apply cooled EGR has not increased that much from previous generations without EGR. Similarly, the weight impact of adding an EGR system is also limited.

SCR system impact

The typical volume of an SCR-catalyst of a 300 kW HD diesel engine is in the order of 25 to 30 litre. This is for a catalyst with small cells (a typical cell density of 400 cpsi) and a corresponding high space velocity. An SCR-system also includes a feed pipe, a mixer unit and a diverging section feeding into the catalyst brick. That means that actual volumes would become even bigger. Allowing for 50% volume increase, a first estimate gives 0,15 litre per kW.
As mentioned above, the use of high-sulphur fuel results in a reduction of this space velocity. In a study on behalf of ICOMIA on the feasibility of SCR application for recreational craft above 24 m, Ricardo assumes a space velocity of 24000 h^{-1} (Hutton & Nicol, 2013), and in follow-up study in 2018 (Allen, 2018) they mention a cell density of 50 cpsi. Other sources indicate a ratio of 0,5 to 0,6 litre catalyst system volume per kW (including mixer). Obviously, the SCR-system becomes considerably larger than with ULSD fuel. For a Volvo Penta D6-330 250 kW recreational marine engine this would add 150 litre to the engine volume of approximately 690 litre (1020x897x754 mm^3). This would correspond to a cylinder with 44 cm diameter and 1 m length.
Based on data from STT Emtec, the weight penalty would be in the order of 100 kg. To be compared with the engine weight of around 675 kg, this is a considerable weight increase.
With SCR also a second fluid (urea-water mixture) needs to be stored on-board. This will add some additional volume/weight penalty.
Again, switching to ULSD would considerably reduce the weight and volume impact of SCR-technology application.

Impact of thermal insulation requirements

For safety reasons the outside temperature of the different components that are part of the exhaust system should not exceed certain temperatures.
Current practice is to inject water in the exhaust to reduce temperatures as fast as possible (to minimize the thermal loading on the non-metal parts that follow). This is referred to as a wet exhaust system. Similarly, turbochargers are also often water-cooled.
When EGR systems are added, or SCR technology, water injection can take place only downstream of these components. With SCR-systems it is further necessary to maintain the temperature drop minimal between engine-out and catalyst. That is why they are usually covered with insulating material. In doing so, external temperatures are kept within acceptable ranges and at the same time temperature drop in the exhaust gas is minimized.
Such blankets are typically 50 mm thick. Volume and weight impact of this thermal insulation is therefore limited.

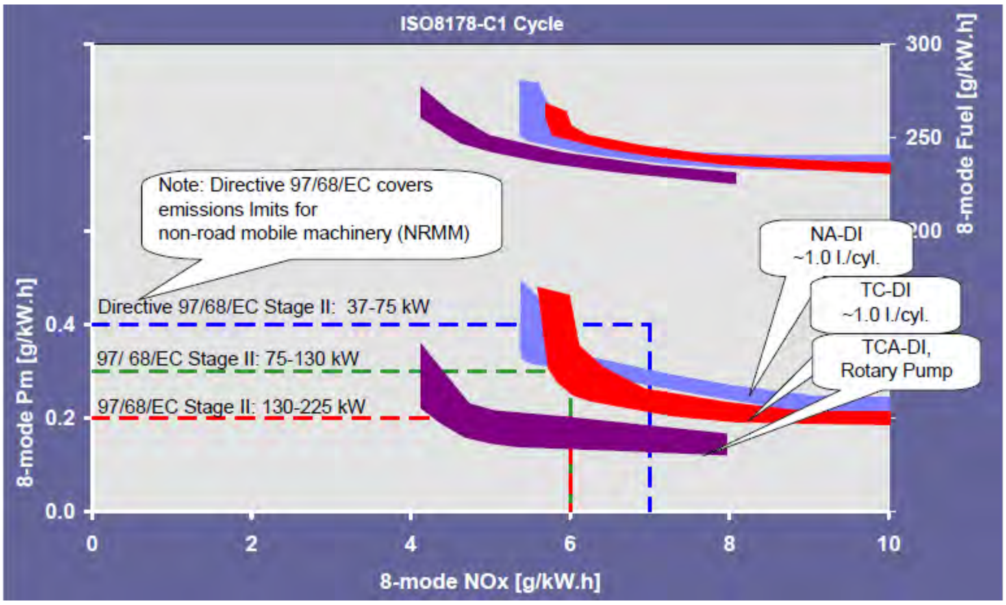
Impact on fuel consumption and greenhouse gas emissions

Per type of technology, the impact on fuel consumption and greenhouse gas emissions are discussed.

Impact of applying combustion system optimization technology

Experience with heavy-duty diesel engine development has shown that reducing emissions from Euro I (8/1,1/0,36 g/kWh HC/NO_x/PM; 1992) to Euro II (7/1,1/0,15 g/kWh; 1997) to Euro III (5//0,66/0,10 g/kWh; 2000) was realized with only a limited increase in fuel consumption. Fuel consumption seems to increase mainly as soon as target NO_x-levels drop below 7 g/kWh. First this increase rate is low, but when these levels drop below 5 g/kWh the increase rate grows rapidly with further reduction in NO_x. A similar observation was made previously in the 2006 ECNI report (ECNI2, 2006) as illustrated in Figure 3-13 from that report.

Figure 3-13 NO_x-PT and NO_x –Fuel Consumption trade-offs for NRMM Stage II in ISO8178-C1 Cycle (ECNI, 2006) (ECNI2, 2006)[31]



If combustion would be advanced on a Euro III –type engine towards earlier injection timings, a fuel consumption reduction would be realized.

Impact of applying EGR technology

First experiments with high pressure EGR technology (Baert, et al., 1996) already indicated that, starting from Euro III levels, even with a substantial 50% NO_x-reduction, fuel consumption increase was minimal. This small effect was in part realized through the application of a venturi-mixer and because the charging system (with VNT) was sized towards EGR application and not-optimal for a no-EGR Euro III configuration. In reality, the impact of this technology varies depending on the engine operating point and on the design choices made (e.g. the application of back-pressure valves in the exhaust system). This was illustrated in (Baert, et al., 1999). Other studies (e.g. (Verbeek R., 2001) mention fuel consumption penalties of 2 to 3%. Based on these results a 2,5% fuel consumption increase could be considered realistic (not too low, not too high).
Because this fuel penalty increases with the NO_x-reduction, usually a minimum required amount of EGR is applied.

Impact of applying SCR technology

This technology marginally increases the exhaust manifold pressure (increasing pumping work). At the same time, given its high NO_x-reduction efficiency, it will allow to advance timing again (earlier than current RCDII 5 g/kWh settings). And thus realize a net fuel consumption benefit.
Based on internal TNO info, an increased engine-out NO_x-level of 8 g/kWh could result in 4 to 5% efficiency gain.

3.3.4 *Electric propulsion systems*

For electric propulsion systems the following is discussed:

- The market description
- The state-of-the art electric system propulsion technology
- The impact on volume and weight
- The impact on durability and maintenance
- Emissions reduction with electric propulsion systems
- Autonomous market share growth

[31] Emissions levels achieved by combustion system re-optimization and injection timing retard (with rotary fuel injection pumps, which enable timing strategy optimization according to speed and load).

Electric propulsion system market description

In recent years, a large number of companies have entered the market for recreational craft with products that are propelled by electric energy that is stored on-board in batteries. Many (in fact most) of these products have a power output that does not exceed 5 kW. A limited number of these products target higher powers up to 50 kW.
Most are fully electric outboard engines (amongst others from Torqeedo, Aquamot, Elco, Krautler, ePropulsion and others). However, inboard driveline solutions (from a multitude of companies such as Oceanvolt, Belmarine, Electric Yacht, Fischer Panda and again from Torqeedo and Elco) are also being marketed. These companies make use of technology that has evolved from developments in the automotive market.
At present the market share of these fully electric craft is small, but growing.

State-of-the art electric propulsion system technology

A fully electric driveline consist of an electromotor, a battery pack with its BMS (battery management system), connecting cables, a charger and power electronics. The electromotor used can be either a DC[32] Brushless type electromotor or a more sophisticated permanent magnet AC electromotor (with higher efficiency). In the latter approach, the power electronics turn the DC power delivered by the battery into AC power at the appropriate voltage level.

Part of the electric energy that is charged from the grid will be lost before it reaches the propeller shaft. These losses occur in the charging unit, in the battery (while charging), in the battery (while discharging), in the power electronics and in the electromotor. Typical efficiencies that correspond to these losses are shown in Table 3-5 (for a situation where a PM AC electromotor is used).

Table 3-5 Typical energy conversion efficiencies in electric propulsion

	Step efficiency	*Overall efficiency (%)*
Grid (AC)		100,00%
AC/DC charger out (DC)	0,96	96,00%
Stored in battery	0,975	93,60%
Released from battery	0,98	91,73%
DC/AC conversion (invertor)	0,96	88,06%
AC PMS electromotor out	0,94	82,78%

The batteries used are at present in majority so-called Deep Cycle Absorbent Glass Mat (AGM) batteries. They are much cheaper than the alternative (and more recent) Lithium-ion batteries. These Lithium-ion batteries are primarily Lithium-iron-phosphate (Li-$FePO_4$) batteries or Lithium Nickel Manganese Cobalt (NCM) batteries. With − until now − often preference for the former technology because of its lower price and because it is more robust (i.e. sensitive to temperature changes).
Table 3-6 gives an overview of some critical properties of these batteries. Because the Li-ion technology continually advances, the reference values mentioned for the automotive market are meant as indication only. These values are from literature (a.o. (König, et al., 2021)). Clearly, price levels (as well as weight) of battery packs in the marine market are significantly above those mentioned for the automotive market.

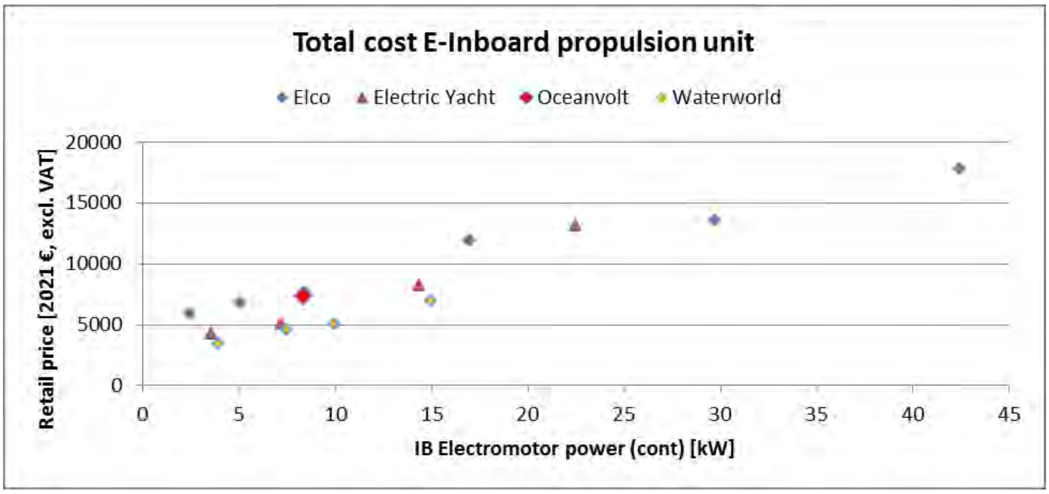
[32] DC = driect current; AC = alternating current

Table 3-6 Typical specifications of battery packs on the market (and expected). Info on marine type batteries collected from manufacturers websites. Info on automotive cost to the manufacturer from (König, et al., 2021)

Battery pack specs	*2020 Marine (price)*			*2020 Automotive cost*		*2030 (expected cost) Automotive*
	AGM	Li-FePO4	Li-NCM	Li-FePO4	Li-NCM	Li-NCM
[€/kWh]	200	400	800	100	200	125
[Wh/kg]	40	80-100	140	200+	160	100

The same observation is made when comparing the prices quoted for an electromotor. As shown in Figure 3-14 these are much higher than those of a similar electromotor in the automotive market (where price levels are mentioned that are below 100 € per kW of maximum continuous power, including the cost of power electronics).

Figure 3-14 Electromotor retail price variation with output power for 4 different manufacturers (information from manufacturers websites gathered in period June/July 2021)



The highest current levels with the electric connecting cables that are in use is between 300 and 400 A. Hence, as power levels increase, also voltage levels in recreational craft have to increase. For most electric outboards, voltage levels are 24 or 48 V (but for highest powers also 96 and 114 V are mentioned). With higher voltages, also safety rules need to be adapted.

An electromotor is further characterized by a high torque at zero speed. In addition, its maximum speed range in marine application can be smaller than that of the small displacement combustion engines (< 0,9 litre swept volume per cylinder) presently in use. Thus a given required thrust power level can be generated with a lower propeller speed and a larger propeller size (than that of a comparable ICE[33]-propelled craft). In turn, the larger propeller operates more efficiently. Hence the required shaft power with an electromotor is smaller than that of the equivalent ICE-solution. Finally, the electromotor also has a higher efficiency than an internal combustion engine, reducing the required input power. Because of this, the manufacturers of electric propulsion systems tend to characterize the performance of their products by mentioning the power output level of the comparable (or equivalent) ICE-solution. Unfortunately, the data from manufacturers does not always mention whether they refer to equivalent shaft power or equivalent crankshaft power.

Impact on volume and weight

Figure 3-15 gives an indication of the impact on weight of the electrification of outboard engines. In this calculation it was assumed that electric outboards will have an input power that is a factor 1,9 lower than that of the equivalent combustion engine rate power. This is in line with the ratios found in the specifications of a number of electric outboard manufacturers (Aquamot, Elco and Torqeedo), be it on the conservative side

[33] Internal Combustion Engine

(possibly underestimating the required E-power). From the corresponding ICOMIA-E4-cycle average power, the energy needed for 8 hours of operation (in one day, or before recharging) was calculated. Battery size was assumed to be 20% larger (allowing for a maximum of 20% depth of discharge). Then the corresponding costs and weight were determined using the data in Table 3-6. The automotive manufacturing costs were increased with 20% (to take into account price margins); this is considered to be a conservative approach.
From the results in Figure 3-15, it is clear that the weight penalty makes electrification challenging for replacing ICE outboards with a rated power above 30 kW. Furthermore, at present battery costs are excessive. However, even in 2030, Li-NCM batteries will pose a serious upfront cost.

Figure 3-15 First estimate of cost and weight impact of outboard engine electrification

Target rated ICE-power	[HP]	8	15	30	115	175		
	[kW]	5,9	11,0	22,1	84,6	128,7	150,0	250,0
Target E-motor input power	[kW]	3,1	5,8	11,7	44,8	68,1	79,4	132,4
Average E-motor input Power	[kW]	0,7	1,2	2,5	9,4	14,3	16,7	27,8
Battery size	[kWh]	7,8	14,5	29,1	111,4	169,6	197,6	329,4
2020 Battery cost Li-FePO4 - Marine	[€]	3101	5814	11628	44572	67827	79045	131742
2020 Battery weight Li-FEPO4 - Marine	[kg]	62	116	233	891	1357	1581	2635
2020 Battery cost Li-NCM - Marine	[€]	6201	11628	23255	89144	135654	158090	263483
2020 Battery weight Li-NCM - Marine	[kg]	55	104	208	796	1211	1412	2353
2030 Battery cost Li-NCM - Automotive	[€]	1163	2180	4360	16715	25435	29642	49403
2030 Battery weight Li-NCM - Automotive	[kg]	39	73	145	557	848	988	1647
Yamaha OB weight	[kg]	40	60	107	193	245		

The same conclusion can be drawn with respect to recreational craft with inboard engines. As many of these boats (especially the largest motorboats) require an autonomy (time between recharging) that exceeds 8 hours, electrification of this craft is even more challenging.

Impact on durability and maintenance

In general, it is expected that maintenance costs of electric drivelines are minimal. There is some concern however about the durability of the batteries. Especially with Li-NCM batteries it is necessary to maintain a proper thermal management as well as to avoid excessive power demands (i.e. excessive C-ratings of the battery).

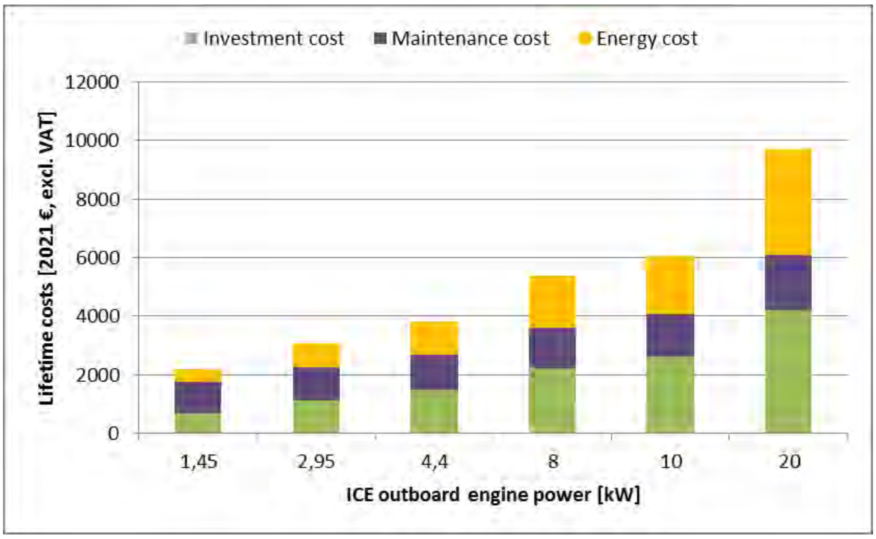
Emissions reduction with electric propulsion systems

Of course, electric drivelines do not produce emissions. The only emissions produced would be during the production of the electricity that is charged from the grid. In Europe, in 2019, average carbon intensity of electricity generation was 255 g/kWh (EEA, 2021).

Projected market share growth

A very rough estimate of the lifetime costs of small conventional outboards is presented in Figure 3-16.

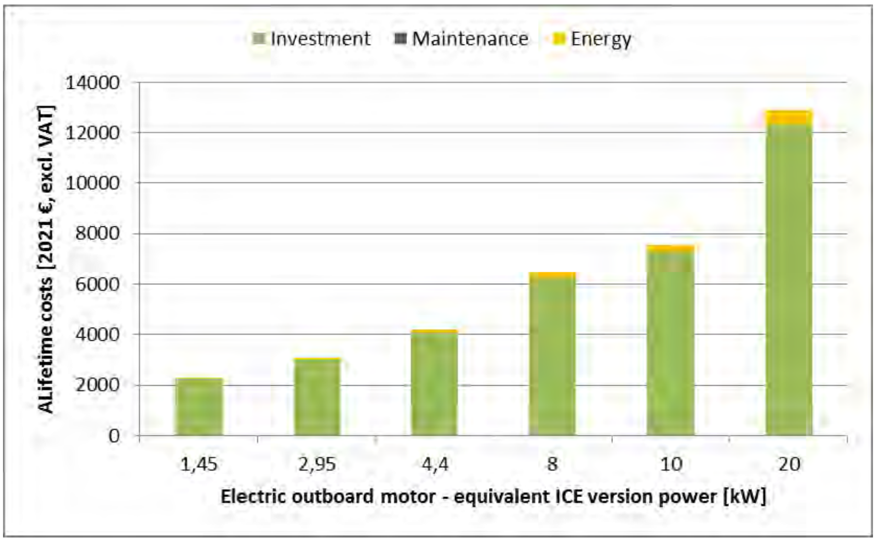
Figure 3-16 Estimated lifetime costs of ICE outboard engines



For this calculation, energy costs were determined from fuel consumption values (in line with data from the EPA certification database) in combination with an EU-average petrol price of 1,263 €/litre (EEA, 2021). Investment costs were determined from the pricelist of one of the major outboard manufacturers. Insurance costs were not taken into account.

For comparison, also the lifetime costs for the comparable electric outboard (in that same power range) is shown in Figure 3-17. These are based on the current price levels of electric outboard components (in line with the data that were also the basis for Figure 3-14). Of course, especially battery prices are expected to decline in the years to come. If prices would reach the 2030 levels as in Table 3-6 the total lifetime cost of smaller electric outboard would become equivalent to that of its conventional counterpart.

Figure 3-17 Estimated lifetime costs for electric outboards – current marine market price levels



From this comparison it is clear that electric outboards are becoming a competitive solution for smaller power ranges. However, the following remarks apply:

- The electric outboard may be somewhat underpowered (as the 1,9 rated power ratio may be underestimating e-power requirements).
- In these calculations a total lifetime use of 1400 hours was assumed (in line with previous assumptions, see section 2.2).
- Battery size for electric outboards was aimed at 4 hours autonomy. A higher battery size would make the electric alternative too much space consuming.

- The electric outboard suffers from a higher upfront investment cost, and energy and maintenance costs shown are not discounted.
- With small outboards, many owners like to do their own maintenance.

Based on the above observations only for boat classes with relatively small motored craft with (outboard) engines with an equivalent ICE rated power up to 8 à 10 kW could shift towards electric propulsion systems. The motivation for this choice would then be that:

- An autonomy of 4 hours is acceptable for these classes.
- Boats operate at relatively low speeds for most of the time (lower than according to the ICOMIA test cycle) and therefore need less energy (allowing for a smaller battery).
- Boats are used more intensively (more than 1400 hrs.), thus increasing the variable cost benefit of the electric alternative.
- The boat operate a considerable part of time in emission free zones.
- Boat owners in these classes are willing to pay higher investment costs for a more eco-friendly propulsion system.

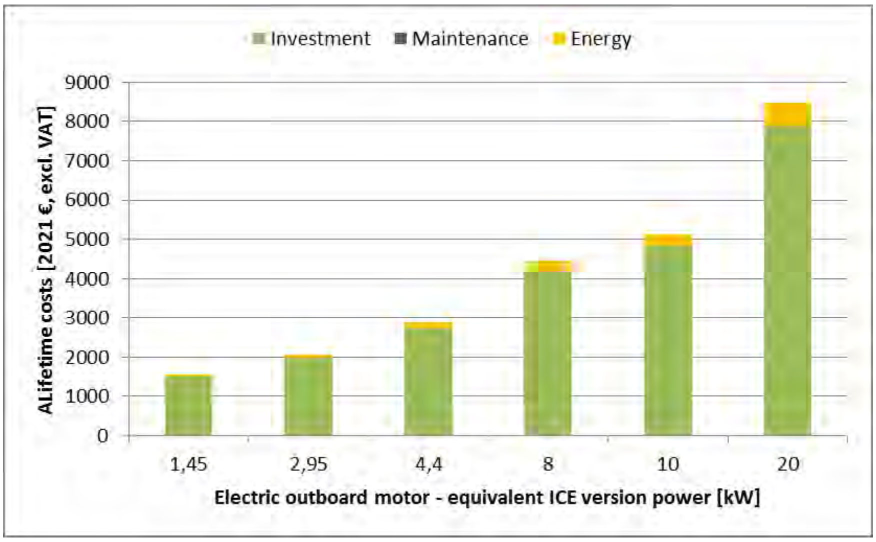
An alternative boat class where electrification seems likely to occur in the coming years is that of small sailing boats. When sailing (with sufficient wind, i.e. at sufficient speed), the water flow around the propeller can be used to drive the electromotor (propeller in so-called regeneration mode) and in this way recharge the battery. Because the speed (when powered by an engine) is typically 7 to 9 km/hr, power demand is relatively low (and decreases with speed) ((Oceanvolt, 2021), (Electric_Yacht, 2021)). Following the same lifetime cost calculation method as mentioned before, an electric sailing yacht with a modest but feasible battery size is already cost-competitive with a similar yacht that is using a conventional diesel in-board engine. Of course the higher upfront cost as well as the battery size limitation (and possible range limitations) will still refrain many buyers from taking that option.
The observation that electrification will be initially focused on small craft with OB engines and on small sailing boats has been confirmed (qualitatively) in discussions with EBI.

Considering the fleet composition classes mentioned before, an optimistic scenario of autonomous growth of electric propulsion would be: 50% of all new "other boats (< 20 ft.)", 50% of all new "petrol sailing boats (< 26 ft.)" and 15% of all new "diesel sailing boats (> 26 ft.)" will become electric. Implicit to this scenario is the assumption that there will be a fast development of adequate charging infrastructure in the geographic areas where these craft tend to operate (something that still needs to be realized).

Finally, an estimate was made of the expected costs of electric outboards where a full 8 hours autonomy is assumed and at the same time lowered E-motor costs (45% lower, in line with 50% market share as well as technology carry-over from the automotive market). Together with 2030-automotive level battery pack prices, this results in lifetime costs as shown in Figure 3-18. Obviously, under these conditions, the electric version becomes the preferred option. Surely this is an optimistic scenario, but it does confirm the potential for electrification.

Still, an additional remark must be made: in this comparison, upfront investment costs and costs later in life are treated in the same way. In practice this may not be the case and buyers may have a preference for the option with the lowest investment costs. Furthermore, although low, there will still be some maintenance costs involved with electric outboards. Finally, this comparison does not take into account insurance costs and other costs.

Figure 3-18 Estimated lifetime cost of electric outboards, assuming 45% reduction in electromotor cost and battery pack prices in line with expected prices in the automotive market.



On the other hand, fossil fuel prices are expected to increase in the years to come. This, in combination with possible tax advantages (for example: via exclusion of VAT on electric solutions), may shift the market towards electric in this power range. The first class of boats that would turn electric would then probably that of "yawl and cabin boats" which in this study has an assumed average power level of 30 kW.

The above discussion focused primarily on craft with relatively low power levels. For larger and more powerful craft (motor boats, speed boats and personal watercraft) that need bigger batteries, a similar shift will happen only when other battery technology with significant weight reduction will become available. In addition this will require wide spread availability of fast charging infrastructure. This is likely to take at least another 10 to 20 years. An alternative path for electrification of larger craft could consist in the application of fuel cell technology in combination with hydrogen as an energy carrier. This will not happen until fuel cell technology development in other markets will have demonstrated an acceptable durability as well as a sufficient price reduction. In addition, this will require solving additional challenges such as hydrogen on-board storage weight penalty as well as setting up a wide spread distribution of high quality hydrogen. A more likely path could be the adoption of renewable liquid fuels in combination with conventional (or hybrid) propulsion systems.

3.3.5 Hybrid propulsion systems

For hybrid propulsion systems the following is discussed:

- The description of the market for hybrid propulsion systems
- The state-of-the art of hybrid propulsion system technology
- The impact on volume and weight of the application of hybrid systems
- The impact on durability and maintenance
- Emissions and fuel consumption reduction with hybrid propulsion systems
- Autonomous market share growth

Hybrid propulsion system market description

In a hybrid propulsion system the driveline consists of a combustion engine and a second power unit as well as an energy storage unit. In current practice the latter will be an electromotor and a battery pack. Such drivelines are currently a mainstream product in many automotive vehicles. By combining these components it is possible to achieve two objectives:

- To recuperate the vehicle kinetic energy that is otherwise lost during braking and to store that energy in the battery for later use
- To decouple the engine operation from the vehicle power demand, and in this way shift the engine operation towards conditions with lowest possible fuel consumption.

- Hybrid propulsion systems have also been considered for implementation in marine applications (both commercial and recreational). For instance, recently Volvo Penta has decided to build a prototype propulsion system for commercial application (Volvo Penta, 2018).
- In the recreational market hybrid propulsion systems have been demonstrated in a limited number of large yachts (> 24 m). These are unique designs by companies such as Zenoro. In addition to that a number of small innovative companies (such as Greenline, Hybrid-Marine, Zenoro, Auxilia, Oceanvolt, Drinkwaard Marine and others[34]) are bringing small volumes of hybrid motorboats and sailboats to the market. Finally, one OEM - Toyota, is marketing a hybrid leisure craft (the Ponam-28V Sports Utility Cruiser). However, numbers are low and the market share of hybrid propulsion systems is almost negligible.

State of the art hybrid propulsion system technology

In principle, both series and parallel hybrid topologies are feasible for ship propulsion. But in practice almost all demonstrator craft implement a parallel hybrid driveline topology. The reasons for this have been identified already in 2013 as a result of the EU Hymar project (EU Cordis, 2013):

- A parallel hybrid has a better efficiency than a series hybrid when power demand is above 10% of rated power.
- In a series hybrid a large electromotor is needed. In addition, for safety reasons, the corresponding combustion engine has to be able to guarantee a minimum (relatively high) power level. In a parallel hybrid however, direct electric propulsion is limited to lower power demand and both electromotor rated power and battery size tend to be smaller. This makes the parallel hybrid the lower cost option.
- Voltage levels are lower than with series hybrid designs, resulting in reduced electric safety concerns.

The only series hybrid configuration that is interesting with recreational craft is when a small generator set is added to an electric propulsion system as a range extender (thus allowing to reduce the battery size, while at the same time significantly increasing the autonomy of the vessel).

The interaction between engine, electromotor and battery is determined by the objectives for introducing the hybrid propulsion system. As mentioned before, one major objective with potential customers is to run the boat quietly in and out of the harbour as well as being able to enjoy silence while lying still (e.g. for swimming). This can be realized by running all appliances from the battery.

The second major objective is to save on fuel. On-board electric generation and release has a corresponding efficiency of 78% (see Table 3-5). Therefore, switching off the combustion engine in operating point A and generating electricity in operating point B makes sense only when the engine efficiency in point B is at least 22% better than in point A. Combustion engines that are running on a propeller curve have their lowest fuel consumption values in the 25 to 80% rated speed range. And fuel consumption increases sharply at lower speeds. That is why such strategy usually focuses at running electric while the relative engine power is below 10% (or relative engine speed below 40%). This approach is even more interesting when the craft is overpowered (as is often the case with large yachts and some speed boats).[35]

When two parallel hybrid propulsion units (each with their own propeller shaft) are being applied, other fuel saving strategies are also possible. For instance: the engine on one of the units is driving its own the propeller shaft, while at the same time generating electric power for the electromotor on the other shaft (Hutton & Nicol, 2013).

In order to decide on the optimal size of the battery and of the optimal power level of the electromotor (and ultimately on the success of such hybridization) it is necessary to know how the recreational craft speed (on average) varies with time and the corresponding power request time series. Although recreational craft are increasingly

[34] This list is not exhaustive but indicative only.

[35] In such a parallel hybrid configuration, the electromotor could also be used to boost the maximum power of the engine (during short time periods). Of course the combustion engine would need to be able to supply the minimum power required for safe and acceptable operation. Such a parallel hybrid would not necessarily allow to reduce fuel consumption. But it would reduce the cost of the craft.

being monitored (using track and trace equipment) it proved to be impossible to collect sufficient of such data for this study.

Impact on volume and weight

Weight and volume of the propulsion system will increase. The biggest volume and weight impact can be expected when aiming to hybridize current outboard engines as well as personal watercraft. Although some patent applications have been filed for hybridization of outboard engines (e.g. by Honda ((Takeshi, et al., 2008) and Yamaha (Hirotaka, 2009)), no demonstrator has been developed and tested until now. The most likely development effort would be to realize emission free electric operation at the lowest speeds (getting in and out of the harbour) with a small electromotor and correspondingly small battery. This would have a minimal impact on emissions or fuel consumption.
For other, in-board applications, volume and weight restrictions are less stringent and most companies seem to believe that this should not be a problem. This is in part because the batteries can be located in other areas than the engine room.

Impact on durability and maintenance

Hybrid propulsion systems are more complex compared to a conventional propulsion system. However, in line with the experiences from the automotive market, it is expected that this will not result in durability issues or increased maintenance costs.

Emissions and fuel consumption reduction with hybrid propulsion systems

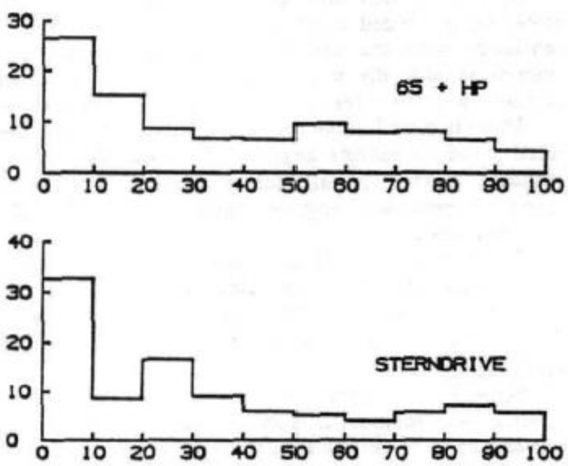
An attempt was made to get an impression of the potential reduction in fuel consumption and emissions when following a strategy where low load operation (10% of rated speed or lower) is electric.

The standard method used previously in this study (as well as in other similar studies to date) to assess the impact of a potential change in engine design or performance on emissions and fuel consumption is to estimate this impact by way of the corresponding test cycle.

This same approach will be followed to estimate the impact of hybridization on emissions and fuel consumption for craft that are using SI engines. For these engines the E4-test cycle is used (as developed by ICOMIA). The weighing factors of the different engine test points in that cycle are supposed to be in accordance with the time spent at different speed/power levels. As shown in Figure 3-3 this cycle assumes that 40% of time is spent at idle (mode 5) and 25% of time at 40% of rated speed (mode 4, corresponding to 10,1% of rated power). This is an average value that represents all type of craft (including sailing boats) as confirmed by ICOMIA (ICOMIA, 2021). As illustrated in Figure 3-19, for higher powered engines this might be an underestimation.

A parallel strategy based on the E4-cycle could then consist of switching the engine off when idling (mode 5) and operating in electric mode when in mode 4 while generating the corresponding required energy at other moments (e.g. in mode 3). Using data on fuel consumption and emissions of a catalysed outboard SI engine (Hilbert, 2011) an estimate was made of the impact. According to this estimate this would result in a fuel consumption reduction of 10% (with similar reductions of CO and CO_2 and with a 37% decrease in $HC+NO_x$).

Figure 3-19 Histogram of time spent at different engine speed levels (as % of rated speed) for higher powered engines as mentioned in (Morgan & Lincoln, 1990).



A similar calculation could not be performed for (parallel) hybrid craft that would be developed starting from a conventional CI engine driven propulsion system. These engines are developed to meet with emission requirements in the E-3 or E-5 cycle. As shown in Figure 3-3 the E-3 cycle has no mode point with a power rating below 25%. The alternative E-5 cycle only adds the low-impact idle operation to this E-3 cycle.

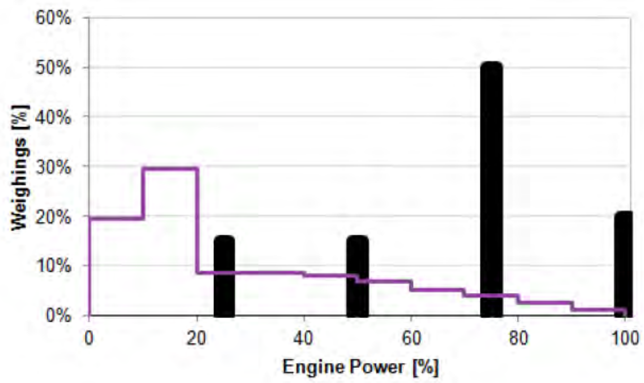
If these test cycles would be really representative of the way recreational craft are operated then hybridization could not bring fuel savings (apart from optimizing hotel loads). This is in contrast to the claims of developers of hybrid diesel powered yachts. This seems to indicate that the E-3 and E5 test cycles neglect the operation at lower speeds and power levels of these yachts. Some confirmation of this is found in the 2013 study performed by Ricardo on behalf of ICOMIA (Hutton & Nicol, 2013) on larger yachts (> 24m). In that study it became evident that these vessels indeed operate a significant part of their time below 25% rated power, as shown in Figure 3-20. Similarly, a 2010 study on the emissions and fuel consumption benefits of a hybrid tug concluded that the average operating load of the engines are well below the load factors specified in the standard ISO duty cycle" (Jayaram, 2010))[36].

ICOMIA as well as Euromot are aware of the challenge that hybridization poses to the continued use of current test cycles. On the other hand, hybridization (and in particular the corresponding energy management strategy) will depend on boat design and actual use. Given the wide variation in applications, the responsibility of hybridization lies primarily with the boat builder[37]. From discussions with ICOMIA it became clear that at present their ideas go in the direction of extending the current test cycles with NTE-areas (with corresponding emissions limitations). These NTE-areas would be the current areas that were already defined (in EPA regulations) but possibly extended with manufacturer defined additional areas (ICOMIA, 2021)[38].

Based on the characteristic shape of emissions and fuel consumption maps of CI engines compared to SI engines it is expected that fuel savings would be lower than those with hybridization of SI-powered recreational craft.

[36] Of course, in the past there was a good reason to allow the E-3 cycle also for CI engine powered recreational craft. It allowed the use of (large) engines that were developed for the marine market, without the need for additional certification.
[37] This situation becomes even more complex with outboard engines. These are often purchased separately from the boat.
[38] With hybridization, average engine load would increase. For hybridized craft therefore E3 (and E5)_cycles would be more representative than for craft with diesel engine only propulsion.

Figure 3-20 Large yacht histogram of time spent at various power levels (as % of rated power) (Hutton & Nicol, 2013)



Given the lack of supporting data and because hybridization and electrification are a baseline scenario only, it is suggested to use the same fuel consumption and emission benefit assumption for both SI and CI hybrids: 10% reduction.

In all of the previous observations it was assumed that the corresponding recreational craft have no means of energy harvesting from other sources. For most classes of recreational craft this is a good first starting point. The exception to this is the diesel-powered sailing boat. This type of craft, by companies such as Alva Yachts (Anon., 2021), allows for hybridization as well as so-called propeller driven battery regeneration. For such craft – as a first rough estimate – this study assumes a possible fuel consumption and emission reduction of 40%.

Projected market share growth

In view of the above observations, this study assumes that hybridization will not take place with outboard engines. The weight and packaging challenge with outboard engines and the high development cost in combination with the (initial) small share of the total outboard market sales is expected to make such development unattractive[39].

Of the remaining market of recreational craft with inboard engines it is assumed that only 10% of new craft will be hybrid. This will be in line with the limited fuel savings in combination with the significant cost increase of hybridization. For the same reason it is expected that an increase in fossil fuel price or battery cost reduction will not have a major impact, apart maybe for range-extended diesel-hybrid sailing boats.

3.4 Candidate scenarios

This section presents the limit levels for different propulsion systems (section 3.4.1) and the suggested changes to test procedures (section 3.4.2).

3.4.1 Limit levels for different propulsion systems

Based on the previous observations a number of possible scenarios for emission reduction have been identified.

Scenario 1 Harmonisation and best practices

The main ideas behind this scenario are described below separately for SI engines and for CI engines.

For OB and PWC SI engines:

- This scenario is shown in Table 3-7.
- For OB SI and PWC SI engines with P < 75 kW, NOx+HC maximum emissions levels are reduced with 30%, in accordance with the cleanest engines that can be found in the EPA database. It should be pointed out that the effective reduction in emission

[39] It is worth pointing out here that outboard engine developers may at the same time be confronted with the need to develop cleaner conventional engines.

will be smaller than the reduction in limit values. The effective reduction compared to model years 2019-2020 will probably be no more than 8%. However, reduction compared to older engines may be higher.

- Similarly, CO maximum emission levels are reduced with 31-33% in line with best-in-class (i.e. cleanest) current engines. As shown in
- Figure 3-7 for OB engines these limits could be significantly reduced further if only sequential multi-point injection technology would be considered. However, this is not as evident for PWC engines (Figure 3-8).
- No PM limit is introduced.

For SD/IB SI engines:

As shown in Figure 3-9, best-in-class SD/IB SI engines could have a 50% lower NO_x+HC emission level than the current emission limits (while retaining current CO limitations). However, no additional emission reduction is however suggested for current SD/IB SI engines. Sales of these engines are predominantly in the US. Imposing lower limits without a similar reduction in US legislation would only further reduce sales in Europe (with a possible switch to CI engines). Under scenario 1, these engines are aligned with current US regulation.

Table 3-7 SI Outboard engines / PWC – Scenario 1

Power range	RCD II maximum emission levels [g/kWh]			Scenario 1 maximum emission levels [g/kWh]		
	CO	NO_x + HC	PM	CO	NO_x + HC	PM
0 ≤ P [kW] < 4,3	$500-5\cdot P$	30	-	$350-3{,}75\cdot P$	21	-
4,3 ≤ P [kW] <40		$15{,}7+\frac{50}{P^{0{,}9}}$	-		$11{,}5+\frac{35}{P^{0{,}9}}$	-
40 ≤ P [kW] < 75	300		-	200		-
75 ≤ P [kW] < 373	300		-	200		-
373 ≤ P [kW]	300		-	300		-

For SD/IB CI engines:

This scenario is shown in Table 3-8. This scenario:

- Excludes application of EGR or aftertreatment.
- As a result of the latter, this scenario is still compatible with current 1000 ppm S marine distillate gasoil composition.
- Further this scenario assumes that EU regulations are harmonised with EPA Tier 3 emission targets for engines with P < 37 kW.
- For larger engines current RCDII levels are retained[40].
- Negligible volume/weight increase of the engines.
- Significant development efforts only for P < 37 kW; but these efforts have already been made as part of NRMM Stage V developments.

Table 3-8 SD/IB CI engines – Scenario 1

Power range	Default (RCD II) maximum emission levels [g/kWh]					Scenario 2 maximum emission levels [g/kWh]		
	CO	HC	NO_x	NO_x + HC	PM	CO	NO_x + HC	PM
0 ≤ P [kW] < 8	5	$1{,}5+2/\sqrt{P}$	9,8		1	8	7,5	0,4
8 ≤ P [kW] < 19						6,6	7,5	0,4
19 ≤ P [kW] < 37						5	4,7 (5,8)	0,3 (0,2)
37 ≤ P [kW] <56	5	-	-	4,7 (5,8)	0,3 (0,2)	5	4,7 (5,8)	0,30 (0,2)
56 ≤ P [kW] < 75								
75 ≤ P [kW] < 300 SV [litre] < 0,9	5	-	-	5,8	0,15	5	5,8	0,15
75 ≤ P [kW] < 300 0,9 < SV[litre] < 1,2	5	-	-	5,8	0,14	5	5,8	0,14
300 ≤ P [kW]	5	-	-	5,8	0,14	5	5,8	0,14

[40] In principle also here emissions could be lowered further (towards 5 g/kWH NO_x+HC), but without EGR (or other measures) this would result in fuel consumption increases.

With this scenario, harmonisation between US and EU regulations is increased. As the limit levels still differ between OB SI engines and SD/IB engines, this scenario is not technically neutral and still favours OB-implementation. If OB CI engines would be applied in recreational crafts, they would be able to comply with the SD/IB limits mentioned above.

Scenario 2 Best available technology – version 1

This scenario is described below for SI engines as well as CI engines.

For OB and PWC SI engines:

- This scenario is described in Table 3-9 below.
- For engines below 75 kW it is similar to scenario 1.
- For more powerful engines, target emission levels are in line with current emission limits for SD/IB engines. This implies the need to implement 3-way catalytic aftertreatment. Because implementation of 3-way catalytic aftertreatment requires sufficient height difference between engine exhaust manifold and waterline, this is applied only for P > 75 kW.
- Recently, CARB (under its 2020 Mobile Source Strategy) developed a scenario which assumes that starting in 2027, HC+NO_x emission limit values from outboard and personal watercraft will be reduced by 40 and 70 percent below current levels for less than 40 kW and above 40 kW engines respectively[41] (CARB, 2020). This CARB scenario is very similar to scenario 2.

Table 3-9 SI Outboard engines / PWC – Scenario 2

Power range	RCD II maximum emission levels [g/kWh]			Scenario 2 maximum emission levels [g/kWh]		
	CO	NO_x + HC	PM	CO	NO_x + HC	PM
0 ≤ P [kW] < 4,3	$500 - 5 \cdot P$	30	-	$350 - 3{,}75 \cdot P$	21	-
4,3 ≤ P [kW] <40		$15{,}7 + \frac{50}{P^{0{,}9}}$	-		$11{,}5 + \frac{35}{P^{0{,}9}}$	-
40 ≤ P [kW] < 75	300		-	200		-
75 ≤ P [kW] < 373	300		-	100	5	-
373 ≤ P [kW]	300		-	350[42]	16	-

For SD/IB SI engines:

Situation is as with scenario 1.

For SD/IB CI engines:

- Scenario 2 for these engines is shown in Table 3-10. It proposes limit values for NOx+HC that are comparable with those in the regulations that are implemented in current IWP and NRMM legislation for engines with power above 75 kW. Taking a Stage V NO_x-limit of 0,4 g/kWh and assuming this is achieved in part through a 85% NO_x-reduction resulting from SCR-aftertreatment would imply an engine-out NO_x emission level of 2,7 g/kWh for such an engine with cooled EGR only.
- Starting from an emissions level of 5 g/kWh on NO_x, typical EGR percentages of 15 to 20% will result in emissions in that same order.
- Target emission values for CO and PM are not changed.
- This scenario requires that ultra-low sulphur diesel (15 ppm S) is widely available.
- Applying this technology results in limited volume and weight increase but somewhat higher maintenance costs.
- CI OB engines would not be able to comply with these limits for P > 75 kW (packaging constraints)

[41] CARB further believes there to be an opportunity for further significant emission reductions from the electrification of marine engines in certain applications. Specifically, small outboard engines less than 19 kW, which are not typically operated aggressively or for extended periods, could be replaced with electric motors within a ten-year phase-in period. Additionally, 25 percent of existing PWC applications could be powered with electric motors over that same ten-year time period.

[42] For harmonization reasons, this limit level was increased to the limit level also used for catalyzed SD/IB engines in the US.

Table 3-10 SD/IB CI engines – Scenario 2

Power range	Default (RCD II) maximum emission levels [g/kWh]					Scenario 2 maximum emission levels [g/kWh]		
	CO	HC	NO_x	NO_x + HC	PM	CO	NO_x + HC	PM
0 ≤ P [kW] < 8	5	$1{,}5 + 2/\sqrt{P}$	9,8		1	8	7,5	0,4
8 ≤ P [kW] < 19						6,6	7,5	0,4
19 ≤ P [kW] < 37						5	4,7 (5,8)	0,30 (0,2)
37 ≤ P [kW] <56	5	-	-	4,7 (5,8)	0,3 (0,2)	5	4,7 (5,8)	0,30 (0,2)
56 ≤ P [kW] < 75								
75 ≤ P [kW] < 300 SV [litre] < 0,9	5	-	-	5,8	0,15	5	3,5	0,15
75 ≤ P [kW] < 300 0,9 < SV[liter] < 1,2	5	-	-	5,8	0,14	5	3,5	0,14
300 ≤ P [kW]	5	-	-	5,8	0,14	5	3,5	0,14

Scenario 3 Best available technology – version 2

- This scenario is the same as scenario 2, apart from SD/IB engines with a power exceeding75 kW.
- In this scenario, it is assumed that for engines with P > 75 kW, SCR-technology can be implemented (i.e. that there is a possibility to fit this in the existing or slightly adapted engine room). It is assumed that with this technology, exhaust emission levels below 2,1 g/kWh of NO_x+HC can be achieved.
- CO and PM maximum levels are not changed (implementing DPF would further add to the volume increase).
- As in scenario 2, also this scenario 3 implies that ULSD must be widely available.
- A benefit of this technology is that the engine development effort is smaller and less complex. And that lower fuel consumption levels become feasible, even though the NO_x-emission level is lower than in scenario 2.
- On the other hand it requires that an urea-mixture is available at refuelling points; furthermore, the mixture reduction realized must be (continuously) monitored to ensure that such mixture is injected (with a sufficiently deterring operational - or other - penalty if tampering is noticed).
- CI OB engines would not be able to comply with these limits for P > 75 kW (packaging constraints)

3.4.2 *Suggested changes to test procedures*

Previously, the following observations were made:

- In the US, limit values are imposed not only on (E4 or E5) cycle emissions, but in addition to that also Not-To-Exceed limit levels are defined in other parts of the engine (speed / torque) map. Such NTE-rules have been set up both for SI engines and for CI engines.
- According to RCDII regulations, CI engines are allowed to be tested in 3 different test cycles: E1 and E5 for all engines, and for P > 130 kW also the E3 test cycle can be applied. The E3 and E5 cycles are very similar and tend to produce similar emission levels. The E1-cycle is very different, however.
- SI engines are tested in the E4-cycle, which is different from the E1/E3/E5 cycles
- There is no test procedure for testing hybrid propulsion systems. Current E1, E3 and E5 test cycles for CI engines neglect low speed/load operation of recreational craft.

It is therefore suggested that:

- EU regulations also introduce NTE-limits (similar to the US)
- A study is performed on the feasibility to reduce the number of test cycles that are considered and to gather real-world data that support the decision to have a different test cycle for SI and CI engines
- To follow up the activities by ISO in its investigation on the adaptation of current marine engine test procedures to make them fit for testing of hybrid propulsion systems.

3.5 Cost estimate of proposed changes

The estimated costs presented in this section are unit costs per type of propulsion system, not total scenario costs.

For calculating the impact of the implementation of lower emission levels, in general, the same approach is used as in other cost assessment studies ((ECNI2, 2006), (Bogaert, et al., 2008), (Dallmann T., 2018)). The methodology used is summarized below:

- Costs are defined as the increase in retail price (MRRP or Manufacturer Recommended Retail Price), exclusive of VAT.
- The retail price of a product is composed of different components. The actual unit manufacturing cost, the unit production overhead, corporate overhead costs, sales costs, dealer costs (and margin), some additional costs and the OEM margin (or net income).
- The increase in retail price that results from an increase in manufacturing costs can be calculated by multiplying the latter with a so-called indirect cost multiplier. The value for this multiplier in large scale automotive production of passenger cars varies between 1,46 (for US companies) and 1,6 (for EU companies) (Kolwich, G., 2013). According to this (and similar sources) the ratio between production overhead and manufacturing cost in this market is around 0,2. An increase of manufacturing cost that would take place without an increase in production overhead (e.g. replacing one component for another or an increase in labour cost) will then result in a 30% higher retail price increase (always in the case of large scale automotive production). This number is in line with previous studies for EPA: in 2006 (ICF International_A, 2006) an OEM mark-up on manufacturing costs of 29 % was assumed.
- It is assumed in this study that a larger profit margin is required in the recreational craft sector than in the automotive sector. For this reason the manufacturing cost multiplier is set at 1,5 (excluding additional production overhead). This would apply to craft with relatively larger production numbers (such as outboard engines). For recreational craft with very low production numbers (with inboard engines) this multiplier has been further increased towards 1,7[43].
- In this study (for consistency with the previous recreational craft cost assessment studies mentioned above) a difference is made between so-called variable costs and so-called fixed costs.
- Variable costs result from the implementation of new technology, i.e. new hardware components. They correspond to the cost of actual manufacturing.
- Fixed costs result from the need to perform the research and development that is needed to implement this new hardware to a certain engine type. Typical activities are basic engine component redesign, re-calibration, production tooling costs, certification costs. Here the fixed costs are split up between fixed costs for certification and fixed costs for all of the other activities. These costs are the largest part of the production overhead costs.
- Fixed costs have to be paid back from selling the new product. It is assumed that the manufacturer wants this payback to occur within a certain period. The fixed costs are allocated evenly to the total sales of that particular engine type in that period. Of course, part of the fixed costs occur in the years preceding the actual production. This is not taken into account. Fixed costs are assumed to have an impact only when new units are sold.
- In this study a recovery period of 3 years was used. This is also the period considered in the study by Arcadis (Bogaert, De Smet, Vermoote, & Van Hyfte, 2008). Other studies on behalf of EPA have assumed a 5 year period (ICF_International_A, 2006). A higher recovery period will result in a lower fixed costs per unit in the first years. For units sold after this recovery period, the fixed additional costs become zero. Because of this, the effect of changing this period is small in the context of this study.
- An increase in production cost (e.g. a new certification) with no additional manufacturing cost) will also result in an increase in retail price. In line with previous cost assessment studies a multiplier of 1,4 has been applied to this cost increase.

[43] For comparison: ICOMIA suggested a 2,5 multiplier on additional component costs related to reducing evaporative emissions; this is to be compared with the 1,5 multiplier used for calculating exhaust emission technology costs (for outboard engines).

- Because of lack of data no changes in maintenance costs are considered. Such changes are estimated to be limited.
- Finally, the above costs do not include the costs made by boat manufacturers for adapting their craft for implementing lower emitting engines. These costs will be higher when EGR or SCR is applied, but will vary depending on the (varying) particularities of the craft under consideration

Cost impact estimates have been performed for the different propulsion systems and power levels that were selected for the Cost-Benefit-Analysis. They are summarized in Table 3-11. To make these estimates, data is searched on representative engines for every type of recreational craft (in line with the average power rating selected per craft type, reference to section 2.1.1). For engines with petrol engines, power is usually marketed in horsepower. For this reason both power in (metric) HP as well as in kW are mentioned. Values in kW are rounded off.

Table 3-11 Overview of propulsion systems considered for the cost impact estimate

Recreational craft type	*Propulsion system*	*Reference power [kW (HP)]*
Motor boat < 27 ft.	Diesel CI SD/IB	40
Motor boat 27 < l(ft.) < 34	Diesel CI SD/IB	150
Motor boat > 34 ft.	Diesel CI SD/IB	250
Sailing boat > 26 ft.	Diesel CI SD/IB	30
Motor sailors	Diesel CI SD/IB	30
Sailing boats < 24 ft.	Petrol SI OB 4-stroke	11 (15)
Yawls and cabin boats	Petrol SI OB 4-stroke	22 (30)
Speed boats	Petrol SI SD/IB 4-stroke	129 (175)
Speed boats	Petrol SI OB 4-stroke	129 (175)
Water scooters (PWC)	Petrol SI OB 4-stroke	85 (115)
Other boats , 20 ft.	Petrol SI OB 4-stroke	11 (15)

In the following sub-sub sections, the unit costs per scenario are presented for the SI outboard engine proposals. The costs mentioned are the cost increases per unit produced compared to current (RCD II compatible) engines.

3.5.1 SI Outboard unit cost impact estimate

Scenario 1 – Harmonisation and best practices

Table 3-12 summarizes the calculation of the price increase for scenario 1. In this scenario, the only activity that needs to be performed is some level of combustion system optimization to meet with best-in-class emissions performance. It is assumed that there are no additional hardware costs.
The fixed cost estimate corresponds to the value suggested by industry in the Arcadis study (Bogaert, et al., 2008). This may be an overestimation of the actual costs. Certification costs again correspond to the costs mentioned in that same study. This cost estimate is somewhat conservative as it has not been corrected for inflation. On the other hand, certification costs mentioned in the interviews of the latter study varied between 8000 € and 27000 € (EPA, 2004).

The production numbers per engine family per year have been determined from the sales numbers in EU and US taken together. In the 2006 study by ICF International on behalf of EPA, the production number per engine family was set at 15000 units per year (ICF_International_A, 2006). As shown in Figure 3-4, larger numbers are produced in the lower power classes. An attempt was made to introduce a corresponding diversification in production numbers per power class. The corresponding numbers are shown in Table 3-12.

Table 3-12 Unit compliance cost calculation for OB/PWC engines – scenario 1

Selected max engine power	*[kW]*	*11*	*22*	*85*	*129*
Current Recommended retail price (excl. VAT)	[€]	2730	4760	11557	16500
Reference/base engine retail price increase compared to current		0	0	0	0
Var. cost increase (excl. mark-up)	[€]	0	0	0	0
Fixed inv. cost increase (excl. certification); per family	[€]	250000	250000	250000	250000
Certification cost	[€]	19900	19900	19900	19900
Total production number per engine family per year	[-]	25000	20000	6500	8000
Fixed unit compliance cost (excl. certification)	[€]	4,7	5,8	17,9	14,6
Fixed unit compliance cost for certification	[€]	0,4	0,5	1,4	1,2
Total unit compliance cost	[€]	**5,0**	**6,3**	**19,3**	**15,8**

For reference a typical current retail price is given (exclusive of VAT). This price indication is based on consulting several websites of suppliers (June 2021) as well as recent price lists of different manufacturers. This number is indicative only, and actual prices show a considerable variation. Cost increases with scenario 1 are small. Even somewhat higher fixed certification costs would have minimal impact.

Scenario 2 and 3 – Best available technology version 1 and 2

Scenario 2 assumes that 3-way catalyst technology is applied to OB and PWC engines. Implementing catalyst technology results in cost for additional components as well as in additional development costs.
The costs for the additional components (catalyst brick, housing, sensors) were determined on the basis of manufacturing cost data mentioned in (ICF_International_A, 2006). OEM manufacturing costs (other than supplier costs) were increased with a factor 2 (to take into account the impact of likely changes to engine envelope and engine cylinder head). All of these were corrected for inflation towards 2021 $ values using US Consumer Price Index data (times 1,3674 (Anon., 2021)). Using current exchange ratio, this was then turned into 2021 € values ($1 = € 0,821).

Table 3-13 Unit compliance cost calculation for OB/PWC engines – scenario 2 and 3

Selected max engine power	*[kW]*	*11*	*22*	*85*	*129*
Current Recommended retail price (excl. VAT)	[€]	2730	4760	11557	16500
Reference/base engine retail price increase compared to current		0	0	0	0
Var.cost increase (excl. mark-up)	[€]	0	0	182,7	220
Fixed inv. cost increase (excl. certification); per family	[€]	250000	250000	6000000[44]	6000000
Certification cost	[€]	19900	19900	19900	19900
Total production number per engine family per year	[-]	25000	20000	6500	8000
Fixed unit compliance cost (excl. certification)	[€]	4,7	5,8	430,8	350
Fixed unit compliance cost for certification	[€]	0,4	0,5	1,4	1,2
Total unit compliance cost	[€]	5,0	6,3	706,2	681,2

The implementation of catalyst technology in outboard engines may require the redesign of the cylinder block and/or cylinder head (Broman, 2012). This would seriously increase the fixed (R&D and tooling) costs. For this reason, in literature widely differing fixed costs are mentioned. In the 2006 EPA study a value of 450000 $ was mentioned (ICF_International_A, 2006). In the (ECNI2, 2006) study a worst-case cost of 8 M€ was mentioned. And in the Arcadis study it was estimated that a complete redesign of an outboard marine engine would cost up to 3 to 4 M€ (Bogaert, et al., 2008). After 2008 to date no real product development has taken place. Therefore these numbers are assumed to be still valid. In that same period the value of the € has depreciated with 19 resp. 14%. For this study the fixed costs have therefore been estimated at 6 M€, irrespective of engine power.
This has resulted in the total additional unit compliance cost values mentioned in the table above. Obviously, expected price increases in case of large OB engines are considerable, but should not make production economically unattractive. A temporary slowdown in sales might occur, however (as happened when catalytic aftertreatment was imposed before on SI inboard engines). For comparison: for a 140 kW SI/IB engine (with lower sales numbers) a retail price difference of around 1300 € was found in recent price lists.

3.5.2 SI Inboard unit cost impact estimate

This is considered not relevant (no changes proposed).

3.5.3 CI Inboard unit cost impact estimate

In the following sub-sub sections the unit costs per scenario are presented for the CI inboard engine proposals.

Scenario 1 – Harmonisation and best practices

In scenario 1, only CI engines with power below 37 kW are concerned. To achieve the target emission levels, current mechanical FIE systems need to be replaced with CR fuel injection technology. These engines would be re-engineered / marizined versions of

[44] This may be an overestimation. The volume constraints with PWC are not as stringent as with OB engines. In fact 3-way catalyst technology is already applied to PWC engines of BRP/ROTAX for implementation in jet boats.

current Stage V NRMM designs. That is why the base engine will show some price increase compared to that of the current marine recreational craft version.
Fixed costs incurred for re-engineering would be limited, since cylinder head and other adaptations have already been done. In fact, most work would be in removing aftertreatment components and EGR-circuitry from these engines. This fixed cost was set at 100 k€. This would allow for (eventual) fast learning about EGR; (adapting) calibration; possibly adapting the cooling system; functionality and short durability testing.
The costs for certification were again set at 19900 €[45].
The number of engines sold per year and per engine family was estimated at 500 (for the larger companies that sell both in the EU and in the US). These numbers are based on the data shared with Arcadis when they performed their 2008 study (Bogaert, et al., 2008): 9000 units per 3 years for a large OEM, with 5 to 7 engine families. For smaller companies, this number could decrease to 150 units per year (same database). On the other hand, these companies tend to have a smaller overhead, so mark-up might be smaller (to remain competitive with products from large OEM's).
Variable costs would be the increase in cost for the more advanced (and expensive) high pressure CR fuel injection equipment. The corresponding increase in manufacturing cost was obtained from a recent cost-estimate for NRMM development (750$ in 2018) in (Dallmann T., 2018) (see Table 3-14). Because several CI/IB engines in the 19 – 37 kW range already have a CR fuel injection system, this cost was reduced with 50% for these engines. The resulting costs are shown in Table 3-15.

Scenario 2 – Best available technology version 1

In scenario 2, only the 40/150/250 kW engine versions are considered. Further it is assumed that ULSD application makes it possible to implement cooled EGR technology.

40 kW engine

No changes in emissions legislation from current RCDII levels implies no additional costs.

Table 3-14 Additional manufacturing costs data (Dallmann T., 2018)

Technology	*Cost (2017 US$)*
Fuel system or extra with respect to unit injector systems	750
VNT extra cost with respect to TC	370
EGR-system – high pressure	439
EGR intercooler	108

150 / 250 kW engine

For the 150 kW and 250 kW engines advanced FIE would be present already on current RCDII engines. Additional variable costs would be limited to that of VNT[46] and EGR-system. It was further estimated that the cost of the 250 kW engine would increase with respect to rated power. Based on data in (Dallmann T., 2018) a proportionality to $P^{0,2}$ has been assumed (with P of course representing rated power).
As to fixed costs: in the light/medium duty market EGR-technology is available and already being implemented. However, for marine application, more EGR at higher loads may be required. There would be an increased need for redesign in comparison with the 40 kW version. For this reason a cost of 250 k€ was taken as a first estimate.

[45] For CI engines that apply EGR there could be additional costs for certification of the NOx Control Diagnostics (NCD) system and for a limited (e.g. 375 hours) ageing test. NTE-testing are assumed to have a negligible impact. These costs could be (partly) avoided when the engine is a derivative from a product in other markets where this certification already took place. If not, the certification cost could increase with a factor 4.
[46] Variable Nozzle Turbine

Table 3-15 Unit compliance cost calculation for CI SD/IB engines – scenario 1 and 2

Selected max engine power	*[kW]*	*30*	*150*	*250*
Swept volume range	[litre]	< 0,9	< 0,9	< 0,9
Current recommended retail price (excl. VAT)	[€]	9030	27900	40000
Reference/base engine retail price increase compared to current (excl. VAT)	[€]	100	0	0
Variable cost increase (excl. mark-up)	[€]	260	679	752
Fixed inv. cost increase (excl. certification); per family; large company (OEM-type)	[€]	100000	250000	250000
Certification cost	[€]	19900	19900	19900
Total production number per engine family per year	[-]	500	500	500
Fixed unit compliance cost (excl. certification)	[€]	93	233	233
Fixed unit compliance cost for certification		19	19	19
Total unit compliance cost	[€]	554	1406	1530

The resulting cost increase is again shown in Table 3-15. This increase is 6% for the 30 kW engines, and approximately 4 to 5% for the larger engines. It is important to note here that implementation of EGR technology by (marinizer) companies with smaller sales numbers will result in higher unit cost increases than those mentioned in Table 3-15. This is because they cannot easily implement OEM-products, because they are confronted with a higher technology learning effort and because they have smaller sales numbers. In interviews they predict much higher price increases. This may result is some smaller companies disappearing from this market.

Scenario 3 – Best available technology version 2

In scenario 3, SCR-technology is applied instead of EGR technology. Of course this results in additional components. The corresponding variable costs were estimated from the cost volume of the catalyst and a cost for the catalyst of 79,25 $ (2018) per litre of catalyst volume. Added are 100 US$ for a NO_x sensor and a constant additional cost of 248 US$ (Dallmann T., 2018). These cost data were obtained from (Dallmann T., 2018). All 2018 US$ costs were transformed in 2021 € by multiplying with 0,82. Further 82 € were added for insulation. This could be an underestimation.
Fixed costs are related to adapting the exhaust system layout / positioning, learning about SVR working, thermal insulation design and calibration. Part of that calibration effort is advancing combustion timing towards 10 g/kWh NO_x. The outcome of these calculations is shown in the table below. Again the same fixed certification costs are added[47].

[47] For CI engines that apply SCR there could be additional costs for certification of the NOx Control Diagnostics (NCD) system and for a limited (e.g. 375 hours) ageing test. NTE-testing are assumed to have a negligible impact. These costs could be (partly) avoided when the engine is a derivative from a product in other markets where this certification already took place. If not, the certification cost could increase with a factor 4.

Clearly, for these larger engines, applying SCR technology (with the corresponding lowest emissions) will result in much higher costs than applying EGR technology (in the order of 10%), double of that of EGR application.

Table 3-16 Unit compliance cost calculation for CI SD/IB engines – scenario 3

Selected max engine power	*[kW]*	*150*	*250*
Swept volume range	[litre]	< 0,9	< 0,9
Current recommended retail price (excl. VAT)	[€]	27900	40000
Reference/base engine retail price increase compared to current (excl. VAT)	[€]	0	0
Variable cost increase (excl. mark-up)	[€]	1387	2038
Fixed inv. cost increase (excl. certification); per family; large company (OEM-type)	[€]	150000	150000
Certification cost	[€]	19900	19900
Total production number per engine family per year	[-]	500	500
Fixed unit compliance cost (excl. Certification	[€]	140	140
Fixed unit compliance cost for certification	[€]	19	19
Total unit compliance cost	[€]	2516	3623

Finally, it is again important to note that implementation of SCR-technology by (marinizer) companies with smaller sales numbers will result in higher unit cost increases than those mentioned in Table 3-16. This is because they cannot easily implement OEM-products, they are confronted with a higher technology learning effort and because they have smaller sales numbers. In interviews they predict much higher price increases. This may result is some smaller companies disappearing from this market.

4 Evaporative emission proposals

In this chapter, proposals to reduce evaporative emissions are presented. For this purpose, the following steps were followed.

- Assess the feasibility of including evaporative emissions provisions for recreational craft sector in the EU (section 4.3).
- Propose evaporative emissions limits (section 4.2).
- Present the candidate emission control scenarios (section 4.4).
- Set cost values as input for cost-benefit analysis (section 4.5).

4.1 Context

The evaporative emissions mechanism from recreational craft has certain similarities with road vehicles, especially with the L-category sector, the emissions of which have been studied extensively in recent years. On the other hand, there are substantial differences to road vehicles, which have been considered carefully under the following topics:

Watercraft/engine design

Diurnal emissions are dependent of the fuel tank position. In crafts with installed fuel tanks, the fuel tank is generally hidden beneath the deck. As a result, there is a certain amount of "inherent" insulation caused by the craft itself. This effect is increased for a craft that is stored in the water. The water acts as a cooling medium for the fuel tank, especially if it is installed in the bottom of the craft. In addition, the thermal inertia of the fuel in the tank can act to dampen temperature variation imposed from the diurnal heating of the ambient air. As a result, crafts stored in water (non-trailerable) contribute less to diurnal emissions than those stored on trailer (trailerable).

In addition, the construction material of fuel system (fuel tank, hoses) affects the fuel permeation emissions rates. Plastic fuel tanks, due to the similar chemical composition with petrol fuel, can be significant sources of permeation, whereas metal fuel tanks are practically impermeable.

Carburetted engines are a major source of evaporative emissions. However, these engines are almost entirely phased out of EU recreational craft fleet.

Typical activity profile

The amount of time that the recreational crafts are out of use can vary from a few hours to several days, weeks, or even months (e.g., for winterization). Thus, the activity data can vary not only by the craft type but have a seasonal variation too.

Fuel specifications

The vapour pressure of petrol fuel is an indication of fuel volatility and thus of the evaporative emissions rates. The fuel vapour pressure also has a seasonal variability and is typically limited to 60 kPa for the summer months in most EU Member States, whereas it is close to 90 kPa in the winter months.

Evaporative emissions from diesel powered vessels are negligible due to the presence of heavier hydrocarbons and the relatively low vapour pressure of diesel fuel.

Emission control technologies

There are currently no emission control technologies for evaporation losses in the EU as there are no such provisions in the current RCD.

4.2 Emission regulation

Over the last decades, US EPA has set the pace for emission reduction in evaporative emissions from recreational crafts, drawing inspiration from other sectors, such as the automotive. In the EU, evaporative emissions from recreational craft are not currently regulated and so, the first examined limits derive from the US recreational craft sector and the EU automotive experience. A first set of examined emission limits is presented in Table 4-1 . Both public consultation results and interviews with industry experts have underlined the importance of harmonised specifications. As a starting point, the investigated limits are in line with the US EPA legislation for recreational craft and are consistent with the respective limits for the L-category sector in the EU.

No limits for running loss and hot soak emissions are examined as these emission sources are responsible for about 1% of the total evaporative emissions and hence are not considered significant. Furthermore, technologies used for controlling diurnal emissions control can effectively reduce hot soak and running losses too (EPA, 2008).

Table 4-1 Evaporative emissions limits examined for the EU recreational craft sector.

Evaporative emissions source	*Emission limits*
Diurnal	0,1 g/lt/day
Hose permeation	15 g/m²/day
Fuel tank permeation	1,5 g/m²/day

4.3 Technical feasibility for emission reduction

The emission control technologies presented in the following are well established in the automotive sector and already used in recreational crafts in the US to comply with the respective emission standards.

4.3.1 Pressurized fuel tank with relief valve (Diurnal emissions control)

Diurnal evaporative emissions occur when the fuel warms up, evaporates and passes through a vent into the atmosphere. In case of closing that vent, evaporative emissions are prevented from escaping, while the pressure builds up as the vapour keeps generating. Once the fuel cools back down, the pressure subsides. An effective way to control these emissions is by sealing the fuel tank, where a pressure relief valve (PRV) is integrated for safety reasons.
To prevent high pressures in marine tanks, a 1 psi (0,07 bar) valve is proposed by the US EPA. Plastic fuel tanks of larger capacity are not designed to operate under pressure. For instance, although they will not leak at 3 psi, rotationally moulded fuel tanks with large flat surfaces could begin deforming at pressures as low as 0,5 psi. At 2,0 psi, the deformation would be greater. This deformation would affect how the tank is mounted in the craft. Despite this, manufacturers agree that back-up pressure relief valves would be necessary for safety.

In fuel tanks of smaller capacity as used in personal watercrafts (PWCs) and portable fuel tanks, pressure is of lesser importance due to their small internal surface. Fuel tanks of PWCs should be equipped with pressure relief valves ranging from 0,5 to 4 psi, while portable fuel tanks are designed to be sealed without any pressure relief (EPA, 2008).

4.3.2 Carbon canister (Diurnal emissions control)

Carbon canister is an effective diurnal emission control application, firstly implemented in the automotive sector. The carbon canister, containing activated carbon, is capable of adsorbing the vapour generated in the fuel tank. The activated carbon collects and stores the hydrocarbons. Ideally, the carbon canister is connected to the engine through a purge valve, which allows air to flow from the ambient through the canister when the engine is running. Purged fuel vapours are thus routed in the engine where they are burned along the fuel mixture.

In recreational crafts, the vessel may sit for weeks without an opportunity for engine purge. Therefore, canisters with purge valves were not originally considered to be a practical technology for controlling diurnal vapour from crafts. When the fuel tank cools, fresh air is drawn back through the canister into the fuel tank. This fresh air will partially purge the canister and lead hydrocarbons back to the fuel tank. Therefore, the canister should have open sited available to collect vapour during the next heating event. Once the canister reaches saturation, it is still capable of achieving more than a 60% reduction in diurnal emissions due to passive purging (EPA, 2008).

In addition to controlling diurnal emissions, both technologies can effectively reduce running losses and hot soak emissions as well.

4.3.3 Low permeability fuel lines (Hose permeation emissions control)

Permeation emissions from fuel hoses emerge from the similar chemical composition of their construction material (polymeric materials, such as plastic or rubber) with the petrol fuel. As a result, constant exposure of petrol to these surfaces allows the material to continually absorb fuel. The permeation phenomenon is driven by the difference in the chemical potentials on either side of the material. Permeation occurs not only through hose walls that are in contact with the liquid petrol, but through surfaces exposed to fuel vapour also (EPA, 2008). In addition, the permeation rate is independent of the activity hours of the craft, hence permeation emissions have a significant contribution to the total evaporative emissions (see also section 2.4.1).

Based on the automotive experience, fuel hose permeation could be controlled by using barrier materials which achieve lower permeation rates. The barrier materials constitute an inner layer of certain diameter, which is applied into vent, fill neck, supply/return hoses. Typical barrier materials are:

- Thermoplastic barriers for small outboard engines and PWCs
- Nylon barriers for crafts with installed fuel tanks.
- FKM[48], which is a fluoroelastomer used in fuel line applications, either in a small percentage or as a whole construction (EPA, 2008).

4.3.4 Low permeability fuel tank (Fuel tank permeation control)

Fuel tanks may be constructed in several ways. Portable fuel tanks and some -smaller production volume- installed for PWCs are generally blow-moulded using high-density polyethylene (HDPE). Larger, installed fuel tanks are constructed either rotationally-moulded using cross-link polyethylene (XLPE) or out of welded aluminium.
Similar to hose permeation control technologies, fuel tank barrier materials are used to reduce tank permeation rates. Typical methods are presented below:

- Barrier layer creation by sulfonation or fluorination method.
- Non-continuous barrier platelets created by the blending of a low permeable resin (nylon or EVOH) and HDPE.
- Thermoplastic layer (EVOH) between two rubber layers.
- Fiberglass fuel tanks with clay nanocomposites as barrier material.
- Layer of epoxy barrier coating (EPA, 2008).

4.4 Candidate scenarios

This section presents the base case and four alternative scenarios for reducing evaporative emissions.

4.4.1 Base case scenario

No emissions control is assumed in the base case scenario and hence all recreational crafts are considered uncontrolled, with the exception of those imported from the US. However, the latter are estimated to be approximately 12000 units per year[49], accounting for about 0,1% of the total EU recreational craft fleet and thus, are of minor importance. Emissions are calculated with the methodology described in Section 2.1.2 and any changes in emissions for the time horizon considered are the result of changes in the size and composition of the recreational craft fleet.

The average emission factors for the base case scenario are presented in Table 4-2.

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48 A class of fluorinated, carbon-based synthetic rubber, commonly known as fluoroelastomer.
49 Based on inputs received during stakeholders interviews.

Table 4-2 Evaporative emission factors by craft type in g/day for the base case scenario.

Craft type	*Diurnal*	*Hose permeation*	*Fuel tank permeation*
Sailing boats (<26 ft.) - outboard	2,3	4,5	5,4
Yawls and cabin boats - outboard	2,3	4,2	5,8
Speed boats - outboard	2,2	7,2	5,5
Speed boats – inboard	1,9	8,7	4,6
Water scooters - outboard	2,5	1,43	4,2
Other boats (<20 ft.) - outboard	1,9	0,5	3,6

4.4.2 Scenario 1 - Diurnal emissions control

For scenario 1, it is assumed that only diurnal emissions are controlled. More specifically, two different emissions control technologies are assumed for the calculations, the first is the activated carbon canister and the second is the pressurized fuel tank. The emission levels are reduced from 2026 to 2040 due the respective reduction in diurnal emissions.

Figure 4-1 depicts the emission results for scenario 1. From 2026 to 2040, a 25% reduction in diurnal emissions is estimated, resulting in a 7,7% reduction of the total evaporative emissions. Figure 4-2 shows the emissions reduction potential by craft type from the implementation of scenario 1.

Figure 4-1 Annual projected evaporative emissions for EU recreational craft in tonnes (Scenario 1).

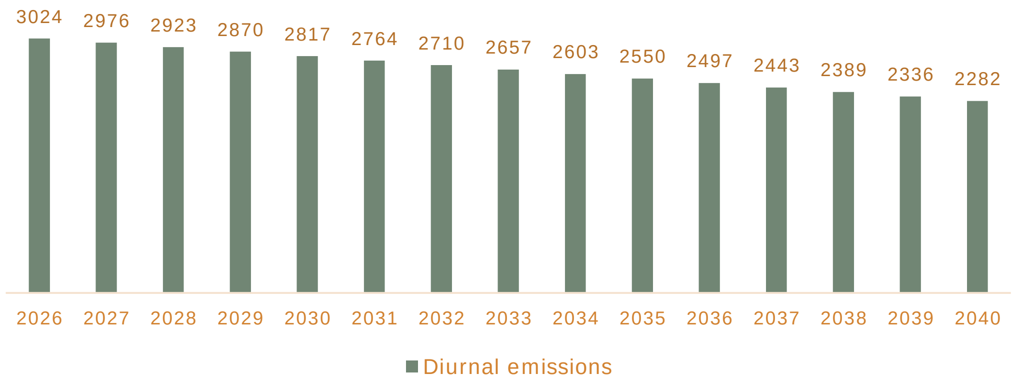
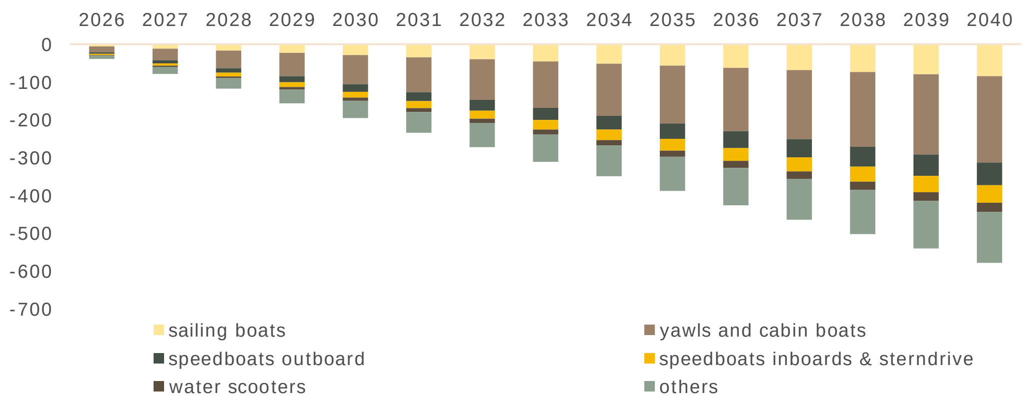


Figure 4-2 Diurnal emissions reduction potential by recreational craft type in tonnes (Scenario 1).



The emission factors for the diurnal emissions control scenario are presented in Table 4-3. In Appendix 2, the average diurnal emission factors by month are presented. A

60% reduction of diurnal emissions from the base case scenario is assumed for all fuel tank types.

Table 4-3 Evaporative emission factors by craft type in g/day for the scenario 1.

Craft type	*Diurnal*
Sailing boats (<26 ft.) - outboard	0,9
Yawls and cabin boats - outboard	0,9
Speed boats - outboard	0,9
Speed boats - inboard	0,7
Water scooters - outboard	1
Other boats (<20 ft.) - outboard	0,8

4.4.3 Scenario 2 - Hose permeation control

For scenario 2, it is assumed that only hose permeation emissions are controlled. It is also assumed that the permeation rate limit of 15 g/m²/day applies only to the supply/return hoses and not for the fill neck and vent hose as these are exposed to vapour rather than liquid fuel. For water scooters and crafts with outboard engines a thermoelastic barrier layer is applied as emission control technique, while for crafts with installed fuel tanks a nylon barrier layer is applied also.

Figure 4-3 shows the emission results for scenario 2. From 2026 to 2040, a 30% reduction of hose permeation emissions is estimated, resulting in a 15,6% reduction of the total evaporative emissions.
Figure 4-4 shows the emissions reduction potential by craft type from the implementation of scenario 2.

Figure 4-3 Annual projected evaporative emissions for EU recreational craft in tonnes (Scenario 2).

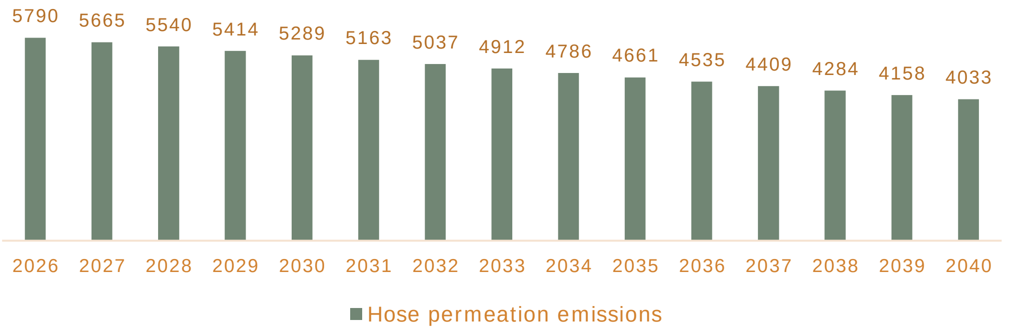
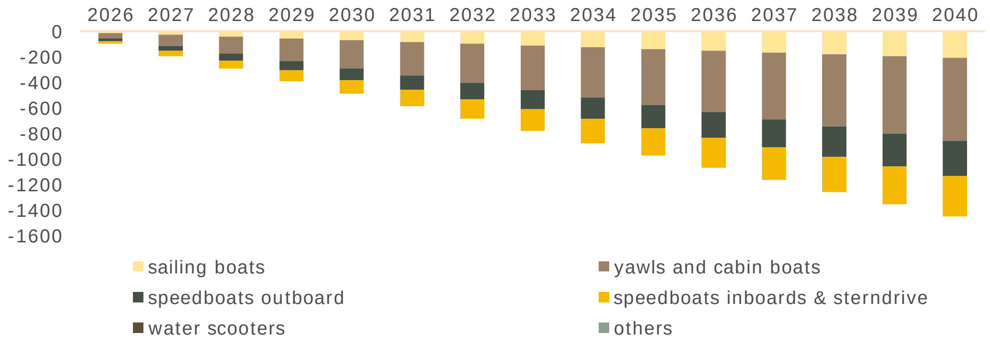


Figure 4-4 Hose permeation emissions reduction potential by recreational craft type in tonnes (Scenario 2).



The emission factors for the hose permeation emissions control scenario are presented in Table 4-4. In Appendix 2, the average hose permeation emission factors by month are presented.

Table 4-4 Evaporative emission factors by craft type in g/day for the scenario 2.

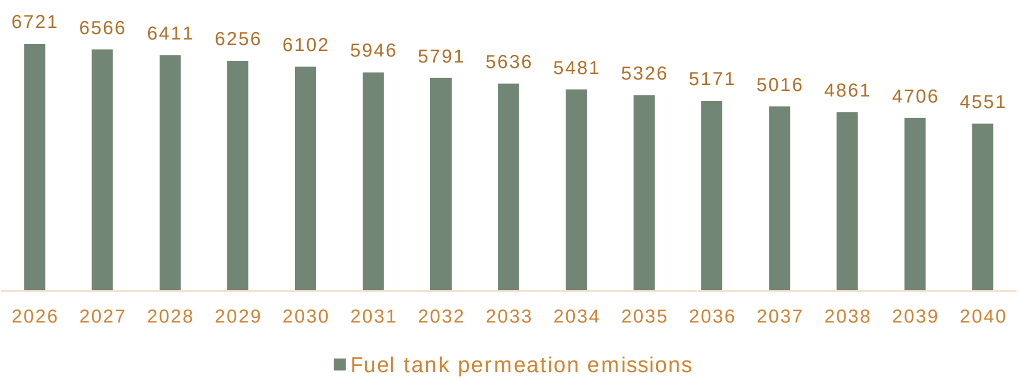
Craft type	*Hose permeation*
Sailing boats (<26 ft.) - outboard	0,9
Yawls and cabin boats - outboard	0,9
Speed boats - outboard	1,7
Speed boats - inboard	2,1
Water scooters - outboard	0,1
Other boats (<20 ft.) - outboard	0,1

4.4.4 Scenario 3 - Fuel tank permeation control

For scenario 3, it is assumed that only fuel tank permeation emissions are controlled. HDPE fuel tanks are assumed to be layered by non-continuous barrier platelets (Selar), while XLPE fuel tanks are assumed to be layered by polyamide 11[50].

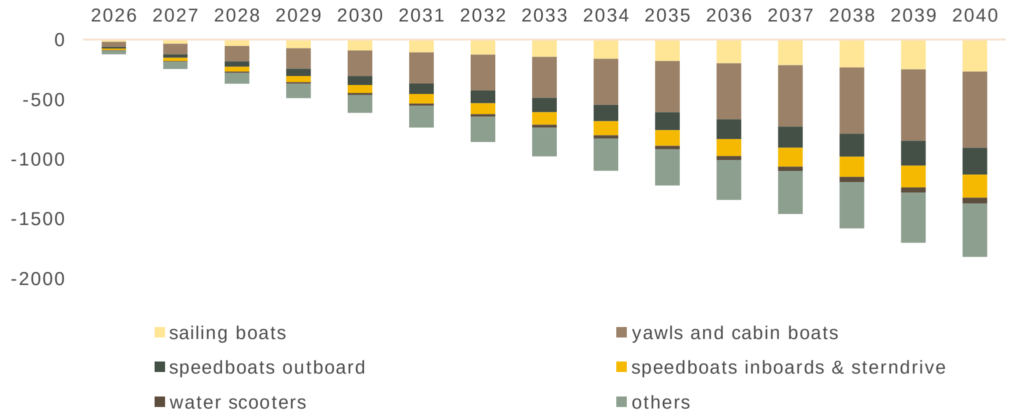
Figure 4-5 indicates the emission results for scenario 3. Through the time period of 2026 to 2040, a 32% reduction of fuel tank permeation emissions is estimated, resulting in a 15,2% reduction of the total evaporative emissions. Figure 4-6 shows the emissions reduction potential by craft type from the implementation of scenario 3.

Figure 4-5 Annual projected evaporative emissions for EU recreational craft in tonnes (Scenario 3).



[50] a high grade, non-hygroscopic nylon

Figure 4-6 Hose permeation emissions reduction potential by recreational craft type in tonnes (Scenario 3).



The emission factors for the fuel tank permeation emissions control scenario are presented in Table 4-5. In Appendix 2, the average fuel tank permeation emission factors by month are presented.

Table 4-5 Evaporative emission factors by craft type in g/day for the scenario 3.

Craft type	*Fuel tank permeation*
Sailing boats (<26 ft.) - outboard	0,9
Yawls and cabin boats - outboard	1,0
Speed boats - outboard	0,9
Speed boats - inboard	0,8
Water scooters - outboard	0,7
Other boats (<20 ft.) - outboard	0,6

4.4.5 Scenario 4 - Implementation of both diurnal and permeation control

For scenario 4, it is assumed that both diurnal and permeation emissions are controlled, so this is a combination of all three above scenarios. Figure 4-7 shows the emission results for scenario 4. From 2026 to 2040, a 30% reduction of total evaporative emissions is estimated.

Figure 4-7 Annual projected evaporative emissions for EU recreational craft in tonnes (Scenario 4).

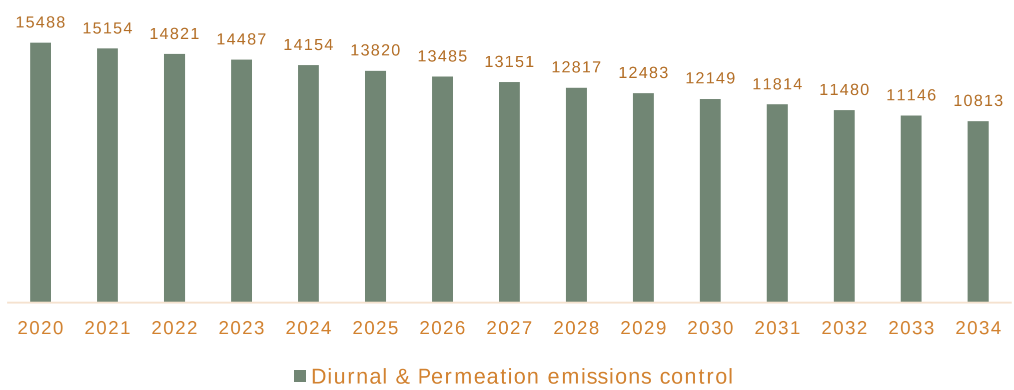
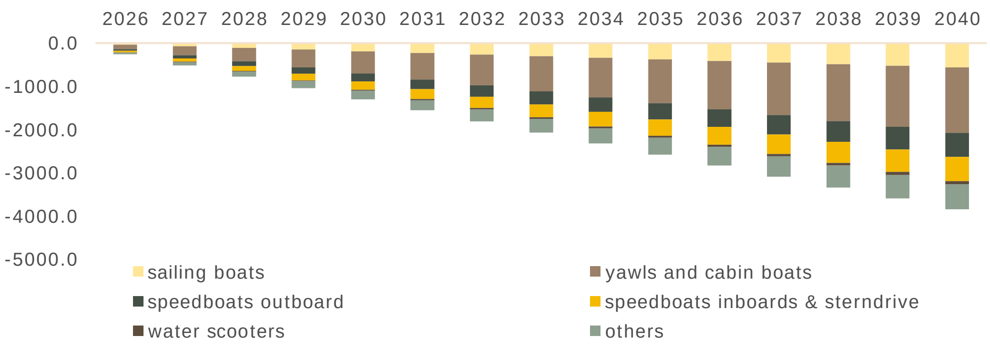


Figure 4-8 shows the emissions reduction potential by craft type from the implementation of scenario 4.

Figure 4-8 Evaporative emissions reduction potential by recreational craft type in tonnes (Scenario 4).



The emission factors for scenario 4 are presented in Table 4-6.

Table 4-6 Evaporative emission factors by craft type in g/day for the scenario 4.

Craft type	*Total evaporative emissions [g/day]*
Sailing boats (<26 ft.) - outboard	2,8
Yawls and cabin boats - outboard	2,8
Speed boats - outboard	3,5
Speed boats - inboard	3,6
Water scooters - outboard	1,8
Other boats (<20 ft.) - outboard	1,4

4.5 Cost estimate of proposed changes

The costs of emission control technologies, proposed in section 4.3, are presented in this section. The cost data have been collected from an extensive literature review and interviews with stakeholders (EPA, 2008).

4.5.1 Scenario 1 - Diurnal control

For diurnal control, two different technology packages are examined. The first concerns the use of a carbon canister installed in the vent line, including a shut-off valve and two hose clamps and the second is a pressurized fuel tank with a pressure relief valve. The shut-off valve will operate as a liquid/vapour separation device to ensure that liquid fuel will not enter the vent line during refuelling. For the recreational craft sector, the canister will contain marine grade carbon which is harder and more moisture resistant than typical carbon used in automotive applications. As a result, the cost is somewhat increased compared to automotive applications (EPA, 2008).

To calculate the costs of diurnal control scenario, Equation 4-1 is applied:

Equation 4-1 Cost estimate of scenario 1.

$$diurnal\ cost = 0{,}5 \times (carbon\ canister\ cost + 2 \times hose\ clamp\ cost + shutoff\ valve\ cost) + 0{,}5 \times relief\ valve\ cost$$

Where all costs are in €/unit and costs of carbon canister and relief valve are proportional to the fuel tank size. A technology share of 50% is assumed for each of the above two technology packages. This is based on inputs from technology suppliers and boat builders in the US.

Table 4-7 presents the incremental costs for diurnal control of the recreational craft types considered in this study. It is noted that these figures include only the hardware cost of the technology. Although the technology is already mature as it is used in other applications, any additional R&D costs are assumed to be included in the price that the boat builders are paying to their suppliers.

Table 4-7 Incremental costs of diurnal control technologies, by craft type.

Craft type	*Incremental Cost (€)*
Sailing boats (<26 ft.) - outboard	2,9
Yawls and cabin boats - outboard	2,9
Speed boats - outboard	21,4
Speed boats - inboard	21,4
Water scooters - outboard	3,4
Other boats (<20 ft.) - outboard	8,1

4.5.2 Scenario 2 - Hose permeation control

The incremental cost estimates for hose permeation control are based on costs of existing products used in marine and automotive sector. For our cost estimates, typical dimensions by craft type are presented on Table 4-8. For water scooters and crafts with outboard engines the cost of a thermoelastic barrier is applied, while for crafts with installed fuel tanks the cost of a nylon barrier is applied. The cost of these technologies is assumed to be 2 €/m, based on experts and information found in the literature.

Table 4-8 Hose dimensions by craft type.

Hose dimensions	*Fill neck hose [m]*	*Supply/return hose [m]*	*Vent line [m]*
		Length [m]	
Sailing boats (<26 ft.) - outboard	1,83	1,83	0,31
Yawls and cabin boats - outboard	1,83	1,83	0,31
Speed boats – outboard	3,05	2,44	2,14
Speed boats – inboard	3,66	3,66	2,44
Water scooters – outboard	0	2,44	0
Other boats (<20 ft.) - outboard	0	2,44	0

To calculate the costs of fuel hose permeation scenario, Equation 4-2 is applied:

Equation 4-2 Cost estimate of scenario 2.

$$fuel\ hose\ cost = incremental\ cost_m \times \sum_m fuel\ hose\ length_m$$

Where:

- m: hose type (supply/return, fill neck, vent)
- incremental $cost_m$: Incremental cost of m [€/m]
- fuel hose $length_m$: fuel tank length of m [m]

Table 4-9 presents the incremental costs arising from the implementation of typical hose permeation control technologies. It is noted that these figures include only the hardware cost of the technology. Similar to diurnal emissions control, any additional R&D costs are assumed to be included in the price that the boat builders are paying to their suppliers. Certification costs are also included in the price and hence these are not considered separately in the figures below. No redesign of the craft is needed for low permeability hoses to be installed and hence to additional manufacturing costs are assumed.

Table 4-9 Incremental costs of hose permeation control technologies, by craft type.

Craft type	*Incremental Cost (€)*
Sailing boats (<26 ft.) – outboard	7,9
Yawls and cabin boats – outboard	7,9
Speed boats – outboard	15,3
Speed boats – inboard	19,5
Water scooters – outboard	4,9
Other boats (<20 ft.) – outboard	4,9

4.5.3 Scenario 3 - Fuel tank permeation control

Portable fuel tanks and fuel tanks of water scooters are typically blow-moulded out of HDPE, while larger installed fuel tanks are rotational-moulded out of XLPE. Because of the manufacturing process and materials used, some permeation control technologies are not suitable for all fuel tank types (EPA, 2008). For the cost estimates, it is assumed that HDPE fuel tanks are layered by non-continuous barrier platelets (Selar), while XLPE fuel tanks are layered by polyamide 11. These two technological options-among the others referred in section 4.3.4 present the minimum incremental cost.

For the cost estimates, typical plastic fuel tank sizes by craft type are presented on Table 4-10. The numbers included in the table concern only plastic fuel tanks, as the metal fuel tanks are impermeable and hence do not contribute to permeation emissions. In addition, based on interviews and literature review the incremental costs by applying non-continuous barrier platelets and polyamide 11 is determined to be 6 €/Kg and 4,80 €/Kg, respectively (EPA, 2008).

Table 4-10 Fuel tank characteristics by craft type

Craft type	*Fuel tank capacity [lt]*	*Fuel tank weight [Kg]*	*Share of **plastic** fuel tanks*
Sailing boats (<26 ft.) - outboard	20	1,6	Portable: 0,0 Installed: 0,8
Yawls and cabin boats - outboard	20	1,6	Portable: 0,3 Installed: 0,4
Speed boats - outboard	160	12,8	Portable: 0,0 Installed: 0,8
Speed boats - inboard	160	12,8	Portable: 0,0 Installed: 0,55
Water scooters - outboard	25	2	Portable: 0,0 Installed: 1,00
Other boats (<20 ft.) – outboard	62,5	5	Portable: 0,0 Installed: 0,6

To calculate the costs of fuel tank permeation scenario, Equation 4-3 is applied:

Equation 4-3 Cost estimate of scenario 3.

$$fuel\ tank\ cost = \sum_{j} incremental\ cost_j \times fuel\ tank\ size_j$$

Where:

- j : fuel tank category (portable plastic, installed plastic)
- incremental $cost_j$: Incremental cost of j [€/Kg]
- fuel tank $size_j$: fuel tank size of j [lt]

Table 4-11 presents the incremental costs arising from the implementation of typical fuel tank permeation control technologies. Similar to hose permeation, these figures include only the purchase cost for the boat builders. Any R&D and certification costs are included in the price offered by fuel tank suppliers. No redesign of the craft is needed for low permeability fuel tanks to be installed and hence no additional manufacturing costs are assumed.

Table 4-11 Incremental costs of fuel tank permeation control technologies, by craft type.

Craft type	*Incremental Cost (€)*
Sailing boats (<26 ft.) - outboard	9,6
Yawls and cabin boats - outboard	8,8
Speed boats - outboard	49,2
Speed boats - inboard	33,8
Water scooters - outboard	10,1
Other boats (<20 ft.) - outboard	14,4

4.5.4 Scenario 4 – Diurnal & permeation control

Scenario 4 combines all three scenarios presented above and is in line with the current legislation in the US, where both diurnal and permeation standards are applied to the recreational craft sector. The incremental costs of scenario 4 derive from the sum of the individual scenarios 1-3.
Table 4-12 presents the incremental costs from the implementation of all three main evaporative emissions sources. As explained previously for the different technologies, these numbers include only the cost of the hardware to be installed on board the different craft types as there are no additional manufacturing, R&D, or certification costs for the boat builders.

Table 4-12 Incremental costs of scenario 4, by craft type

Craft type	*Incremental Cost (€)*
Sailing boats (<26 ft.) - outboard	20,5
Yawls and cabin boats - outboard	19,7
Speed boats - outboard	85,8
Speed boats - inboard	74,7
Water scooters - outboard	18,4
Other boats (<20 ft.) - outboard	27,4

5 Design categories proposals

This chapter considers the current design categories taking into account developments in international standardization and evaluates whether the watercraft design categories require additional specifications or subdivisions. First of all, current design categories and a number of comments are presented. Special attention is paid to a number of specific aspects, such as wind force and significant wave height as division criteria. Then, the legislative and regulatory framework in other jurisdictions is presented, as well as the developments in the field of international standardization. Subsequently, a number of scenarios for possible adjustments is proposed with regards to the design categories and a cost estimate is made for the further determination of the economic effects (reference to Chapter 6).

5.1 Context

The Review clause (Article 52) of the RCD 2013/53/EU requires the Commission to submit a report to the European Parliament (EP) and to the Council by 18th January 2022 that considers the impact of the watercraft design categories listed in Annex I, which are based on resistance to wind force and significant wave height, on consumer information and on manufacturers.

In the past, especially between 2003 and 2012, there were discussions about the set-up of the design categories with diverging views among Stakeholders and Experts, concerning the correctness of the total number of categories, the specifications and the appropriateness of ranges as well.

The main revision in design categories between RCD 2013/53/EU and previous RCD 94/25/EC as amended by 2003/44/EC, was to remove the navigational or geographical title descriptions "ocean, offshore, inshore and sheltered waters", leaving wind force and significant wave height as the only division criteria for the categorization of watercrafts.

5.2 Design categories regulation

5.2.1 Watercraft design categories of current RCD

Annex I of RCD 2013/53/EU describes the following watercraft design categories:

Table 5-1 Watercraft design categories

WATERCRAFT DESIGN CATEGORIES		
Design category	Wind force (Beaufort scale)	Significant wave height (H 1/3, metres)
A	exceeding 8	exceeding 4
B	up to, and including, 8	up to, and including, 4
C	up to, and including, 6	up to, and including, 2
D	up to, and including, 4	up to, and including, 0,3

Explanatory notes:

A. A recreational craft given design category A is considered to be designed for winds that may exceed wind force 8 (Beaufort scale) and significant wave height of 4 m and above but excluding abnormal conditions, such as storm, violent storm, hurricane, tornado and extreme sea conditions or rogue waves.
B. A recreational craft given design category B is considered to be designed for a wind force up to, and including, 8 and significant wave height up to, and including, 4 m.
C. A watercraft given design category C is considered to be designed for a wind force up to, and including, 6 and significant wave height up to, and including, 2 m.
D. A watercraft given design category D is considered to be designed for a wind force up to, and including, 4 and significant wave height up to, and including, 0,3 m, with occasional waves of 0,5 m maximum height.

Recreational craft in each Category must be designed and constructed to withstand the parameters in respect of stability, buoyancy, and other relevant essential requirements listed in Annex I, and to have good handling characteristics.

5.2.2 *First comments on the current RCD*

A. The definition of category A has only lower limits and excludes abnormal conditions, such as storms, hurricanes and tornadoes and extreme sea conditions or rogue waves, but without stating an upper limit for wind force or significant wave height. From the UK Meteorological Office Fact Sheet 6 Beaufort wind force scale (UK Meterorological Office, n.d.), we see that storm is Beaufort wind force 10, violent storm is Beaufort wind force 11 and hurricane is Beaufort wind force 12. Therefore the true meaning of the first explanatory note is "exceeding 8 but excluding 10 and above". On the other hand the expression "exceeding 4 but excluding extreme sea conditions or rogue waves" is not precise as it would be if it set a maximum value for the significant wave height. There is no common approach on the lower limit of a rogue wave. According to the paper "Extreme waves and ship design" (Smith, 2007), extreme or rogue waves have crest to trough heights of 20 to 30 meters and they are observed to be asymmetrical and with unusually steep faces. This paper presents a working definition that a rogue wave is a wave with heights greater than 2,3 times the significant wave height. It also states that they lie at the extreme of what would be expected for a Rayleigh distribution of wave heights. Therefore, it is obvious that between 4 m and 8,7 m (=20/2,3) significant wave height, there are a lot of intermediate sea states for the designer.
B. There is no definition of significant wave height either in the RCD or in the RCD application guidelines of June 2018 (EC, 2018).
C. There is no reference on gusts in relation to Beaufort scale.
D. Concerning wave height of category D, apart from the specification of significant wave height up to, and including, 0,3m, there is reference to occasional waves of 0,5 m maximum height. We observe that it is the only category with statement of maximum wave height value even though it means waves generated from passing vessels or other local disturbances. A designer will obviously use the maximum value of 0,5 m for the calculations of category D whereas in all other categories' calculations he uses significant wave height values.

5.2.3 *Literature review*

The literature on this specific subject is very limited since there are only two studies, both before 2013, "Stocktaking study on the current status and developments of technology and regulations related to the environmental performance of recreational marine engines–Final Report" (TNO, 2004) and "Design Categories of Watercrafts" (Cocheril, 2012), which were submitted to European Commission (EC) and European Parliament (EP) respectively. The latter study identified the following possibilities for improvements:

- A possible subdivision of category D in two parts: First division of wind force up to and including 2 with significant wave height up to 0,3 m and another division of wind force between 3 and 4 with significant wave height up to 1,5 m, in order to correspond better to weather conditions found in sheltered and some areas of non-sheltered waters respectively. Also because in Beaufort force (BF) 4, the corresponding probable maximum height of waves is 1,5 m.
- A possible subdivision of category C since this category encompasses the larger part of the market.
- A possible review of weather conditions for design categories A and B due to toughness and severity.
- Setting upper limits for the category A.

The aforementioned proposals will be used as input for public consultation questions and also for scenarios for impact assessment.

5.2.4 *Wind speed and significant wave height as division criteria for the design categories*

There is no literature from the time of the first RCD 94/25/EC to explain the choice of wind speed and significant wave height as division criteria as well as the choice of the selected ranges leading to a number of four categories. EC guidelines for the application of the RCD (EC, 2018) state that the "watercraft design categories refer just to the combination of weather and water conditions" and also "wind speed and significant wave height are intended to define the physical conditions that might arise in any category for design evaluation and should not be used to limit the geographical areas of operation".

Nevertheless, it is obvious that the choice of wind speed in terms of the well-known Beaufort scale was made because wind power is used to propel sailboats and also affects the heeling moment of the boat, increasing the risk of capsizing. On the other hand, the choice of significant wave height was made because it is included in the scantlings calculations of every Classification Society's rules and it expresses the actual sea condition –not only waves from wind action- that causes (apart from rolling, pitching etc.) the stresses affecting directly the structural integrity of the watercraft, increasing the risk of cracks, damages or flooding.

The existence of these two criteria in each category ensures that in every physical condition, the watercraft is designed and built to withstand the combined effects, up to the specified values, no matter which of the two is the dominant. Nevertheless, as it is written in EC guidelines (EC, 2018): "The significant wave height is considered to be the primary factor". Indeed, the wave height (e.g. in breaking waves) is far more dangerous than wind force itself.

The total number of four had obvious to do with the choice during the first RCD to relate weather and/or water conditions with the navigational notations of ocean, offshore, inshore and sheltered waters, as this combination was common practice in some Classification Societies rules at that time. Even today Registro Italiano Navale (RINA) rules for Fast Patrol Vessels (2007) Part A provides three navigation notation assignments exactly like the first RCD: Unrestricted navigation (BF>8 and H_s>4), Offshore navigation (BF≤8 and H_s≤4) and Inshore navigation (BF≤6 and H_s≤2).

5.2.5 *Beaufort scale*

From Beaufort scale, as can be seen in World Meteorological Organization (WMO) -No 306 Volume I.1 Annex II page A-379 (WMO, 2019), we can see for each wind force from 1 to 12, a range of wind average speeds. They are averaged over 10 minutes' period by convention, at a 10 m height above the sea surface, and they do not capture wind gusts. The non-linear formula for the calculation of wind speed is the following:
$V = 0{,}836 \times B^{3/2}$ (m/s) where B is the Beaufort number, and V the corresponding wind speed.

It should be noted that the wind force causes wind loads on hull surfaces and sails which are proportional to the square of wind speed. In the same table (WMO, 2019) there are descriptions of corresponding sea conditions, with estimations of probable wave height and probable maximum wave height in brackets. Although it is not clarified, the probable wave height of this table maybe is the same as defined in the wave spectrum bell curve of the typical distribution of wave heights (see Figure 5-1). If so, the relation between probable wave height (H_m) and the significant wave height (H_s) is the following: $H_m = 0{,}6 \times H_s$.

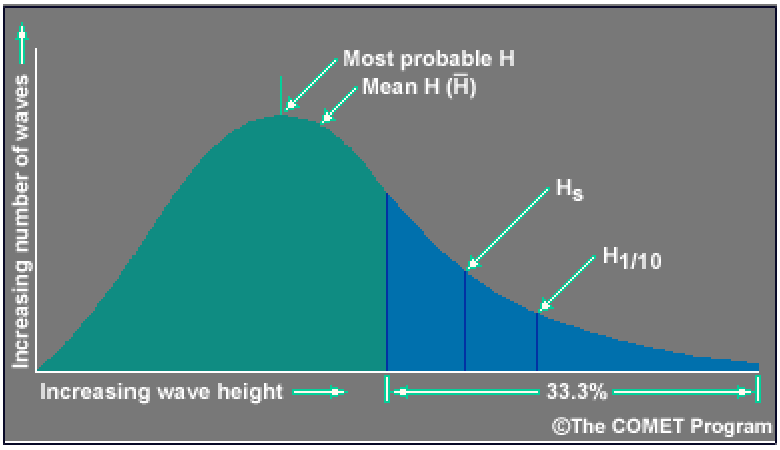
What is worth mentioning, is the note under the table which states: "This table is only intended as a guide to show roughly what may be expected in the open sea, remote from land. It should never be used in the reverse way; i.e., for logging or reporting the state of the sea. In enclosed waters, or when near land, with an offshore wind, wave heights will be smaller and the waves steeper".

Therefore, Beaufort scale is a wind force empirical scale which, in case of fully developed waves, is also providing sea condition estimations for wind waves. Nevertheless, it has to be clear that these estimations can be used only as guidance and not as a primary reference tool to log or report the sea state.

5.2.6 *Significant wave height and sea states*

In oceanography and naval architecture, the significant wave height (H_s or $H_{1/3}$) is a term used to introduce a well-defined and standardized statistic to denote the characteristic height of the random waves in a sea state. It is defined as the mean wave height (trough to crest) of the highest one-third (33,3%) of the waves. It can be seen in the following well-known bell curve figure (NOAA, n.d.) as the average value of the blue coloured area.

Figure 5-1 Typical distribution of wave heights



Significant wave height, which although is a stochastic variable that can be calculated from the wave spectrum, is defined in such a way that it corresponds more or less to what an experienced mariner observes from the bridge or from main steering position when visually estimating the average wave height and logs the sea state condition. Since there are no instruments on a ship or watercraft to measure wave height, the logging of sea state is in descriptive terms and significant wave height is estimated only by observation. It should be noted that there are International Maritime Organization (IMO) guidelines (IMO, 2009) for visual estimation of significant wave height. Nevertheless, it is important for end-users to understand that, when experiencing a significant wave height of 2 m, as in the range of category C, this is the average of the highest one-third waves in a wave spectrum, and waves close to double this height can be expected to occur, although infrequently.

The aforementioned are summarized in the note 1 of EN ISO 12217-1:2017 as follows: "The significant wave height is the mean height of the highest one-third of the waves, which corresponds to the wave height estimated by an experienced observer. Some waves will be double this height".
In harmonised standard EN ISO 12215-5: 2019 Annex K table J.4 states that "$H_{1/3}$ is the average of one-third highest waves in a given sea state".

In general, the official sea states coding is described in WMO No 306 (WMO, 2019), which adopted the Douglas sea states scale, and it is used as reference by International or National Meteorological Services for their marine forecasts. As we can see in the Table 5-2 Sea states according to WMO Doc No 306 Vol. I.1 Annex II p. A 326, sea states are defined by a scale of numbers from 0 to 9 with corresponding descriptive terms (but no images like the ones in Beaufort scale) and ranges of wave heights.

Table 5-2 Sea states according to WMO Doc No 306 Vol. I.1 Annex II p. A 326

Code figure	Descriptive terms	Height* in meters
0	Calm (glassy)	0
1	Calm (rippled)	0 – 0,1
2	Smooth (wavelets)	0,1 – 0,5
3	Slight	0,5 – 1,25
4	Moderate	1,25 – 2,5
5	Rough	2,5 – 4
6	Very rough	4 – 6
7	High	6 – 9
8	Very high	9 – 14
9	Phenomenal	Over 14
Notes: *These values refer to well-developed wind waves of the open sea. While priority shall be given to the descriptive terms, these height values may be used for guidance by the observer when reporting the total state of agitation of the sea resulting from various factors such as wind, swell, currents, angle between swell and wind, etc. The exact bounding height shall be assigned for the lower code figure; e.g., a height of 4 m is coded as 5.		

The wave heights of the above table are significant wave heights, although it is not mentioned, for the following reasons:

A. These sea states' wave heights are references of marine forecasts which clearly declare that the forecast is given in descriptive term and significant wave height as per WMO or Douglas sea states scale.
B. Since these values are guidance for the observer, we explained before that significant wave height is the only statistical value that approximates the visually observed wave height.
C. NATO Standard STANAG 4194 NAV: Standardized wave and wind environments and shipboard of sea conditions (NATO, 1983) presents at Table 5-3 NATO STANAG 4194 table D-1 for sea states numbers and significant wave heights the sea states with the same numbers and wave height ranges, as exactly as defined by WMO sea states, describing clearly the wave heights as significant wave heights. Although it is an old document, it is valid until today for the recognition of sea states in all NATO operational areas and is referenced by NATO Standards dealing with ship design and seakeeping calculations.

Table 5-3 NATO STANAG 4194 table D-1 for sea states numbers and significant wave heights

Sea State Number	Significant Wave Height (m)		Sustained Wind Speed (Knots)*		Percentage Probability of Sea State	Modal Wave Period (Sec)	
	Range	Mean	Range	Mean		Range **	Most Probable ***
0-1	0-0,1	0,05	0-6	3	0,70	-	-
2	0,1-0,5	0,3	7-10	8,5	6,80	3,3-12,8	7,5
3	0,5-1,25	0,88	11-16	13,5	23,70	5,0-14,8	7,5
4	1,25-2,5	1,88	17-21	19	27,80	6,1-15,2	8,8
5	2,5-4	3,25	22-27	24,5	20,64	8,3-15,5	9,7
6	4-6	5	28-47	37,5	13,15	9,8-16,2	12,4
7	6-9	7,5	48-55	51,5	6,05	11,8-18,5	15,0
8	9-14	11,5	56-63	59,5	1,11	14,2-18,6	16,4
>8	>14	>14	>63	>63	0,05	18,0-23,7	20,0

***** Ambient wind sustained at 19,5m above surface to generate fully-developed seas.
To convert to another altitude, H_2, apply $V_2=V_1(H_2/19{,}5)^{1/7}$
******Minimum is 5 percentile and maximum is 95 percentile for periods given wave height range
*******Based on periods associated with central frequencies included in Hindcast Climatology

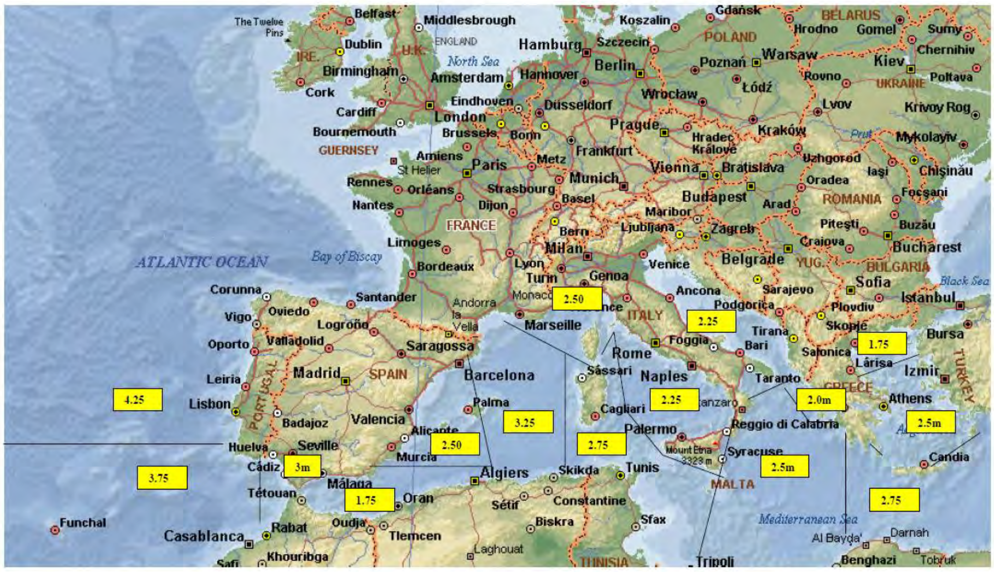
Sea states references are very often used in technical documents of commercial ships and recreational crafts, specifying the sea condition for the execution of sea trials and verification and acceptance of contractual maximum or cruising speed. For example "maximum speed of 40 knots is to be achieved at sea state 2".

In order to have an indication of some actual values of significant wave heights in European seas that are used as input for designers, we will extract values of significant wave heights that are written in the wave height maps of the final report "Assessment of specific EU stability requirements for ro-ro passenger ships" made by DNV-GL for the European Commission (EC, DNV-GL, 2019):

Range of H_s for North Sea and Atlantic (fig. 38 p.62) H_s= 2,5 ÷ 4,0 m
Range of H_s for Skagerakk and Baltic Sea (fig. 39 p.63) H_s= 1,5 ÷ 3,8 m
Range of H_s for Atlantic (Spain, southwest France, fig. 40 p.64) H_s= 3,1 ÷ 4,9 m
Range of H_s for West Mediterranean (fig. 40 p.64) H_s= 2,5 ÷ 3,1 m
Range of H_s for Italian waters (Appendix A p.42) H_s= 2,1 ÷ 3,7 m

For East Mediterranean sea, we will reproduce the map and the values from the paper "Stockholm Agreement – Past, Present & Future (Part II)" (Vassalos, 2002)
Range of H_s for East Mediterranean H_s= 1,75 ÷ 2,75 m

Figure 5-2 H_s values of East Mediterranean sea (Vassalos, 2002)



5.2.7 Misconception of design categories by the end-users and information from marine forecasts

The problem with the misconception of design categories by a lot of end-users as explained in the latest literature study (Cocheril, 2012) and was verified during consultation with all kind of Stakeholders, even with end-users associations, is the following:

- They confuse wind speed of Beaufort scale with the gust speed. When they measure wind speed with an anemometer in less than one minute measurements, they may measure gusts, which have a duration of a few seconds and are usually 20-50% higher than the average wind speed value of ten minutes measurements which characterizes the actual Beaufort force.
- They confuse or they don't have a correct understanding of the concept of significant wave height. Apart from the difficulty of the definition –mean value of one-third of the highest wave heights- they have to realize that H_s is not just a single value but rather a value which implies a range of heights, from approximately 60% of H_s (most probable) to 200% of H_s (maximum), range which is valid in the fully developed seas where wave spectra functions are applied. In closed seas and of course in inland channels, this range is narrower. In any case, if a skipper is not aware that he will face some waves of 127%, some waves of 167% and maybe of 200% of H_s, he may underestimate the safety risk by the physical conditions that will be encountered.

Marine weather forecasts, by which recreational craft users are informed before departure, report on prevailing direction of wind and wind force in Beaufort scale and also direction of wave, significant wave height and wave period. In the concise report, sea state is forecasted through its description term according to WMO sea states descriptions (calm, smooth, slight, moderate, rough, very rough etc.).

Additionally, in most cases, there are also information on gusts and on maximum wave height. In all sea bulletins of Hellenic National Meteorological Service Invalid source specified., it is stated that "wind gusts can be 40% stronger than those given here and max wave height up to twice than significant". In some cases, the end-users are also informed about the exact value of gusts' speed (e.g. windy.com).

Therefore, end-users of recreational crafts, apart from their training or qualification, should be able to understand the difference between average wind speed and gust speed and also between significant wave height and maximum wave height, because they are already familiar through careful attention of marine forecasts. In general, they are not obliged to know what EN ISO 12217 states about gusts and max wave heights but they should be able to make the link between the marine forecast, the actual weather and water conditions they face and the construction capabilities of their watercraft as it depicted in the owners' manual in relation to the design category.

A recommendation for improvement would be to amend Annex I explanatory notes of the RCD with simple technical information regarding significant wave height definition, maximum average wind speeds, gust speeds and maximum wave height, so as to be incorporated in the owner's manual, helping end-users to make the comprehension links with marine forecasts.

A second recommendation for improvement would be, in case of future revision of design categories, the significant wave heights upper limits to be chosen in line with the maximum values of the WMO sea states. Since marine forecasts state not only the value but also the description of sea state (e.g. slight, moderate, rough, very rough etc.), it is the simplest way for the end-user to understand the link between the forecast and the capabilities of his watercraft in relation to its design category. For example: Nowadays, an end-user of category B watercraft must remember that the construction safety of his craft is until "rough" broadcasted sea state. This is the simplest way of understanding the construction safety limits of his boat in relation to the design categories. The same could be regulated for all the categories. This recommendation will be taken into account in creating the design categories in scenario 3 for the impact assessment analysis.

5.2.8 *Legislative and regulatory framework in other jurisdictions*

The US recreational boating regulations, as well as the Australian and Chinese regulations are studied.

A) US recreational boating regulations

There are no American Boat & Yacht Council (ABYC) or United States Coast Guard (USCG) regulations which describe design categories like the ones found in the RCD and ISO stability Standard, which are related to wind force and significant wave height, or any other environmental parameters as categorization criteria. This result of desk research was verified by both National Marine Manufacturers Association (NMMA) and also ABYC. Therefore, there is no possibility for international harmonisation of the legislative requirements concerning design categories for these two main markets, US and EU.

B) Australian recreational crafts regulations

There are no Australian standards with similar categorization criteria with the one of RCD's design categories. The regulated standard for recreational crafts is Australian Builders Plate edition 5 which states RCD, ISO Standards especially ISO 12217, ABYC Standards and Australian Standard (AS) 1799.1 as reference documents.

AS 1799.1:2009 sets out requirements for stability, reserve buoyancy, maximum load and number of persons for power boats up to 15 m in overall length used as recreational crafts. In clause 1.5 states that where reference "protected waters" shall be considered as ISO design category C and where reference "open waters" shall be considered as ISO design category B.

The National Standard for commercial vessels (NSCV) of the Australian Maritime Safety Authority regulates national commercial leisure crafts (class 4 vessels) which are used as bare boats (hire and drive). NSCV Part F and Part B have as service categories seven operational areas, A (Unlimited domestic operations), B extended (extended offshore operations), B (offshore operations), C (restricted offshore operations), C restricted (restricted offshore operations-specified areas), D (partially smooth waters) and E (smooth waters), linked in clause 3.4 of Part B with Beaufort scale, significant wave height, assumed gusting wind pressure and water and air temperature as design environmental parameters. Additionally, tables 7 and 9 of the NSCV Part F regulations, present the correspondence between these operational areas and RCD design categories D, C and B. These Australian regulations even if they are referring to commercial leisure boats, follow a similar to previous RCD approach by maintaining a link between geographical areas and environmental conditions. It should be noted that there is reference in gusting wind pressure in relation to the corresponding Beaufort force.

C) Chinese recreational crafts regulations

According to Rules for construction and classification of Yachts less than 24 m (2020) as well as Guidelines for Survey of Sailing Craft (2012), the design categories of yachts and sailing crafts are as follows:
Category I for navigating exceeding 200 nautical (n) miles off the place of refuge and with the minimum design significant wave height of 6 m, Category II navigating within 200 n miles off the place of refuge and with the minimum design significant wave height of 4 m, Category III for navigating within 20 n miles off the place of refuge and with the minimum design significant wave height of 2 m, Category IV for navigating within 10 n miles off the place of refuge and with the minimum design significant wave height of 1 m and Category V for navigating within 5 n miles off the place of refuge and with the minimum design significant wave height of 0,5 m.
We can observe that these regulations are more close to the first RCD since they have as division criteria a combination of a sea state condition in terms of significant wave height and an operational rule in terms of distance from shore. Another remark is that there are five categories since in significant wave heights scale, they have another one category between category D and category C of RCD II.

5.2.9 Review on developments of International Standardisation

The only relevant International Standard for stability and buoyancy assessment and categorization are harmonised Standards EN ISO 12217-1,2,3: 2017, which include the definition and division criteria of design categories. According to ISO/TC 188 N 1465, all other harmonised standards should reference or quote ISO 12217 when referring to design categories. Clause 7.2 of this Standard summarises watercraft design categories as follows:

Table 5-4 EN ISO 12217-1 summary of design categories descriptions

SUMMARY OF DESIGN CATEGORY DESCRIPTIONS				
Parameter	Design category			
	A	B	C	D
Typical Beaufort wind force	<10	≤8	≤6	≤4
Wave height up to	approx. 7 m significant	4 m significant	2 m significant	0,3 m significant 0,5 m maximum
Maximum average wind speed for 10 min	24,4 m/s	20,7 m/s	13,8 m/s	7,9 m/s
NOTE 1: The significant wave height is the mean height of the highest one-third of the waves, which approximately corresponds to the wave height estimated by an experienced observer. Some waves will be double this height. NOTE 2: According to atmospheric conditions, gusts may temporarily increase the wind speed. NOTE 3: Maximum average wind speed taken from UK Met Office Fact sheet 6.				

The comparison of EN ISO 12217 developments in relation to RCD 2013/53/EU lead to the following remarks:

A. EN ISO 12217-1: 2017 specifies the upper limit values of Category A both on Beaufort force (<10) and on significant wave height (approx. 7 m), whereas RCD states no upper limits. Only in Beaufort scale the upper limit is implied to be less that BF 10 through exclusion of storms. This remark in combination with what is written in paragraphs 5.2.2 and 5.2.3 will be used as input for public consultation questions and also for scenarios for impact assessment.
B. EN ISO 12217-1: 2017 states maximum values of average wind speed for 10 minutes whereas RCD makes no reference of wind speed.
C. EN ISO 12217: 2017 states at note 2 that "gusts may temporarily increase the wind speed" and in paragraph 7.2 defines gust values as 32 m/s, 27 m/s, 18 m/s, 12 m/s for categories A, B, C and D respectively. RCD makes no reference on gusts.
D. EN ISO 12217: 2017 states at note 1 that some waves will be double the significant wave height whereas RCD makes no reference on maximum wave height, except category D (see 5.2.2).

Remarks B, C and D can be considered in combination with remarks of section 5.2.7, so as to increase clarity of information for the end-users and thus reducing safety risks from misunderstanding of the technical information.

5.2.10 Additional remarks on RCD

In order to compare RCD, EN ISO 12217-1, Beaufort scale and WMO sea states, we created the following two comparative tables, one concerning wind force (Table 5-5) and another concerning wave height (Table 5-6):

Table 5-5 Comparative table between RCD, Beaufort scale and EN ISO 12217-1 concerning wind force

Cat.	**RCD & EN ISO 12217 specification of Beaufort force**		**Beaufort scale wind speed** (average wind speed for 10 min, UK Met Office Fact Sheet 6 or WMO No 306)		**EN ISO 12217 Gust value** (*& gust factor*)		**EN ISO 12217 Calculation value** (worksheets 6 & 7 (& gust factor)	**Correspondence of ISO calculation value with Beaufort scale**
	RCD	ISO	RCD	ISO	RCD	ISO	ISO	
A	> 8 (**≤9** due to storm exclusion)	<10 (≤9 since 10 is not included)	20,8–24,4 m/s (41-47 knots)	24,4 m/s (47 knots)	-	32 m/s (62 knots) *gust factor 1,31*	28 m/s (55 knots) *gust factor 1,15*	**BF 10** (one unit above, 24,5–28,4 m/s)
B	**≤8**	≤8	17,2-20,7 m/s (34-40 knots)	20,7 m/s (40 knots)	-	27 m/s (53 knots) *gust factor 1,30*	21 m/s (41 knots) *gust factor 1,02*	**BF 9** (one unit above, 20,8–24,4 m/s)
C	**≤6**	≤6	10,8-13,8 m/s (22-27 knots)	13,8 m/s (27 knots)	-	18 m/s (35 knots) *gust factor 1,30*	17 m/s (33 knots) *gust factor 1,23*	**BF 7** (one unit above, 13,9–17,1 m/s)
D	**≤4**	≤4	5,5-7,9 m/s (11-16 knots)	7,9 m/s (16 knots)	-	12 m/s (23 knots) *gust factor 1,52*	13 m/s (25 knots) *gust factor 1,65*	**BF 6** (two units above)

Table 5-6 Comparative table between RCD, Beaufort scale, EN ISO 12217 and WMO sea states concerning wave height

Cat.	**Wave height specification in RCD 2013/53/EU**		**Beaufort scale indicative wave heights** (UK Met Office Fact Sheet 6)			**Wave height as specified in EN ISO 12217-1**		**WMO states of the sea (Douglas scale)** (WMO No 306 p. A-326)	
	Beaufort force	**H_s (m)**	**$H_{most\ probable}$ (m)**	H_{max} (m)	Sea state description	**H_s (m)**	H_{max} (m) (=2 x H_s)	**H_s (m)**	Sea state number & description
	10		9	12,5	Very high			9-14	8 – Very high
A	≤9	**>4**	**7**	10	Very high	**≤7**	14	**6-9**	7 - High
								4-6	6 - Very rough
B	≤8	**≤4**	**5,5**	7,5	High	**≤4**	8	**2,5-4**	5 - Rough
	7		4	5,5	Very rough			**1,25-2,5**	4 - Moderate
C	≤6	**≤ 2**	**3**	4	Rough	**≤2**	4	**1,25-2,5**	4 - Moderate
	5		2	2,5	Moderate			**0,5-1,25**	3 - Slight
D	≤4	**≤0,3 0,5 max**	**1**	1,5	Slight	**≤0,3 0,5 max**	0,6	**0,1-0,5**	2 – Smooth (wavelets)
	3		0,6	1	Smooth			0,1-0,5	2 – Smooth (wavelets)

Observations on these two comparative tables lead to the following additional remarks:

A. From the wind force table we observe that gust values stated in EN ISO 12217 fluctuate from 30% to 50% more than the maximum average wind speed of each category Beaufort scale. Calculation values fluctuate from 2% to 65%, corresponding to the ranges of one Beaufort scale higher in case of categories A, B and D and two scales higher in category D.

B. Beaufort scale indicative probable wave heights and significant wave height scales at RCD, EN ISO 12217 and WMO sea states, are related, but should not be confused. While wind and sea waves are causally related, Beaufort numbers and sea state numbers are not identical. Waves are caused by winds, by swells, by currents, tides etc. and in case of wind waves are dependent on the fetch length and the duration of time the wind blows consistently over the fetch. In case of limited fetch, it is very usual to have a high Beaufort force unit with a relevant small significant wave height. For example, in Aegean sea in Greece, which is considered a closed sea with a lot of islands, it is often observed to have high Beaufort force e.g. BF 7 with significant wave height no more than 2 m (sea state 4). Wind speed is an input for wave height calculation but wind speed and significant wave height are forecasted by Meteorological Services through separate numerical models.

C. Since significant wave height is the primary factor (see 5.2.4), we observe that in category B, specification of Hs≤4 m is in line with BF 7 indicative wave heights and not BF 8 which is specified in RCD. In the same logic, category C specification Hs≤2 m is in line with BF5 instead of BF6 and category D specification Hs ≤ 0,3 m is in line with BF3 instead of BF4. This means that design categories, if remain four, could be scientifically improved by keeping current Hs and by lowering Beaufort scale specification of categories B, C and D by one unit in order to have better alignment with the indicative probable wave heights of the Beaufort scale. This would suit also the purpose to reduce the Beaufort limits of categories B and A which are severe. Moreover, if design categories were about to be increased in number for even better improvement, significant wave heights could be chosen in line with the WMO sea states upper limit values for Hs, since these sea states values and descriptions are presented in marine forecasts, and then to find the closest corresponding Beaufort force according to Table 5-6. In such a way the gap of one sea state between design categories D and C, which is sea state 3, would be covered by a separate category between D and C. Scenario 3 of the impact analysis was created in line with this concept.

5.2.11 Strengths and weaknesses of current categorization and Stakeholders' consultation

Following all previous analysis and taking into account the feedback from Stakeholders through public and targeted consultation, strengths and weaknesses of current categorization can be presented as follows:

Strengths of current categorization:

- The combination of Beaufort scale and significant wave height as division criteria is correct because these two main parameters are involved and combined in all physical conditions, with the one of the two being the prominent one.
- The removal of navigation rule (ocean, offshore, inshore, sheltered waters) helped in eliminating the confusion between physical conditions and geographical location.
- The vast majority of Stakeholders (manufacturers associations, end-users associations, Notified Bodies, Market Surveillance Authorities, Design Offices, individuals) are satisfied with the current categorization. There were no criticism on the number or the range of the categories and there were no specific proposals for modifications or subdivisions. After five years of familiarization with the last amendment of RCD and in relation to the progress achieved after many years of efforts with the harmonised Standards (e.g. scantling Standard), the stakeholders expressed the position that the market of recreational sector is running smoothly with a high percentage of consensus.
- Although detailed data are limited, there is no sufficient evidence from the European Maritime Safety Agency (EMSA) or Member States national investigation reports which state that the causal factor of a number of accidents was the environmental conditions in terms of wind and wave height although the watercraft sailed within the limits of its assigned design category and there were no mistake by the user.

Weaknesses of current categorization:

- There is no upper limit for category A especially concerning significant wave height.
- There are no technical information about wind speeds, gusts and maximum wave heights
- There is no equal distribution in terms of scientific soundness. In other words, there are unequal and large steps or increments between the categories. The significant wave of category C is nearly seven times the upper limit of category D. The significant wave of category B is two times the upper limit of category C. In Beaufort scale, as explained in 2012 study (Cocheril, 2012), the range of physical forces in wind forces of category D is much higher (ratio 1 to 8) than the range of physical forces in wind forces of category C (ratio 1 to 3).
- There is no equal distribution in terms of market share. Category C was expected to be dominant due to preferred boats' length (roughly 4,8 – 10 m) but it covers more than two-thirds (68%) of the market and additionally it includes a variety of different boat types and also boats of various capabilities and seaworthiness. A boat that just fails to be assigned in category B is in the same category with a boat that just achieves to be assigned in category C. This is clearly a marketing or commercial issue that is mainly of manufacturers' concern. Maybe this is one of the reasons that EBI in the past promoted the idea of more design categories, but no official position paper is available for more details on this subject. Nevertheless, nowadays both ICOMIA and EBI as manufacturers' associations are satisfied with the current categorization, as explained in the strengths.

Other interesting issues raised as feedback from stakeholders included:

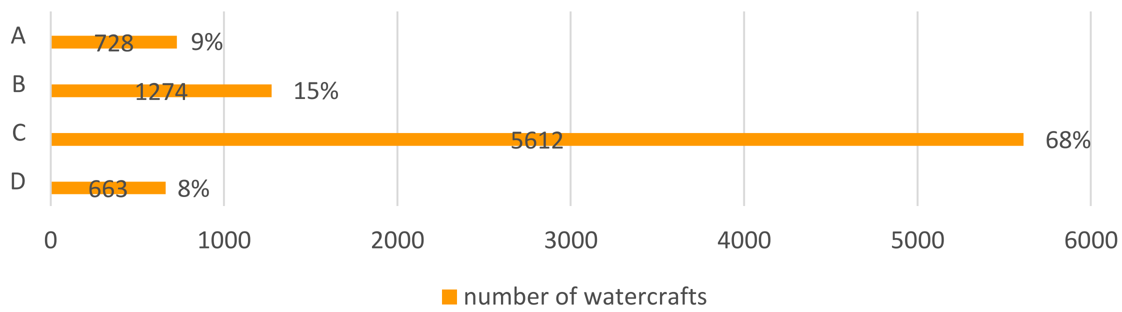
A. Market Surveillance should increase efficiency in performing audits or checks to ensure proper implementation of the RCD in terms of complete and correct information in the technical files and in certificates of Conformity especially in cases of assessment module A.
B. All Notified Bodies (NBs) should acknowledge the need to provide full and consistent data in the RSG database, because these data will be used as statistics to support studies or policy makers in their proposals and decisions.

C. The paradox with some rigid inflatable boats (RIBs) that are certified for many persons at category B which are in compliance with regulations and Standards, but raise concerns on consumers' safety risks upon full implementation (e.g. 5,3 m open deck RIB certified category B for 8 persons is safe at sea with 4m significant wave height?)
D. The French Leisure Boating Division emphasized the need to provide consumers with better information on what is a design category through comprehensive descriptions in the owner's manual and through stickers on the boat with short and descriptive sentences, drawings, sketches, etc., describing the state of the sea according to Beaufort scale and waves heights.

5.2.12 Statistical analysis of available data concerning the design categories

Due to the fact that national registration authorities have different regulations and the majority of them do not keep records for design categories, we have limited sources of relevant information.
For the purpose of our study, we will use the official data from the French Maritime Administration (Ministère de la mere, 2020), of the total number of new watercrafts over 2,5 m hull length (except PWCs) registered last year, from 1/9/2019 till 31/8/2020 for the sea waters and from 1/1/2020 till 31/8/2020 for the inland waters. Although the statistics from French fleet may not be representative for all European countries (e.g. Nordic countries or Baltic states), due to lack of other available data, will be used as input for the necessary statistics for the impact assessment analysis.
The percentages of each design category fleet (except PWCs) in relation to the total fleet are shown in the following Figure 5-2.

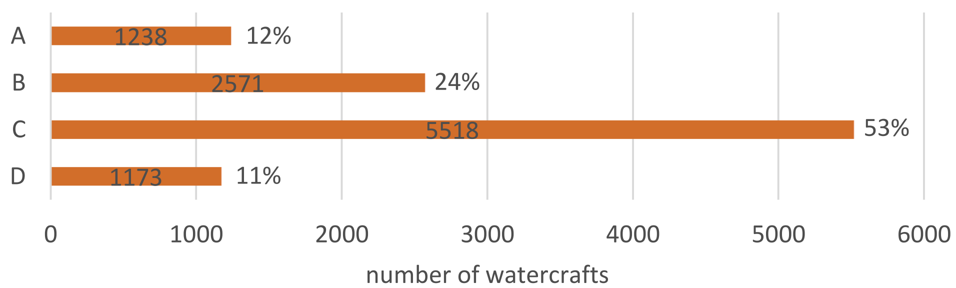
Figure 5-2 Design categories distribution of new registrations in France (2020)



From the same official data we also extract the information that 98% of the watercrafts have length less than 12 m.

Another source of information is Recreational Sectorial Group (RSG) which gathers data from Notified Bodies. The below Figure 5-3 is derived from RSG database gathered from 13 Notified Bodies (out of today's 32 in total), provided to us through ICOMIA and EBI. It includes 10500 records for all kind of watercrafts (motorboats, sailboats, RIBs etc.) that were constructed or imported to Europe for a period from early 90s till August of 2020. In cases of records with dual or multiple assignments of categories for the same boat, we took into account for the statistical process only the highest category.

Figure 5-3 Watercraft design categories distribution acc. to RSG data till August 2020 (excl. PWCs)



When observing the figures and noting that there are no data from all Notified Bodies, it is expected that percentages wouldn't be the same, because data from France are only from new registrations and more important, for watercrafts of categories D and C (when l<12 m, there is the choice of module A (self-assessment). Therefore, that is why the sum of category C and D in France is 76% whereas in RSG data is 64%.

There are also 8 extra records for PWCs which are all assigned to category C. Section 3.12 of EN ISO 13590: 2018 states that PWCs are assigned to either D or C design category. According to ICOMIA statistics book 2019 (ICOMIA, sd), three companies represent nearly 100% of the PWC market in Europe. It is verified by EBI and the French Maritime Administration that all PWCs are assigned to category C, so this information will be taken into account in the impact assessment analysis.

5.3 Candidate scenarios

Although the public and targeted consultation provided no proposals for additional or different subdivisions to the watercraft design categories, we will present four scenarios in relation with the analysis carried out in section 5.2 in order to assess possibilities for further subcategories and/or different specifications and the impact of them to the industry and consumers.

A basic assumption for the cost benefit analysis structure in design categories is that costs for re-design, re-certification, communication and manufacturing affects only current fleet with the precondition that a certain percentage of manufacturers will choose to continue to produce the same models after the start date of the implementation of the new RCD. In such case, changes in categories' numbering, ranges, re-calculations in the technical files, revisions in owners' manual, etc. will result in re-issuance of the CE certificates through office work only. For the purpose of simplification here, when we refer to certification by a Notified Body we won't make distinctions if it is assessment module A1 or B or G etc. although there is a lot of difference between them. For new watercrafts, there is no incremental cost in no one of the aforementioned cost categories. In case of subdivision, the alphanumeric designation with the digit 1 denotes the upper subcategory and with the digit 2 the lower category (e.g., C1 and D1 are the upper C and D sub-categories respectively).

5.3.1 Base case scenario

Base case scenario is presented in Table 5-7.

Table 5-7 Baseline scenario: No change (status quo)

Design Category	Beaufort force	H_s(m)
A	>8 (excluding BF 10)	>4 (excluding rogue seas)
B	≤8	≤4
C	≤6	≤ 2
D	≤4	≤0,3 (0,5 max)

Base case scenario implies that the current design categories remain unchanged. This is the baseline option for the comparison.

5.3.2 Scenario 1 – Subdivision category D

Scenario 1, which is subdivision of Category D, is presented in Table 5-8.

Table 5-8 Scenario 1: Subdivision of category D

	Scenario 1: Subdivision of category D	
Design Category	Beaufort Force	H_s (m)
A	>8 (excluding BF 10)	>4 (excluding rogue seas)
B	≤8	≤4
C	≤6	≤2
D1	**≤4**	**≤1,5**
D2	**≤2**	**≤0,3 (0,5 max)**

Scenario 1 implies subdivision of category D in two subcategories D1 and D2, exactly as it was proposed in the EP study (Cocheril, 2012): D1 division with weather conditions of wind force up to and including 2 and significant wave height up to and including 0,3 m (occasional 0,5 m max) and D2 division of wind force up to and including 4 and with significant wave height up to and including 1,5 m, in order to correspond better to weather conditions found in sheltered and some areas of non-sheltered waters respectively. The choice of H_s=1,5 m is also justified in the EP study because this is the corresponding probable maximum wave height in Beaufort scale for BF 4. Measurement scale of category C remains the same although there is only half a meter difference of significant wave height in relation with category D1. The total number of categories is increased from four to five.

Assumptions for Scenario 1:

- No change at conformity assessment modules.
- Technical files of watercrafts contain all engineering data needed for the new calculations and updates.
- The percentage of watercrafts models of category D which are certified by a Notified Body (although is not mandatory by the Directive according to Article 20.1) is assumed as 5%.
- The estimation of watercrafts' models of category D which are to be re-designed (meaning review of technical file and re-calculations) to meet requirements of category D1 (increased wave height up to 1,5 m) is 5%, the same as the percentage for re-certification.
- Since re-certification cost depends on crafts' length, assessment module and man-days at office and at place of survey in each individual case, in order to simplify calculations we assume fixed cost for all cases.
- The percentage of watercrafts models of category D that are to be modified in order to comply with the more strict requirements of category D1 due to higher H_s, is assumed as 5%. Another assumption is that this manufacturing cost will be the result caused by increased hull and stiffeners' thicknesses and that the specified engine and the new freeboard are sufficient for the increased weight in order to be assigned to category D1 (from H_s=0,3 to H_s=1,5 m). For a case study of a Glass reinforced plastic (GRP) motorboat with hull length of 4,5 m and a beam hull of 1,4 m (taken as representing the average size of the category), the increased thickness is approximately 3 mm and the additional weight about 70 kg, depending on the lamination scheme and the glass to resin ratio.

5.3.3 Scenario 2 – Subdivision category C

Scenario 2, which is subdivision of Category C within its initial range, while other categories remain unchanged, is presented in Table 5-9.

Table 5-9 Scenario 2

	Scenario 2: Subdivision of category C within its initial range (other categories remain unchanged)	
Design Category	Beaufort Force	H_s (m)
A	>8 (excluding F10)	>4 (excluding rogue seas)
B	≤8	≤4
C1	**≤6**	≤2
C2	**≤5**	**≤1,25**
D	≤4	≤0,3 (0,5 max)

Scenario 2 implies subdivision of category C in two subcategories C1 and C2, without changing initial range, since this category encompasses the larger part of the market (68%): C2 division with weather conditions of wind force up to and including 5 and significant wave height up to 1,25 m which is in line with sea state 3 (slight sea) and C1 division of wind force up to and including 6 with significant wave height up to 2 m which is the current limit of the previous category C. Measurement scales of categories D and B remain the same. The total number of categories is increased from four to five.

Assumptions for Scenario 2 are:

- No change at conformity assessment modules.
- The estimation of watercrafts of category C which can be re-designed to meet requirements of category C2 is not of great importance, since they already meet the requirements and can be all assigned to category C1. Hence, no cost for re-design is to be calculated.
- The percentage of watercrafts models of category C which are certified by a Notified Body (both those above 12 m that is mandatory by the Directive according to Article 20.1 and those below 12 m that is not) is assumed as 10%.
- Since re-certification cost for the new category C1 depends on crafts' length, assessment module and man-days at office (only paper work in this case) in each individual case, in order to simplify calculations we assume fixed cost for all cases.
- All the PWCs of category C can be assigned to category C1 since they already meet the requirements, so there are no extra cost for re-design and re-certification.

5.3.4 Scenario 3 – Subdivision category C and revised ranges

Scenario 3, which is subdivision of Category C and specification of new ranges in all categories in order to improve scientific or technical soundness, is shown in Table 5-10.

Table 5-10 Scenario 3

	Scenario 3: Subdivision of category C and specification of new ranges in all categories in order to improve scientific soundness	
Design Category	Beaufort Force	H_s (m)
A	≤9	≤7
B	**≤7**	≤4
C1	**≤5**	**≤2,5**
C2	**≤3**	**≤1,25**
D	**≤2**	**≤0,5**

Scenario 3 implies subdivision of category C in two subcategories C1 and C2, since this category encompasses the larger part of the market (68%) and specification of new ranges to all categories in order to have an improved distribution in terms of scientific or technical soundness. In simple words, through alignment with WMO sea states and reducing the steps in Beaufort scale.

Concerning Beaufort scale, it implies better distribution through commencement of category D at Beaufort force 2 and from category C2 and up, we have a constant difference of two force units till category A. Moreover, by lowering category B one force unit, becomes less tough and severe. Bearing in mind the nonlinear increase of wind speed from one Beaufort force to the next one as well as the fact that physical forces (generated by wind) on hull and sails are proportional to the square of wind speed, this distribution is scientifically better because it leads to nearer ratios of increased physical forces under each category range (see relevant weakness point in 5.2.11). The technical improvement is that we do not have larger steps than 2 units of Beaufort scale wind force.
Concerning significant wave height (H_s) scale, it implies better distribution through full alignment of categories D, C2, C1 and B with WMO sea states: 0,5 m is for sea state 2 (smooth), 1,25 m for sea state 3 (slight), 2,5 m for sea state 4 (moderate sea) and 4 m for sea state 5 (rough) respectively. Therefore each design category from D to B corresponds to the discrete sea states from 2 to 5 and at the same time is closer than before to the probable wave height estimation of the Beaufort scale, which is 0,2 m, 0,6 m, 2 m and 4 m respectively (see Table 5-11). The technical improvement is that until category A we do not have steps of significant wave height that are larger than 1,5 m and we have alignment with four WMO sea states which are presented in the marine forecasts.

Category A is modified in order to transpose harmonised Standard EN ISO 12217-1: 2017 upper limit values, that is wind force up to, and including, 9 and significant wave height up to, and including, 7 m. Additionally, explanatory notes of the Annex I table to be enriched with technical information concerning maximum average wind speed, gust speed and possible maximum wave height. The total number of categories is increased from four to five. In general, this scenario implies a proposal of scientific or technical improvement of the design categories with the minimum (one) increase in the total number.

Table 5-11 Scenario 3 correspondence with WMO sea states and Beaufort scale wave heights

	Proposals for new ranges		**Beaufort scale wave height** (UK Met Office Fact Sheet 6)			**WMO states of the sea (Douglas scale)** (WMO No 306 p. A-326)	
Design Category	Beaufort force	H_s (m)	$H_{most\ probable}$ (m)	H_{max} (m)	Sea state description	H_s (m)	Sea state number & description
A	**≤9**	**≤7**	7	10	Very high	6-9	7 - High
B	**≤7**	≤4	4	5,5	Very rough	2,5-4	5 - Rough
C1	**≤5**	**≤2,5**	2	2,5	Moderate	1,25-2,5	4 - Moderate
C2	**≤3**	**≤1,25**	0,6	1	Smooth	0,5-1,25	3 - Slight
D	**≤2**	**≤0,5**	0,2	0,3	Smooth	0,1-0,5	2 – Smooth (wavelets)

Assumptions for Scenario 3:

- No change at conformity assessment modules.
- Technical files of watercrafts contain all engineering data needed for the new calculations and updates.
- All watercrafts of category D are assumed to be assigned to new category D, watercrafts of category B already meet the requirements of new category B and only watercrafts of category C will be split into new categories C1 and C2.
- The percentage of watercrafts models of category C which are certified by a Notified Body (both those above 12 m that is mandatory by the Directive according to Article 20.1 and those below 12 m that is not) is assumed as 10%. The same percentage is valid for watercrafts models of category C which are to be re-designed to meet requirements of category C1 (increased wave height up to 2,5 m).
- The percentage of watercrafts models of category D which are certified by a Notified Body (only office work because they meet already with the requirements) is assumed as 5% (the same with scenario 1).
- The percentage of watercrafts models of category B which are certified by a Notified Body (only office work because they meet already with the requirements) is 100%.
- Since re-Certification cost depends on crafts' length, assessment module and man-days at office and at place of survey in each individual case, in order to simplify calculations we assume fixed cost for all cases of categories C1 and another lower fixed cost for all cases of categories D and B which require only office work.
- The percentage of PWCs models of category C which are certified by a Notified Body (although is not mandatory by the Directive according to Article 20.2) is assumed as 5%. The estimation of PWCs models that will be re-designed is also 5 %.
- The percentage of watercrafts models of category C that are to be modified in order to comply with the more strict requirements of category C1 due to higher H_s, is assumed as 10%. Another assumption is that the manufacturing cost will be the result caused only by increased hull and stiffeners' thicknesses and that the specified engine and the new freeboard are sufficient for the increased weight in order to be assigned to category C1 (from H_s=2 to H_s=2,5 m). For a case study of a GRP motorboat with hull length of 7,2 m and a beam hull of 2,6 m (taken as representing the average size of the category), the increased thickness is approximately 3,5 mm and the additional weight about 250 kg, depending on the lamination scheme and the glass to resin ratio. All PWCs are excluded from this manufacturing cost since there are no technical data available for thickness calculations and it is claimed by some manufacturers that they already meet the requirements for the 0,5 m increase of the significant wave height.

5.3.5 Scenario 4 – Harmonisation upper limits with ISO Standard

Scenario 4, which is the existing categories remain with transposition of EN ISO 12217-1 category A upper limits, is presented in Table 5-12.

Table 5-12 Scenario 4

	Scenario 4: Existing categories with category A upper limits defined	
Design Category	Beaufort Force	H_s (m)
A	**≤9**	**≤7**
B	≤8	≤4
C	≤6	≤ 2
D	≤4	≤0,3 0,5 max

Scenario 4 implies the existing categories D, C and B to remain unchanged and category A to be modified in order to transpose harmonised Standard EN ISO 12217-1: 2017 upper limit values, that is, the watercraft to be designed for a wind force up to, and including, 9 and significant wave height up to, and including, 7 m. Concerning the Beaufort force, the existing RCD explanatory note already states that storm, which is BF 10, is excluded, implying BF 9 as the upper limit of the category. Concerning wave height, although the existing RCD explanatory note states that extreme sea conditions or rogue waves are excluded, it didn't define an upper limit for the designer, so the transposition of the value 7 m is an improvement (see also analysis in first comment of 5.2.2). Additionally, explanatory notes of the RCD Annex I table are to be enriched with technical information concerning maximum average wind speeds, gust speeds and possible maximum wave height.

5.4 Cost estimate of proposed changes

Breakdown of costs for implementation of scenarios 1-4 (where applicable):

- Cost for revision of harmonised Standards related with RCD and especially EN ISO 12217-1,2,3 and EN ISO 12215-5 for stability/buoyancy and scantlings calculations respectively. Additionally, other 19 Standards have to be revised because they reference ISO 12217 design categories. These Standards are: ISO 12216:2020 (Windows, portlights, hatches, deadlights and doors), ISO 10240:2019 (Owner's manual), ISO 15083:2020 (Bilge pumping systems), ISO 6185 parts 3:2014, 4:2011 (Inflatable boats), ISO 12215 parts 6, 7, 9, 10 (Hull construction and scantlings), ISO 11812:2020 (watertight or quick-draining recesses and cockpits), ISO 8848:2020 (remote mechanical steering systems), ISO 14946:2021 (Maximum load capacity), ISO 14945:2021 (Builders plate), ISO 14895:2016 (liquid fuelled galley stoves & heating appliances), ISO 15085:2017 (Man overboard prevention and recovery), ISO 10239:2014 (LPG Systems), ISO 15084:2003 (Anchoring, mooring and towing), ISO 13590:2003 (PWC) and ISO 8666:2020 (Principal data). A rough estimation for this cost for all 23 Standards is 1,08 million € for a period of three years. This value is based on an estimation for an annual cost for the secretariat of ISO/TC 188 of 15000 € per standard plus minimum cost of 15000 € per year for the meeting rooms of the working groups.
- Re-design cost for reviewing and updating technical file in case of design categories' revisions in order to evaluate the possibilities of assignment the upper category when there are more strict requirements, which is the increased significant wave height in scenarios 1 and 3. It includes repetition of stability and scantlings calculations, revision of owner's manual and review of any other document included in the initial technical that is affected by the revised design categories. Rough estimation of this cost is 3000 € per watercraft model. This cost estimation is made under the assumption that the current technical files contain all the necessary technical data in order to perform the re-calculations.
- Re-certification cost (upon external assessment by a Notified Body) in case of design categories' revisions (except category A which has no change in calculations in all scenarios). Since the range of this cost is estimated between 2000 – 6000 € depending on the crafts' length, the mean value which is taken is 4000 € per watercraft model in cases of re-assessment of the boat (scenario 1 for D1 and scenario 3 for C1) and 500 € in cases of just office work with no need of boat re-assessment (scenario 2 for C1 and scenario 4 for D and B categories). In the second case a range was used between 300 – 700 € and the mean value of 500 €.
- Communication cost in order manufacturers and consumers to be familiar with the modifications. The number of European leisure boats manufacturers according to Eurostat (EC, 2018) is 4066 whereas the number of manufacturers outside European

Economic Area (EEA) that export their watercrafts in Europe is 780 as found in RSG database of August 2020. That makes a total of 4846 manufacturers. A rough cost estimation is made about 10000 € per manufacturer for a period of two years for training, booklets and brochures. Cost for participation in Boat Shows is considered non incremental and is excluded from the aforementioned estimation. Thus, the total communication fixed cost for all the manufacturers for two years period is calculated 48,46 million €.

- Manufacturing cost for the manufacturers who will choose to bear the cost of modifying their watercrafts due to increased hull and stiffeners thickness, under the assumption that there will be no other manufacturing cost. This assumption implies that specified engine and the new freeboard are sufficient for the increased weight and there will be no other change in craft configuration or in moulds. In case of complying with category D1 in scenario 1, the material and labour cost for the additional 70 kg weight is estimated at 1000 € per craft. In case of complying with category C1 in scenario 3, the material and labour cost for the additional 250 kg weight is estimated at 3200 € per craft. To be noted for the category C1 of the scenario 3, as stated before, that all PWCs are excluded from the manufacturing cost since there are no technical data available for thickness calculations and it is claimed by some manufacturers that they already meet the requirements for the 0,5 m increase of the significant wave height.

Additional assumptions for the cost calculations:

- A very rough estimation of the number of different models of recreational crafts is the following: From the RSG 2020 data we have 10500 records. We assume that we have 10500 different models certified from 13 Notified Bodies' inputs, as if they were all B module (EU type approval certificates). By proportional calculation, we have 2,5 times more models from 32 Notified Bodies, which gives us 26250 models for the total 5644988 (5,6 million) watercrafts (all data of year 2020). Therefore the rough estimation of various different models is 26250. Maybe there is no proportionality from the input from the rest of NBs but the factor 2,5 will cover also the number of models that are not assessed by a NB (assessment module A). This rough estimation of the total number of models is necessary for the cost benefit analysis since there are no other available data. We must not forget that the production of recreational craft is very diverse and ranges from model series to one-off boats and also the definition of model is not always easy to decide. As an example, there are cases with sailboats that for the same hull have different and multiple combinations of configurations (different masts or keels or accommodations) and it is not clear if they are different models or different versions of the same model.
- All PWCs are considered to be given category C with an estimation of 40 different models.

Below in Table 5-13 is a comparative overview for cost breakdown analysis per scenario.

Table 5-13 Cost overview per scenario

Costs	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*
Revision of 23 Standards	Yes (fixed cost)	Yes (fixed cost)	Yes (fixed cost)	No
Re-design	Yes for D1 (5% estimation)	No because they are all fit for C1	Yes for C1 (10% estimation)	No
Re-certification	Yes for 5% of D	Yes for 10% of C	Yes for 10% of C, 5% of D and PWCs and 100% for B	No
Communication	Yes (fixed cost)	Yes (fixed cost)	Yes (fixed cost)	No
Manufacturing	Yes (variable cost, 5% estimation of cat. D)	No	Yes (variable cost, 10% estimation of cat. C)	No
PWCs (All cat. C)	No	No	Yes, 5% for update of technical file and 5% for re-certification	No

5.4.1 Scenario 1 – Subdivision category D

The costs for implementation of the scenario 1 are the following:

- Cost for revision of 23 Standards: 360000 € per year for three years
- Re-design cost for the 5% of models of category D that will be charged with 4000 €/model to explore the possibilities to be upgraded to category D1.
- Re-certification cost for the 5% of models of category D
- Communication cost of 24,23 million € per year for two years for the manufacturers in order to disseminate the change of ranges in categories D2 and D1.
- Manufacturing cost of 1000 € per craft for the crafts of the 5% of the models which are assumed to be modified to be assigned to category D1.

5.4.2 Scenario 2 – Subdivision category C

The costs for implementation of the scenario 2 are:

- Cost for revision of 23 Standards: 360000 € per year for three years
- Re-certification cost for the 10% of models of category C.
- Communication cost of 24,23 million € per year for two years for the manufacturers in order to disseminate the change of ranges in in categories C2 and C1.

5.4.3 Scenario 3 – Subdivision category C and revised ranges

The costs for implementation of the scenario 3 are the following:

- Cost for revision of 23 Standards: 360000 € per year for three years
- Re-design cost for the 10% of models of category C.
- Re-design cost for the 5% of the PWCs to review or perform the calculations to comply with the requirements of increased wave height.
- Re-certification cost for the 10% of models of category C, for the 5% of models of category D and PWCs and for 100% of category B.
- Communication cost of 24,23 million € per year for two years for the manufacturers in order to disseminate the change of ranges in categories D, C and B.
- Manufacturing cost of 3200 € per craft for the crafts of the 10% of the models of category C which are modified to be assigned to category C1. No manufacturing cost for PWCs.

5.4.4 Scenario 4 – Harmonisation upper limits with ISO Standard

There are no costs for the implementation of scenario 4.

6 Economic impact of scenarios

In this chapter, the economic impact of the scenarios formulated earlier is assessed. First, the methodology applied for economic modelling as well as the input assumptions are presented. In the analysis, costs and benefits at different points in time are considered. To be able to compare these costs and benefits at different points in time, discounting is applied. A time horizon is established that allows to fully incorporate the benefits that are realized. The impact of the scenarios is calculated for each of the different components (exhaust emissions, evaporative emissions, design categories) and the results are presented in an overview table.

6.1 Methodology and input assumptions

The methodology used for estimating the economic impact is in line with the recommended methodology in the Guide to Cost-Benefit Analysis of Investment Projects (economic appraisal tool for cohesion policy 2014-2010), as published by the European Commission (EC, 2014) - from now on also referred to as "Guide to Cost-Benefit Analysis". This chapter shows the results of the Cost-Benefit Analysis.

The following steps are taken:

- Definition of the modelling timeline, economic performance indicators and economic input parameters (e.g. discount factors, Net Present Value (NPV) year, escalation rates, price levels) - sub section 6.1.1.
- Identification of a range of possible impacts (qualitative analysis) of the scenarios proposed per scenario and target stakeholder group and a selection of significant impacts identified to be detailed - sub section 6.1.2.
- Specification and quantification (monetization) of the of selected significant impacts per scenario in real prices, definition of discounted cash flows and calculating economic performance indicators per scenario - sub section 6.1.3.
- Comparison of the scenarios based on the most relevant economic performance indicators - sub section 6.1.4.

6.1.1 Definition timeline and economic input assumptions

This sub section presents (a) the timeline and NPV year assumed, followed by (b) the economic performance indicators used in this study for the purpose of comparing the scenarios, (c) the discount factors assumed and (d) price levels and escalation rates assumed.

Timeline and NPV year

First, a timeline is set for determining the impact of the actions proposed per scenario. The Guide to Cost-Benefit Analysis recommends difference reference periods for economic analysis, depending on the type of "project". For example, a reference period of 15-25 years for research and innovation, 15-25 years for energy projects, 25-30 years for infrastructure projects and 10-15 years for other type of projects.

For this study, a reference period of approximately 20 years is assumed (reference period up to 2040). The impact assessment will explore the impact of the action proposed per scenario (change in legislation, e.g., changing emission limits) for this specific period. The impact assessment will also include the economic impact of the action in 2020-2040 in the remaining life-years (so after the reference period), which in this case mainly are environmental benefits (resulting from investments in engines during the reference period). This approach is line with the Guide to Cost-Benefit Analysis, which states to include the economic impact in the remaining life-years as "residual value" in the analysis. These benefits or costs will (like the other benefits and costs obtained during the reference period) be discounted to the NPV year assumed.
In this analysis, benefits will be experienced until a recreational craft lifetime after the production of the last craft in 2040. Since a lifetime of 40 years is assumed, a time horizon up to 2080 is considered for including the residual value (40 years after the year 2040).

As NPV year, the year 2022 is assumed, in line with a possible year for decision making on implementation of the scenarios proposed.

Economic Performance Indicators

The Guide to Cost-Benefit Analysis recommends calculating the following economic performance indicators, which are determined per scenario, defined in comparison to the base case of no action:

- *ENPV (Economic Net Present Value)*, the difference between the discounted total social benefits and costs. A high (and positive) value of the ENPV indicates a positive sign of a project or investment.
- *Economic Rate of Return (ERR)*, the rate that produces a zero value for the ENPV. A high (and positive) value of the ERR indicates a positive sign of a project or investment.
- *Net Benefit/Cost ratio (B/C ratio)*, i.e. the ratio between the net discounted economic benefits (discounted benefits minus discounted costs) and the discounted costs. A high (and positive) value of the B/C ratio indicates a positive sign of a project or investment.

The Guide to Cost-Benefit Analysis states the ENPV is the most reliable Cost-Benefit Analysis indicator and should be used as the main reference economic performance signal. Furthermore, the ERR and B/C are considered meaningful because they are independent of the project size.

To obtain additional insight in the impact of each of the proposed scenarios, also the following performance indicators are determined:

- *ENPV benefits total* and ENPV benefits per component, specifically for (1) emission reduction and (2) fuel consumption reduction in the case of the exhaust and evaporative emission scenarios. The ENPV benefits is either positive (unless there are also negative benefits) or zero. A high, positive value of the ENPV benefits indicates a positive sign of a project or investment.
- *ENPV costs* for the various cost components. The ENPV costs is either negative (due to the costs) or zero. A high, negative value of the ENPV costs indicates a negative sign of a project or investment.
- *Payback period*, to obtain insight in how many years (after the NPV year of 2022) it will take before the cumulative discounted benefits through the years are larger than the cumulative discounted costs through the years. This value is either positive (presenting the number of years before there is a return on investment) or non-existent (if there is no payback period, the project will, at the end of the project period, not return the investment made). The absence of a payback period is a negative sign of a project or investment. A short payback period indicates a positive sign of a project or investment.

Discount factors

As discount factor, a (real) social discount value of 5% is used, as recommended in the Guide to Cost-Benefit Analysis.

Price levels and escalation rates

In this study, the costs are estimated (1) excluding VAT and (2) excluding subsidies, direct and indirect taxes, in line with the recommendations for economic analysis in the Guide to Cost-Benefit Analysis (page 55).

Regarding price levels, all costs used in this study are real prices with price level 2021 (so not corrected for inflation in the years after), in line with the recommendation for economic analysis in the Guide to Cost-Benefit Analysis to use real prices.

The Consumer Price Index development of the past few years (1,5% per year) is used to correct for inflation in cost assumptions with price levels before 2021 (European Central Bank, 2021).

6.1.2 Qualitative impact analysis

For the scenarios of exhaust emissions, evaporative emissions and design categories, which include technical feasible solutions, a range of possible impacts are explored per stakeholder or "target group". The following target groups are considered:

- *Industry*: all actors in the industry, including the manufacturers, suppliers, users and related associations.
- *Society*: the target group experiencing the environmental burden or benefits of emission reduction.
- *Government*: The European Commission and national governments of the EU member states.

Based on the expected order of magnitude of the impact, the likelihood and the availability of sufficient data for quantification, impacts are selected for the quantitative assessment.

6.1.3 Quantitative impact analysis

Details on the cost estimates for the various scenarios are presented in Chapters 3, 4 and 5.

To estimate the economic performance indicators as presented in sub section 6.1.2 for the timeline presented in section 6.1.1, cash flows have to be defined, using real costs (excluding VAT, taxes and indirect subsidies). Although the costs are already estimated in monetized values (real prices) as presented in the previous chapters for 2021, the benefits of emission reduction- and reduction of fuel consumption are not. The following subsection presents how these benefits are monetized.

Monetization emission reduction benefits

To monetize the impacts per pollutant and Greenhouse Gas (NO_x, PM, HC (NMVOC), CO_2), shadow prices are assumed as presented in the Handbook on the external costs of transport (EC, 2019). The shadow prices for CO are based on the Environmental Prices Handbook EU28 version of 2018 (CE Delft, 2018), since shadow prices for CO are not included in the Handbook on external costs of transport (2019). Noted is the shadow prices used are from the most recent publications available, however, before the presentation of the Green Deal in 2021. Bringing investments to reduce emissions forward could lead to higher investments on the short term and therefore to higher environmental prices (shadow prices) on the short term. This could in turn lead to an increase of the environmental benefits of the scenarios proposed within the reference period considered in this study. As a consequence, the economic performance of the scenarios proposed could become more positive.

The shadow prices of environmental air emissions used are presented in the Table 6-1.

Table 6-1 Environmental prices

Substance	*Time period*	*Price level*	*Unit*	*Value*
NO_x	All	2016	€/kg	17
PM	All	2016	€/kg	22,30
NMVOC	All	2016	€/kg	1,2
CO	All	2015	€/kg	0,05
CO_2	Up to 2030	2016	€/ton	100
CO_2	2040-2060	2016	€/ton	269

For the assumptions of CO_2 costs in €/ton between 2030 and 2040, interpolation between the values presented is applied (between the environmental price up to 2030, 100 €/ton and the price after 2040, 269 €/ton). For the benefits after 2060, the same value (269 €/ton) for the period of 2040-2060 is assumed.

The 2016 prices are escalated to account for inflation based on the Consumer Price Index development to the year 2021 (see sub section 6.1.1), the base year for the real prices assumed in this study.

For evaporative emissions, the shadow price of HC (NMVOC) is used since evaporative emissions are hydrocarbons.

For the scenarios of design categories there is no reduction of emissions, therefore no shadow prices are used.

Monetization reduction fuel consumption benefits

The benefits of the reduction of fuel use is based on the fuel price excluding VAT and excluding taxes (excise). In the case of fuel prices in the EU, the costs for VAT and excise are relatively large compared to the product price - product prices were in the order of 20-30% in 2020. For diesel, a product price (excluding VAT and taxes) of 0,6 €/litre is assumed and for petrol 0,5 €/litre (FuelsEurope, 2021).

6.1.4 Comparison of scenarios

The various options of exhaust emissions, evaporative emissions and design categories will be compared with a base case.

In this report, an initial result on the "ranking" of the scenarios' and base case option will be discussed for (1) exhaust emissions, (2) evaporative emissions and (3) design categories.

6.2 Impact exhaust emission scenarios

This section presents a range of possible impacts for the exhaust emission scenarios (section 6.2.1), followed by a scenario-specific quantitative impact analysis in which the economic performance indicators are estimated per scenario (section 6.2.2 – 6.2.4) and a comparison of the exhaust emission scenarios (section 6.2.5).

6.2.1 Range of possible impacts

Table 6-2 shows a range of types of impacts per scenario and target group in case of realization of one of the exhaust emission scenarios.

Table 6-2 Range of types of impacts exhaust emission scenarios

Scenario	*Target group*	*Impact description*
1, 2, 3	Society	Additional jobs for research in development, certification and manufacturing
1, 2, 3	Society	A reduction of NO_x and HC emissions of diesel- and petrol engines, a reduction of PM emissions by diesel engines and a reduction of CO emissions by petrol engines
1, 2, 3	Society	A general decrease of CO_2 emissions due to changed fuel consumption
1, 2	Society	An general increase of CO_2 emissions of diesel engines specifically
3	Society	A decrease of CO_2 emissions by larger motor boats with diesel engines
1, 2, 3	Industry	A general decrease of fuel consumption and a decrease of petrol consumption specifically
1, 2	Industry	An increase of fuel consumption by some craft types with diesel engines
3	Industry	A decrease of fuel consumption by some craft types with diesel engines
2, 3	Industry	Effect on durability and maintenance (reference to chapter 3)
2, 3	Industry	Limited effect on volume and weight (reference to chapter 3)
1, 2, 3	Industry	Certification needed for the introduction of new technologies
1, 2, 3	Industry	Investment required for Research and Development. In scenario 2 and 3 possibly too much for non-OEM companies with small sales numbers.
1, 2, 3	Industry	Investment for manufacturing of new technology In scenario 2 and 3 possibly too much for non-OEM companies with small sales numbers.

Scenario	*Target group*	*Impact description*
1, 2, 3	Industry	A minor decrease of the demand for recreational crafts due to price increase
1, 2, 3	Industry & Government	A decrease of fuel consumption in all scenarios, leading to less income for the government via taxes and VAT
2, 3	Industry & Government	A need for a wide availability of ultra-low sulphur diesel.
1, 2, 3	Government & Industry	Communication/dissemination cost in order for manufacturers and consumers to be familiar with the modifications
1	Government	Harmonisation (partially) with the US legislation
1, 2, 3	Government	Change of legislation required
1, 2, 3	Government	Change in market surveillance

Following the exploration of possible types of impacts, the following cost- and benefit components are considered the most relevant (regarding their likelihood and impact) and are therefore selected to further detail and to quantify in the quantitative impact assessment.

Costs:
- Research and development costs of technology to be applied
- Certification of new technology
- Manufacturing costs of hardware devices

Benefits:
- Reduction of fuel consumption
- Reduction of Greenhouse Gas emissions (CO_2)
- Reduction of pollutants: NO_x, PM, CO and HC (NMVOC)

Noted all costs and benefit mentioned are additional (incremental) to the base case scenario of no action.

6.2.2 Scenario 1 – Harmonisation and best practices

In this sub section the following is presented, related to scenario 1 of exhaust emissions: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to the "do nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- A (partial) harmonisation of the emission legislation with the related US legislation. Stricter emission limits are proposed for engines to be produced when the RCD would be updated, which can be realized by the application of current "best-in-class" engines by manufacturers (no new "innovative" measures required).
- Stricter limitations for OB and PWC SI-engines: a 30% reduction of NO_x+HC for engines with P < 75 kW, a 31-33% reduction of CO, no limit for PM.
- Stricter limitations for IB SI engines: a 50% reduction of NO_x+HC only.
- Stricter limitations for IB CI engines, in harmonisation with the EPA Tier 3 emission targets for engines with P < 37 kW regarding HC+NO_x and PM.
- Introducing of NTE-limits in dedicated NTE-areas as in the EPA-legislation.

Cost overview

An overview of the main (real, non-discounted) costs (and benefits) is presented in Figure 6-1, which are:

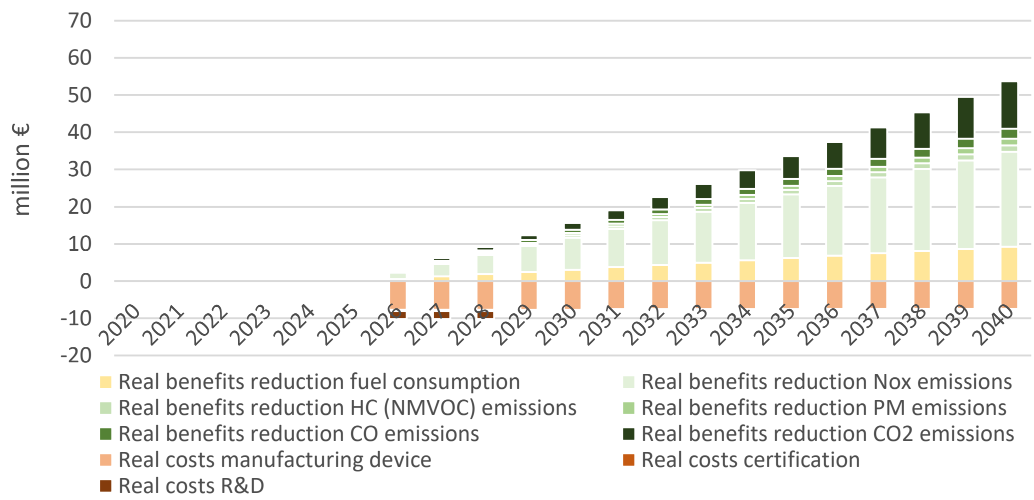
- R&D costs, allocated to all crafts to be produced in the first 3 years after an update of the RCD, specifically assumed from 2026-2028 (~€5 to ~€95 per craft, depending on the craft type and measures to be implemented, total costs of €6,5 million).
- Certification costs, allocated to all crafts to be produced in the first 3 years after an update of the RCD, specifically assumed from 2026-2028 (~€0,5 to ~€19 per craft,

depending on the craft type and measures to be implemented, total costs of €1,1 million).

- Costs for manufacturing of a hardware device: €442 per craft, allocated to all crafts with smaller diesel engines produced after the updated RCD is implemented until the end of the reference period in 2040 (total costs ~€113 million).

An elaboration on the cost definitions of the main components relevant to this scenario is referred to Chapter 3.

Figure 6-1 Cost and benefit overview (yearly) scenario 1 "Harmonisation and best practices"



Benefits overview

Main (real, non-discounted) benefits accounted for in the reference period and beyond (up to 2080, until all crafts produced in 2040 are dismantled) are:

- A CO_2 emission reduction with an economic benefit of ~€480 million.
- A NO_x emission reduction with an economic benefit of ~€1,0 billion.
- A HC (NMVOC) emission reduction with an economic benefit of ~€71 million.
- A PM emission reduction with an economic benefit of ~€71 million.
- A CO emission reduction with an economic benefit of ~€108 million.
- A fuel consumption reduction with an economic benefit of ~€373 million.

Economic performance

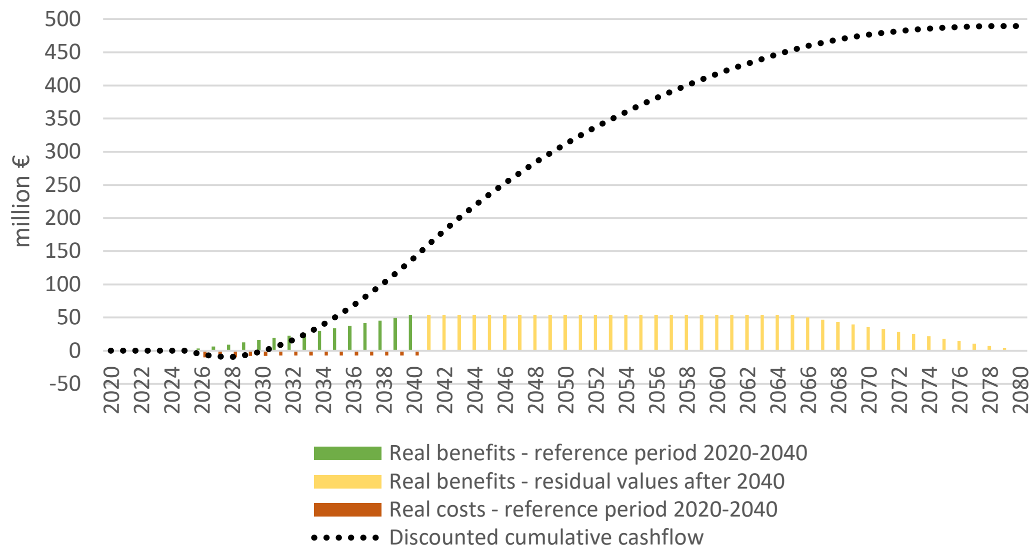
An overview of the costs- and benefits, as well as the discounted cumulative cash flow, is presented in Figure 6-2.

The ENPV is **€**490 million, accounting for the costs and benefits in the reference period (2020-2040), as well as the "residual values", the benefits of emission- and fuel consumption reduction after 2040 up to 2080.
The ENPV of emission reduction benefits is €463 million, the ENPV of fuel consumption reduction is €100 million and the ENPV of the costs is €-74 million.

The ENPV of the residual value (benefits after 2040) is much higher than the ENPV of the reference period only, with values of €350 and €139 million respectively. The benefits are mainly experienced after the production of the last craft in 2040, when most crafts produced from 2026 on are operational.

The ERR is 51%, much higher than the discount factor of 5%. The payback period is 9 years (2031), this is the year in which the line of the discounted cumulative cash flow in Figure 6-2 crosses the zero line. The B / C ratio is 6,7.

Figure 6-2 Cash flow projection scenario 1 "Harmonisation and best practices"



Recommendation for action

This scenario shows clear positive results from the economic performance indicators and therefore, it is preferred above the "base case" scenario. However, a comparison between the various exhaust emission scenarios is required to obtain insight in which scenario is preferred, depending on the economic performance of the various scenarios: this is elaborated on in the comparison presented in section 6.2.5.

6.2.3 *Scenario 2 – Best available technology version 1*

In this sub section the following is presented, related to scenario 2 of exhaust emissions: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to the "do nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- The application of best available technology. Stricter emission limits are proposed for engines to be produced when the RCD would be updated, which can be realized by the application of (new) technology by manufacturers.
- Stricter limitations for OB SI-engines: for engines with P < 75 kW, the limitations proposed are the same as for scenario 1. For engines with P > 75 kW, emission limits are set in line with the current emission limits for IB engines, requiring 3-way catalytic after treatment technology to be applied by manufacturers. This results in a NO_x+HC emission reduction of 70%.
- For PWC SI engines: same limit reduction as for OB SI engines.
- For IB (including sterndrive) SI engines no emissions reduction is suggested (continued existing alignment with US legislation).
- Stricter limitations for IB CI engines, in harmonisation with the current IWP and NRMM legislation for engines above 75 kW; resulting in a 40% NO_x+HC lower limit value for these engines. No changes to CO and PM limits. For smaller engines: as in scenario 1.
- This scenario assumes the implementation of EGR-technology in order to achieve further NO_x-reduction; for this reason this scenario also assumes the availability of ultra-low Sulphur diesel.
- Introducing of NTE-limits in dedicated NTE-areas as in the EPA-legislation.

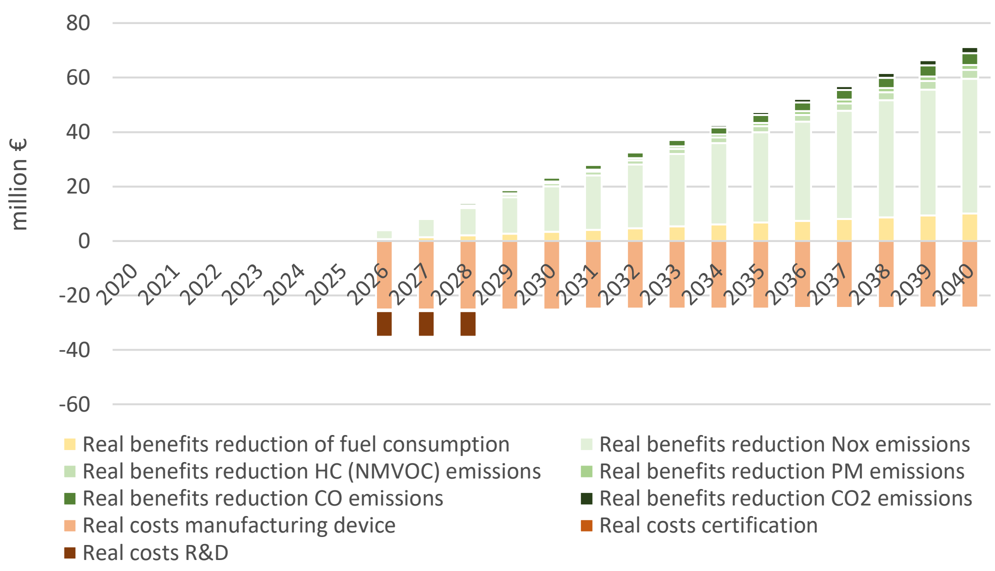
Cost overview

An overview of the main (real, non-discounted) costs (and benefits) is presented in Figure 6-3, which are:

- R&D costs, allocated to all crafts to be produced in the first 3 years after an update of the RCD, specifically assumed from 2026-2028 (~€5 to ~€430 per craft, depending on the craft type and measures to be implemented, total costs of ~€28 million).
- Certification costs, allocated to all crafts to be produced in the first 3 years after an update of the RCD, specifically assumed from 2026-2028 (~€0,5 to ~€19 per craft, depending on the craft type and measures to be implemented, total costs of €1,8 million). Although the minimum and maximum certification cost per craft types are the same as in scenario 1, the total costs of scenario 2 are larger since there are additional certification costs, specifically for larger motor boats (crafts which is not invested in in scenario 1).
- Costs for manufacturing of hardware devices: varying up to ~€1300 per craft, allocated to all crafts with diesel engines and some of the crafts with petrol engines, after the updated RCD is implemented and until the end of the reference period in 2040 (total costs ~€373 million).

For an elaboration on the cost definitions of the main components relevant to this scenario is referred to Chapter 3.

Figure 6-3 Cost and benefit overview (yearly) scenario 2 "Best available technology version 1"



Benefits overview

Main (real, non-discounted) benefits accounted for in the reference period and beyond (up to 2080, until all crafts produced in 2040 are dismantled) are:

- A CO_2 emission reduction with an economic benefit of ~€84 million.
- A NO_x emission reduction with an economic benefit of ~€2 billion.
- A HC (NMVOC) emission reduction with an economic benefit of ~€135 million.
- A PM emission reduction with an economic benefit of ~€71 million.
- A CO emission reduction with an economic benefit of ~€175 million.
- A fuel consumption reduction with an economic benefit of ~€402 million.

Economic performance

An overview of the costs- and benefits, as well as the discounted cumulative cash flow, is presented in Figure 6-4.

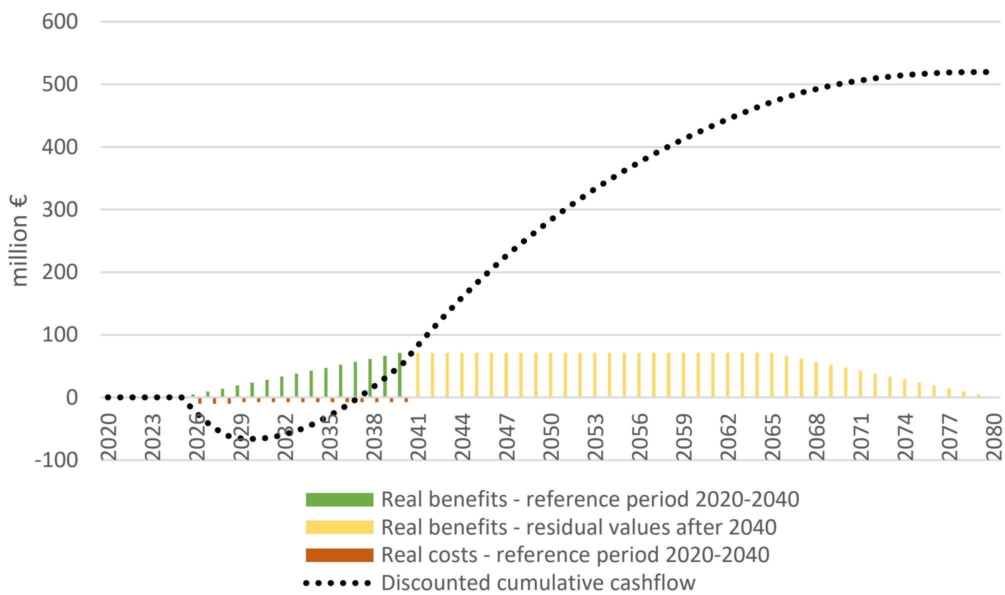
The ENPV is **€**520 million, accounting for the costs and benefits in the reference period (2020-2040), as well as the "residual values", the benefits of emission- and fuel consumption reduction after 2040 up to 2080.

The ENPV of emission reduction benefits is €658 million, the ENPV of fuel consumption reduction is €108 million and the ENPV of the costs is €-247 million.

It should be noted that the ENPV of the residual value (benefits after 2040) is much higher than the ENPV of the reference period only, with values of €465 and €55 million respectively. The benefits are mainly experienced after the production of the last craft in 2040, when most crafts produced from 2026 on are operational.

The ERR is 19%, much higher than the discount factor of 5%. The payback period is 16 years (2038), this is the year in which the line of the discounted cumulative cash flow in Figure 6-4 crosses the zero line. The B / C ratio is 2,1.

Figure 6-4 Cash flow projection scenario 2 "Best available technology version 1"



Recommendation for action

Similar to scenario 1, this scenario shows clear positive results from the economic performance indicators and therefore, it is preferred above the "base case" scenario. However, a comparison between the various exhaust emission scenarios is required to obtain insight in which scenario is preferred, depending on the economic performance of the various scenarios: this is elaborated on in the comparison presented in section 6.2.5.

6.2.4 *Scenario 3 – Best available technology version 2*

In this sub section the following is presented, related to scenario 3 of exhaust emissions: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to the "do nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- The application of best available technology. Stricter emission limits are proposed for engines to be produced when the RCD would be updated, which can be realized by the application of (new) technology by manufacturers.
- Stricter limitations for OB SI-engines: for engines with P < 75 kW, the limitations proposed are the same as for scenario 1. For engines with P > 75 kW, emission limits are set in line with the current emission limits for IB engines, requiring 3-way catalytic after treatment technology to be applied by manufacturers. This results in a NO_x+HC emission reduction of 70%.
- For PWC engines: same lowering of limits as for OB engines.

- For IB (including sterndrive) SI engines no emissions reduction is suggested (continued existing alignment with US legislation): stricter limitations for IB CI engines, similar to scenario 2 (in harmonisation with the current IWP and NRMM legislation for engines above 75 kW), resulting in a 64% NO_x+HC lower limit value for these engines. No changes to CO or PM limits values. For smaller engines: as in scenario 1.
- This scenario assumes the implementation of SCR-technology in order to achieve further NO_x-reduction; for this reason this scenario also assumes the availability of ultra-low sulphur diesel.
- Introducing of NTE-limits in dedicated NTE-areas as in the EPA-legislation.

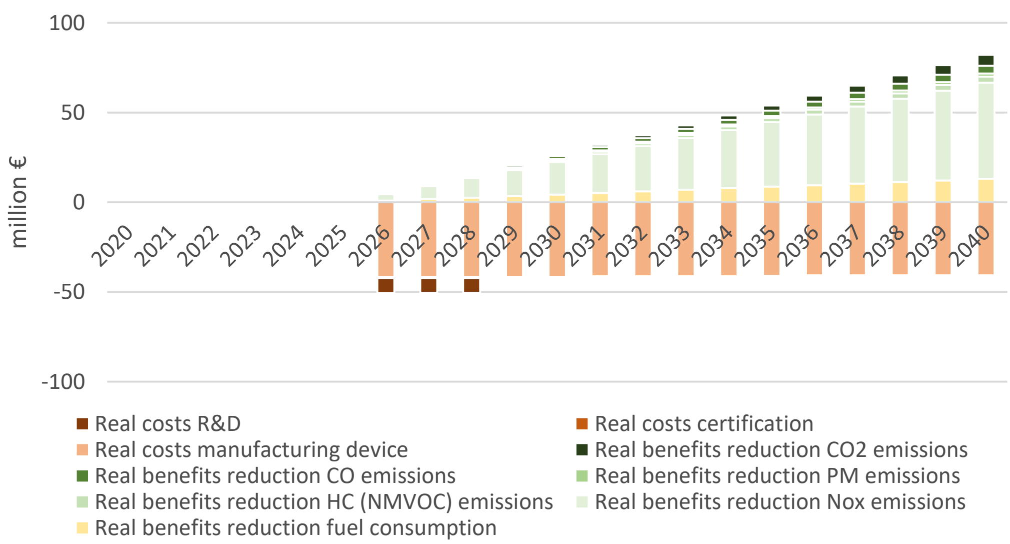
Cost overview

An overview of the main (real, non-discounted) costs (and benefits) is presented in Figure 6-5, which are:

- R&D costs, allocated to all crafts to be produced in the first 3 years after an update of the RCD, specifically assumed from 2026-2028 (~€5 to ~€430 per craft, depending on the craft type and measures to be implemented, total costs of ~€24,9 million).
- Certification costs, allocated to all crafts to be produced in the first 3 years after an update of the RCD, specifically assumed from 2026-2028 (~€0,5 to ~€19 per craft, depending on the craft type and measures to be implemented, total costs of €1,8 million).
- Costs for manufacturing of hardware devices: varying up to ~€3500 per craft, allocated to all crafts with diesel engines and some of the crafts with petrol engines, after the updated RCD is implemented and until the end of the reference period in 2040 (total costs ~€617 million).

For an elaboration on the cost definitions of the main components relevant to this scenario is referred to Chapter 3.

Figure 6-5 Cost and benefit overview (yearly) scenario 3 "Best available technology version 2"



Benefits overview

Main (real, non-discounted) benefits accounted for in the reference period and beyond (up to 2080, until all crafts produced in 2040 are dismantled) are:

- A CO_2 emission reduction with an economic benefit of ~€230 million.
- A NO_x emission reduction with an economic benefit of ~€2,1 billion.
- A HC (NMVOC) emission reduction with an economic benefit of ~€138 million.
- A PM emission reduction with an economic benefit of ~€71 million.
- A CO emission reduction with an economic benefit of ~€175 million.
- A fuel consumption reduction with an economic benefit of ~€521 million.

Economic performance

An overview of the costs- and benefits, as well as the discounted cumulative cash flow, is presented in Figure 6-6.

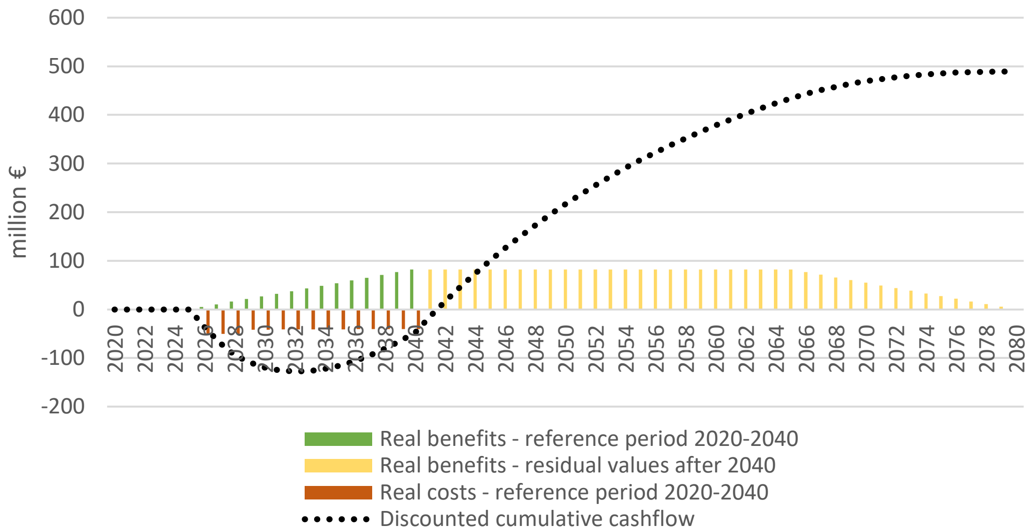
The ENPV is **€**489 million, accounting for the costs and benefits in the reference period (2020-2040), as well as the "residual values", the benefits of emission- and fuel consumption reduction after 2040 up to 2080.

The ENPV of emission reduction benefits is €739 million, the ENPV of fuel consumption reduction is €140 million and the ENPV of the costs is €-391 million.

It should be noted that the ENPV of the residual value (benefits after 2040) is positive with €537 million, but the ENPV of the reference period only is negative with a value of €-48 million. In other words, the benefits are mainly experienced after the production of the last craft in 2040, when most crafts produced from 2026 on are operational.

The ERR is 14%, higher than the discount factor of 5%. The payback period is 20 years (2042), this is the year in which the line of the discounted cumulative cash flow in Figure 6-6 crosses the zero line. The B / C ratio is 1,3.

Figure 6-6 Cash flow projection scenario 3 "Best available technology version 2"



Recommendation for action

Similar to scenarios 1 and 2, this scenario shows a positive result from the economic performance indicators and therefore, it is preferred above the "base case" scenario. However, a comparison between the various exhaust emission scenarios is required to obtain insight in which scenario is preferred, depending on the economic performance of the various scenarios: this is elaborated on in the comparison presented in section 6.2.5.

6.2.5 Comparison of exhaust emission scenarios

Also noted is the requirement for the availability of low-sulphur diesel in scenario 2 and 3, as well as the need to have second fluid (Adblue-like) available at all refuelling points) in scenario 3. A similar requirement is not needed with scenario 1. Furthermore both application of EGR (scenario 2) and SCR (scenario 3) may – in some cases – be difficult because of engine room volume constraints (a point that is repeatedly brought forward in discussions with engine and boat manufacturers) which in turn could result in additional costs with those boat manufacturers. Finally, maintenance costs increase (not part of the cost calculation because of lack of data) will most likely be somewhat higher with scenario 2 and 3.
Table 6-3 shows an overview of the most relevant economic performance indicators for the comparison of the scenarios, which are according to the Guide to Cost-Benefit Analysis the ENPV total, the ERR and the B/C. The table also shows the ENPV of industry

investments (costs for industry, excluding the benefit of reduction of fuel consumption costs) and the ENPV of environmental benefits (pollutants and CO_2).

Concluding the results and considering the "ENPV total" as most important indicator, all three scenarios are considered a better option than the base case scenario of "no action".

Scenario 2 (Harmonisation and best practices) scores best on the ENPV total, however, it is noted that in reality scenario 2 and 3 are expected to score slightly less good than presented by the ENPV values: costs for smaller manufacturers could be larger than estimated due to a lack of experience compared to larger manufacturers. The impact of this is smaller in scenario 1, since relatively less innovation is required for the technologies applied. In other words, if the ENPV values of scenarios 2 and 3 are relatively smaller, the ENPV values of scenario 1, 2 and 3 are in the same order.

Looking at the economic indicators ERR, B/C and ENPV of industry investments, scenario 1 scores best. On the other hand, scenario 1 has the least environmental benefits (€463 million compared to respectively €658 and €739 million in scenarios 2 and 3).

Depending on the (environmental) priorities of the Commission, the willingness to allocate cost to or invest by stakeholders and the desire for return on investment on a short term, a scenario preference could be defined: if environmental benefits (reduction of pollutants) are considered most important, scenario 3 is most interesting. If looking at the least costs for the industry, scenario 1 is most interesting. Scenario 1 is as most cost-beneficial scenario also scoring best regarding the payback period (9 years only). Scenario 2 can be considered as "in-between" solution (relatively high environmental benefits compared to scenario 1, but lower cost than scenario 3).

Also noted is the requirement for the availability of low-sulphur diesel in scenario 2 and 3, as well as the need to have second fluid (Adblue-like) available at all refuelling points) in scenario 3. A similar requirement is not needed with scenario 1. Furthermore both application of EGR (scenario 2) and SCR (scenario 3) may – in some cases – be difficult because of engine room volume constraints (a point that is repeatedly brought forward in discussions with engine and boat manufacturers[51]) which in turn could result in additional costs with those boat manufacturers. Finally, maintenance costs increase (not part of the cost calculation because of lack of data) will most likely be somewhat higher with scenario 2 and 3.

Table 6-3 Economic impact per exhaust emission scenario

Economic performance indicator	*Unit*	*Scenario 1* ***Harmonisation and best practices***	*Scenario 2* ***Best available technology version 1***	*Scenario 3* ***Best available technology version 2***
ENPV total	million €	490	520	489
ERR	%	51	19	14
B/C	-	6,7	2,1	1,3
ENPV industry investments	million €	-74	-247	-391
ENPV environmental benefits	million €	463	658	739
Payback period	Years	9	16	20

6.3 Impact evaporative emission scenarios

This section presents a range of possible impacts for the evaporative emission scenarios (section 6.3.1), followed by a scenario-specific quantitative impact analysis in which the economic performance indicators are estimated per scenario (section 6.3.2 – 6.3.4) and a comparison of the evaporative emission scenarios (section 6.3.5).

[51] Although these same manufacturers do not mention similar concerns when considering implementation of hybrid propulsion systems.

6.3.1 Range of possible impacts

Table 6-4 shows a range of types of impacts per target group if (one of the) evaporative emission scenarios will be realized.

Table 6-4 Range of types of impacts evaporative emission scenarios

Scenario	*Target group*	*Impact description*
1, 2, 3, 4	Society	Additional jobs in manufacturing
1, 4	Society	A reduction of diurnal emissions
2, 4	Society	A reduction of hose permeation emissions
3, 4	Society	A reduction of fuel tank permeation emissions
1, 2, 3, 4	Industry	Investment required for additional Research and Development
1, 2, 3, 4	Industry	Investment for manufacturing of hardware devices for petrol engines
2, 3, 4	Industry	Investment for certification
1, 2, 3, 4	Industry	Very minor implication on space requirements of recreational crafts due to the addition of a hardware device
1, 2, 3, 4	Industry	Possible decrease of demand for production of recreational crafts due to an increase of the production price
1, 2, 3, 4	Industry & Government	A decrease of petrol fuel consumption, leading to less costs for users but also to less income for the government via taxes and VAT
1, 2, 3, 4	Government & Industry	Communication/dissemination cost in order for manufacturers and consumers to be familiar with the changed legislation
1, 2, 3, 4	Government	Alignment (partial) with the US EPA legislation
1, 2, 3, 4	Government	Update of EU legislation required
1, 2, 3, 4	Government	Change in market surveillance

Following the exploration of possible types of impact, the following cost- and benefit components are considered the most relevant (regarding their likelihood and impact) and are therefore selected to further detail and to quantify in the quantitative impact assessment.

Costs:
- Manufacturing costs for a hardware device (including research and development costs and possibly certification)

Benefits:
- Reduction of diurnal, hose- and fuel tank permeation emissions – a reduction of HC (NMVOC)Fuel savings

Evaporative emissions are essentially fuel vapours that escape from the fuel tank. Hence, any emissions reductions achieved from the implementation of different emissions control technologies will result in equal amounts of fuel saved.
Fuel savings are expressed in €/craft/year and are estimated per craft type and emission source using the following equation:

$$Fuel\ savings_{a,n} = \frac{10^3 \times ER_n \times petrol\ price}{\rho_{petrol} \times N_a}$$

Where:
- a: craft category (according EEA classification)
- n: emission source (diurnal, hose permeation, fuel tank permeation)
- ER_n: emission reduction of emission source n [tons/year]
- petrol price: the average price of petrol in EU [€/lt]
- ρ_{petrol}: petrol density [kg/lt]
- N_a: Number of craft fleet of category a

It is noted that all costs and benefit mentioned are additional (incremental) to the base case scenario of no action.

6.3.2 Scenario 1 – Diurnal control

In this sub section the following is presented, related to scenario 1 of evaporative emissions: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to the "do nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- The control of diurnal emissions by setting an emission limit of 0,1 g/lt/day (Table 4-1), resulting in a 25% reduction in diurnal emissions and a 7.7% reduction in total evaporative emissions , for crafts produced from 2026 on.
- The application of 2 technologies: (1) an activated carbon canister and (2) a pressurized fuel tank.

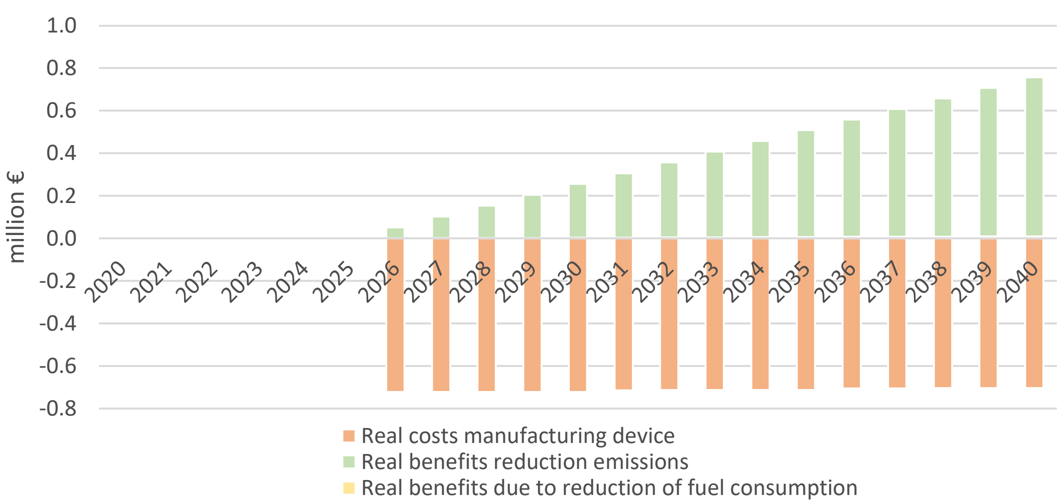
Cost overview

An overview of the distribution in time of the main (real, non-discounted) cost component (and benefits) is presented in Figure 6-7, which is:

- The costs for manufacturing of a hardware device, which includes any required additional R&D costs. The costs per craft vary from ~€3 to ~€21, with a total cost over the reference period of €11 million.

For an elaboration on the cost definitions relevant to this scenario is referred to Chapter 4.

Figure 6-7 Cost and benefit overview (yearly) scenario 1 "Diurnal control"



Benefits overview

Main (real, non-discounted) benefits accounted for in the reference period and beyond (up to 2080, until all crafts produced in 2040 are dismantled) are:

- A HC (NMVOC) emission reduction, as a consequence of diurnal emission control, with an economic benefit of ~€30 million.
- A fuel consumption reduction with an economic benefit of ~€0,4 million.

Economic performance

An overview of the costs- and benefits, as well as the discounted cumulative cash flow, is presented in Figure 6-8.

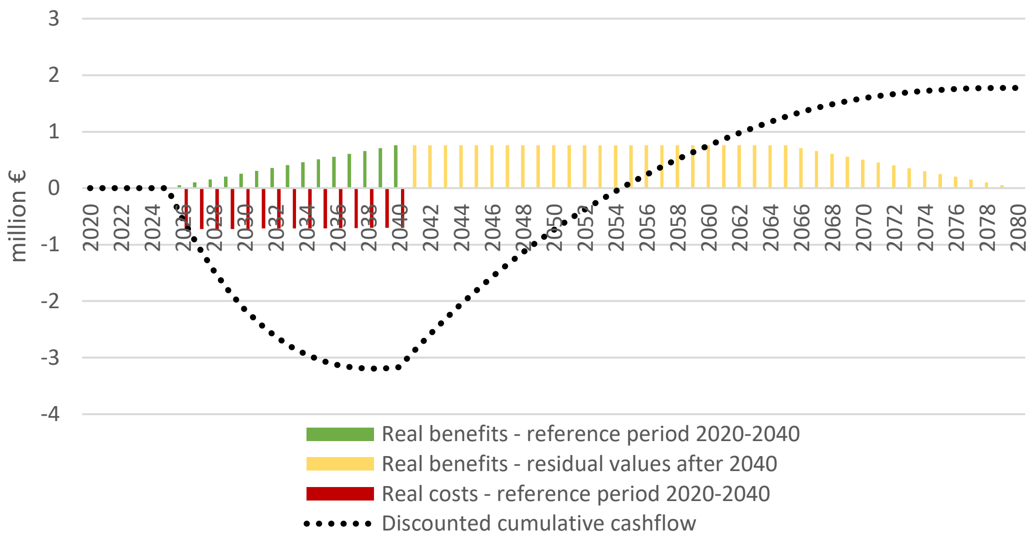
The ENPV is €2 million, accounting for the costs and benefits in the reference period (2020-2040), as well as the "residual values", the benefits of emission- and fuel consumption reduction after 2040 up to 2080.

The ENPV of emission reduction benefits is €8 million, the ENPV of fuel consumption reduction is €0,1 million and the ENPV of the costs is €-6 million.

It should be noted that the ENPV of the residual value (benefits after 2040) is positive with €5 million, but the ENPV of the reference period only is negative with a value of €-3 million. In other words, the benefits are mainly experienced after the production of the last craft in 2040, when most crafts produced from 2026 on are operational.

The ERR is 7%, higher than the discount factor of 5%. The payback period is 33 years (2055), this is the year in which the line of the discounted cumulative cash flow in Figure 6-8 crosses the zero line. The B / C ratio is 0,3.

Figure 6-8 Cash flow projection scenario 1 "Diurnal control"



Recommendation for action

This scenario shows a positive result for the most important economic performance indicator considered, the ENPV, and therefore, realization of this scenario is preferred above the "base case" scenario. However, a comparison between the various evaporative emission scenarios is required to obtain insight in which scenario is preferred, depending on the economic performance of the various scenarios: this is elaborated on in the comparison presented in section 6.3.6.

6.3.3 Scenario 2 – Hose permeation control

In this sub section the following is presented, related to scenario 2 of evaporative emissions: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to the "do nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- The control of hose permeation emissions by setting an emission limit of 15 g/m²/day (Table 4-1), resulting in a 30% reduction in fuel hose permeation

emissions and 15.6% reduction in total evaporative emissions, for crafts produced from 2026 on.
- The application of a thermoelastic barrier layer to water scooters and crafts with an outboard engine.
- The application of a nylon barrier layer to crafts with installed fuel tanks.

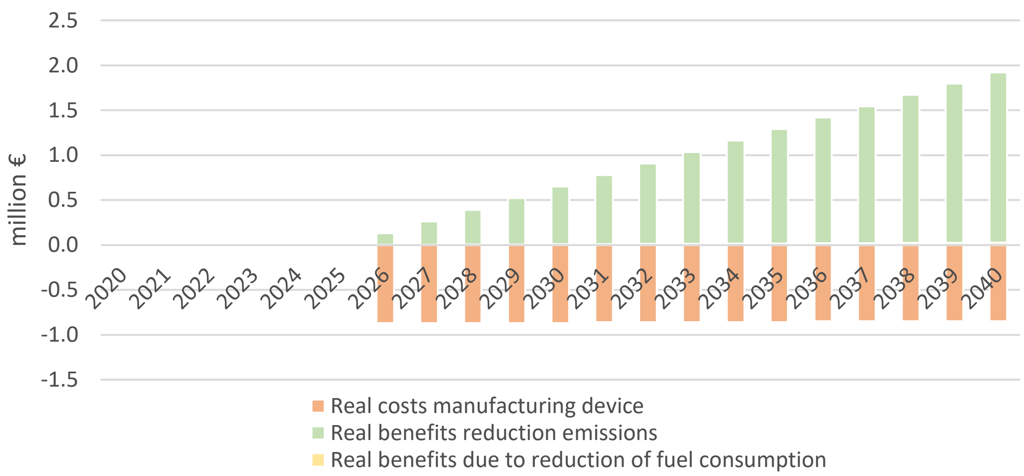
Cost overview

An overview of the distribution in time of the main (real, non-discounted) cost component (and benefits) is presented in Figure 6-9, which is:

- The costs for manufacturing of a hardware device, which includes any required additional R&D and certification costs. The costs per craft vary from ~€5 to ~€20, with a total cost over the reference period of €13 million.

An elaboration on the cost definitions relevant to this scenario is referred to in Chapter 4.

Figure 6-9 Cost and benefit overview (yearly) scenario 2 "Hose permeation control"



Benefits overview

Main (real, non-discounted) benefits accounted for in the reference period and beyond (up to 2080, until all crafts produced in 2040 are dismantled) are:

- A HC (NMVOC) emission reduction, as a consequence of hose permeation emission control, with an economic benefit of €~76 million.
- A fuel consumption reduction with an economic benefit of €~1,1 million.

Economic performance

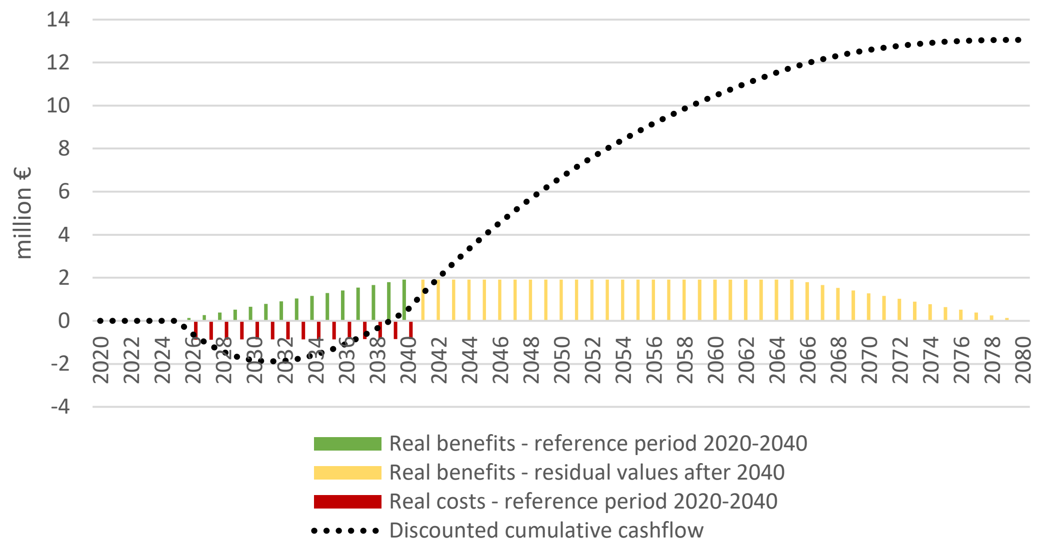
An overview of the costs- and benefits, as well as the discounted cumulative cash flow, is presented in Figure 6-10.

The ENPV is **€**13 million, accounting for the costs and benefits in the reference period (2020-2040), as well as the "residual values", the benefits of emission- and fuel consumption reduction after 2040 up to 2080.
The ENPV of emission reduction benefits is €20 million, the ENPV of fuel consumption reduction is €0,3 million and the ENPV of the costs is €-8 million.

It should be noted that the ENPV of the residual value (benefits after 2040) is much larger than the ENPV of the reference period only, with values of €13 and €1 million respectively. In other words, the benefits are mainly experienced after the production of the last craft in 2040, when most crafts produced from 2026 on are operational.

The ERR is 18%, much higher than the discount factor of 5%. The payback period is 17 years (2039), this is the year in which the line of the discounted cumulative cash flow in Figure 6-10 crosses the zero line. The B / C ratio is 1,7.

Figure 6-10 Cash flow projection scenario 2 "Hose permeation control"



Recommendation for action

This scenario shows a positive result for the most important economic performance indicator considered, the ENPV, and therefore, it is preferred above the "base case" scenario. However, a comparison between the various evaporative emission scenarios is required to obtain insight in which scenario is preferred, depending on the economic performance of the various scenarios: this is elaborated on in the comparison presented in section 6.3.6.

6.3.4 Scenario 3 - Fuel tank permeation control

In this sub section the following is presented, related to scenario 3 of evaporative emissions: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to the "do nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- The control of fuel tank permeation emissions by setting an emission limit of 1,5 g/m²/day (Table 4-1), resulting in a 32% reduction in fuel tank permeation emissions and a 15.2% reduction in total evaporative emissions of crafts produced from 2026 on.
- Layering of HDPE fuel tanks by non-continuous barrier platelets.
- Layering of XLPE fuel tanks by polyamide 11.

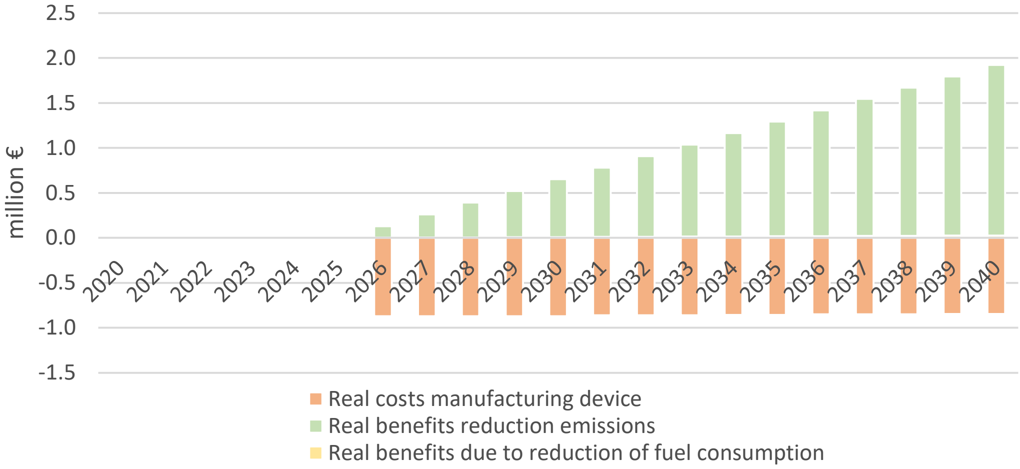
Cost overview

An overview of the distribution in time of the main (real, non-discounted) cost component (and benefits) is presented in Figure 6-11, which is:

- The costs for manufacturing of a hardware device, which includes any required additional R&D and certification costs. The costs per craft vary from ~€9 to ~€49, with a total cost over the reference period of €23 million.

An elaboration on the cost definitions relevant to this scenario is referred to in Chapter 4.

Figure 6-11 Cost and benefit overview (yearly) scenario 3 "Fuel tank permeation control"



Benefits overview

Main (real, non-discounted) benefits accounted for in the reference period and beyond (up to 2080, until all crafts produced in 2040 are dismantled) are:

- A HC (NMVOC) emission reduction, as a consequence of fuel tank permeation emission control, with an economic benefit of ~€95 million.
- A fuel consumption reduction with an economic benefit of ~€1,3 million.

Economic performance

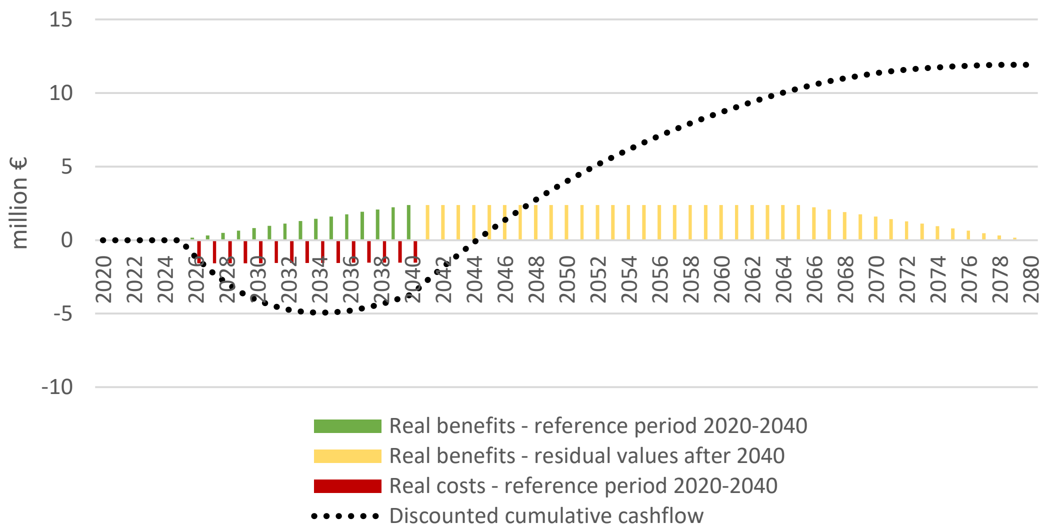
An overview of the costs- and benefits, as well as the discounted cumulative cash flow, is presented in Figure 6-12.

The ENPV is **€**12 million, accounting for the costs and benefits in the reference period (2020-2040), as well as the "residual values", the benefits of emission- and fuel consumption reduction after 2040 up to 2080.
The ENPV of emission reduction benefits is €25 million, the ENPV of fuel consumption reduction is €0,3 million and the ENPV of the costs is €-14 million.

It should be noted that the ENPV of the residual value (benefits after 2040) is positive and the ENPV of the reference period only is negative, with values of €16 and €-4 million respectively. In other words, the benefits are mainly experienced after the production of the last craft in 2040, when most crafts produced from 2026 on are operational.

The ERR is 11%, higher than the discount factor of 5%. The payback period is 23 years (2045), this is the year in which the line of the discounted cumulative cash flow in Figure 6-12 crosses the zero line. The B / C ratio is 0,9.

Figure 6-12 Cash flow projection scenario 3 "Fuel tank permeation control"



Recommendation for action

This scenario shows a positive result for the most important economic performance indicator considered, the ENPV, and therefore, it is preferred above the "base case" scenario. However, a comparison between the various evaporative emission scenarios is required to obtain insight in which scenario is preferred, depending on the economic performance of the various scenarios: this is elaborated on in the comparison presented in section 6.3.6.

6.3.5 *Scenario 4 - Implementation of both diurnal and permeation control*

In this sub section the following is presented, related to scenario 4 of evaporative emissions: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to the "do nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are the combination of the first 3 scenarios:

- The control of diurnal emissions, by the application of 2 technologies: (1) an activated carbon canister and (2) a pressurized fuel tank.
- The control of hose permeation emissions, by (1) the application of a thermoelastic barrier layer to water scooters and crafts with an outboard engine and (2) the application of a nylon barrier layer to crafts with installed fuel tanks.
- The control of fuel tank permeation emissions, by (1) layering of HDPE fuel tanks by non-continuous barrier platelets (Selar) and (2) layering of XLPE fuel tanks by polyamide 11.
- The combined measures lead to a 30% reduction of estimated evaporative emissions of crafts produced from 2026 on.

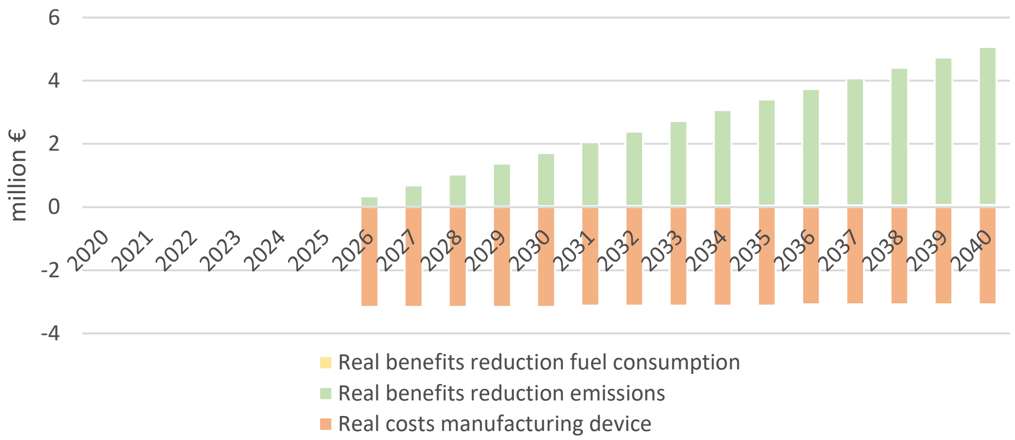
Cost overview

An overview of the distribution in time of the main (real, non-discounted) cost component (and benefits) is presented in Figure 6-13, which is:

- The costs for manufacturing of a hardware device, which includes any required additional R&D and certification costs. The costs per craft vary from ~€20 to ~€86, with a total cost over the reference period of €47 million.

An elaboration on the cost definitions relevant to this scenario is referred to Chapter 4.

Figure 6-13 Cost and benefit overview (yearly) scenario 4 "Implementation of both diurnal and permeation control"



Benefits overview

Main (real, non-discounted) benefits accounted for in the reference period and beyond (up to 2080, until all crafts produced in 2040 are dismantled) are:

- A HC (NMVOC) emission reduction, as a consequence of evaporative emission control, with an economic benefit of ~€200 million.
- A fuel consumption reduction with an economic benefit of ~€2,8 million.

Economic performance

An overview of the costs- and benefits, as well as the discounted cumulative cash flow, is presented in Figure 6-14.

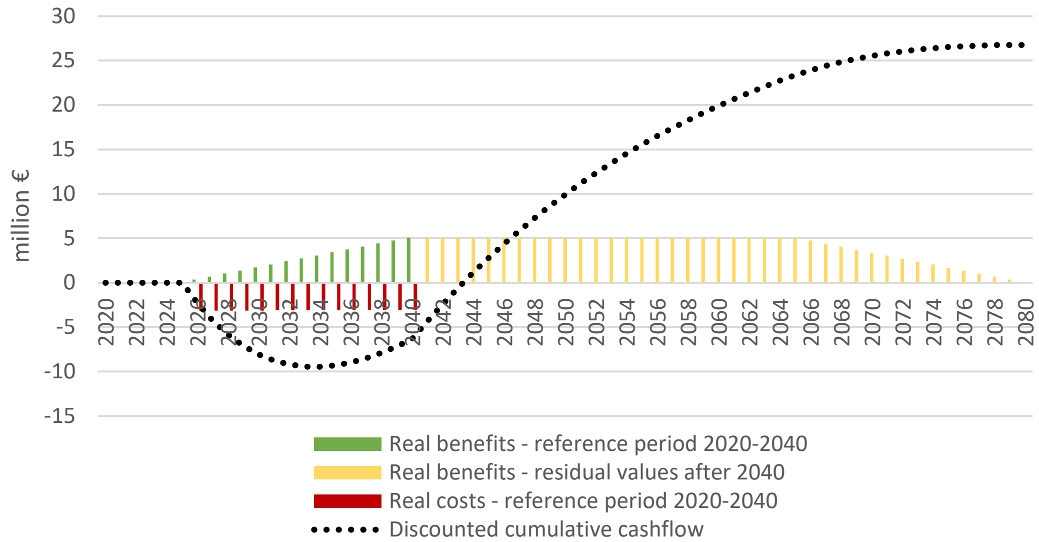
The ENPV is **€**27 million, accounting for the costs and benefits in the reference period (2020-2040), as well as the "residual values", the benefits of emission- and fuel consumption reduction after 2040 up to 2080.

The ENPV of emission reduction benefits is €54 million, the ENPV of fuel consumption reduction is €0,7 million and the ENPV of the costs is €-28 million.

It should be noted that the ENPV of the residual value (benefits after 2040) is positive and the ENPV of the reference period only is negative, with values of €33 and €-6 million respectively. In other words, the benefits are mainly experienced after the production of the last craft in 2040, when most crafts produced from 2026 on are operational.

The ERR is 12%, higher than the discount factor of 5%. The payback period is 22 years (2044), this is the year in which the line of the discounted cumulative cash flow in Figure 6-14 crosses the zero line. The B / C ratio is 1,0.

Figure 6-14 Cash flow projection scenario 4 "Implementation of both diurnal and permeation control"



Recommendation for action

This scenario shows a positive result for the most important economic performance indicator considered, the ENPV, and therefore, it is preferred above the "doing-nothing" scenario. However, a comparison between the various evaporative emission scenarios is required to obtain insight in which scenario is preferred: this is elaborated on in the comparison presented in section 6.3.6.

6.3.6 *Comparison of evaporative emission scenarios*

Table 6-5 shows an overview of the most relevant economic performance indicators for the comparison of the scenarios, which are according to the Guide to Cost-Benefit Analysis the ENPV total, the ERR and the B/C ratio. The table also shows the ENPV of industry investments (costs for industry, excluding the benefit of reduction of fuel consumption costs), the ENPV of environmental benefits (HC) and payback period of the investments (compared to 2022, the NPV year).

Concluding the results and considering the "ENPV total" as most important indicator, scenario 4 is preferred: it is the sum of all ENPV results of the individual scenarios 1, 2 and 3, which are all positive. Regarding the ERR, B/C and Payback Period, scenario 2 "Hose permeation control" specifically is preferred.

Table 6-5 Economic impact per evaporative emissions scenario

Economic performance indicator	*Unit*	*Scenario 1 Diurnal control*	*Scenario 2 Hose permeation control*	*Scenario 3 Fuel tank permeation control*	*Scenario 4 Implementation of both diurnal and permeation control*
ENPV total	million €	2	13	12	27
ERR	%	7	18	11	12
B/C	-	0,3	1,7	0,9	1,0
ENPV industry investments	million €	-6	-8	-14	-28
ENPV environmental benefits	million €	8	20	25	54
Payback period	years	33	17	23	22

6.4 Impact design categories scenarios

This section presents a range of possible impacts for the watercraft design categories scenarios (section 6.4.1), followed by a scenario-specific qualitative and quantitative impact analysis (sections 6.4.2 – 6.4.5) and a comparison of the design categories scenarios (section 6.4.6).

6.4.1 Range of possible impacts

Table 6-6 shows a range of types of impacts per target group if (one of the) design categories scenarios will be realized.

Table 6-6 Range of possible types of impacts design categories scenarios

Scenario	*Target group*	*Impact description*
1, 2, 3	Society	Additional jobs created for the revision of 23 ISO standards, for updating the technical files, re-certification and communication of changes.
1, 2, 3	Society	In case of subcategorization, it allows to produce crafts which meet less strict requirements for wind and wave conditions, possibly leading to lower manufacturing costs and sales prices for users
1, 3	Society	In case of subcategorization, it allows to produce crafts which meet more strict requirements for wave conditions, possibly leading to modifications of designs, resulting in higher manufacturing costs and sales prices for users
1, 2, 3	Industry	Creation of confusion to manufacturers and consumers, where new categories (D1 and D2 or C1 and C2) have different letters or alphanumeric designations and/or different scales (D and B in scenario 3) from the current categories.
3, 4	Industry	Increase of legal certainty (clearer liability implications) for manufacturers by replacing the ambiguous text concerning significant wave height of category A (exclusion of extreme seas and rogue waves) with upper limit value.
3, 4	Industry	Increase of clarity on the information provided to the users through specification of upper limits of Beaufort force and significant wave height as weather conditions suitable for operation in category A. Additionally increase of consumer understanding of the specifications by adding technical information concerning maximum average wind speed, gust speeds and possible maximum wave height, as notes to the RCD Annex I table. The aforementioned have a positive impact on the safe use of the watercrafts.
1, 2, 3	Industry	Communication cost
1, 3	Industry	Manufacturing cost
1, 2, 3	Government / Industry	Cost for revision of 23 harmonised ISO Standards related with RCD and primarily EN ISO 12217-1,2,3 and EN ISO 12215-5 for stability/buoyancy and scantlings calculations respectively.
1, 3	Industry	Cost for re-design in the case of design categories' revisions.
1, 2, 3	Industry	Cost for re-design and re-certification in the case of design categories' revisions.
4	Government & industry	Advantage on a potential future target of harmonisation of regulations between different jurisdictions since RCD and ISO 12217-1,2,3 would be already fully harmonised.
1, 2, 3, 4	Government	Change of legislation required.
1, 2, 3	Government	Change in market surveillance.

Furthermore, it is noted there is generally (1) no environmental impact (no habitat loss or fragmentation), (2) no impact on navigational safety and (3) no impact on human health of end-users and manufacturers' personnel.

There are no quantified or measurable benefits of the various scenarios proposed. This is elaborated by the following (for scenarios 1 to 4):

- No benefit to stability and buoyancy because the calculation methods of harmonised Standard EN ISO 12217-1,2,3:2017 remain the same. Changes of wind speed affect the wind heeling moment whereas changes of significant wave height do not enter directly into the calculations. In case of the new categories the requirements will obviously come out of interpolations / extrapolations.

- No benefit to structural integrity because the scantlings' calculation methods of harmonised Standard EN ISO 12215-5:2019 remain the same. Changes of wind speed do not affect the calculations. A change in the significant wave height (H_s) affects scantling calculations through design category factor K_{DC} and also is used in Annex K-formula J.1 for the creation of the table relating recommended max speed and H_s. In cases of increased wave heights, the requirements will obviously come out of interpolations / extrapolations.
- No benefit to safety in terms of reduced casualties. There is no solid evidence to underpin that modification of design categories would lead to accident reduction. Furthermore, recreational crafts' accidents are not included in EMSA reviews because they are not directly covered by the Directive on Accident Investigation 2009/18/EC, unless they are involved in an event (e.g., collision) with a ship covered by the Directive. Recreational crafts are found in EMSA reviews under the category "other ships". According to EMSA "Annual overview of marine casualties and incidents 2020" (EMSA, 2020) and for the period 2014-2019, 16 fatalities occurred on board recreational crafts and 16 recreational crafts lost. From the total 53 accident events analysed during the investigations for the whole category "other ships", not specifically for recreational crafts, 30 (56,6%) were attributed to "Human Action" and 7 (13,2%) to "Other agent or vessel" as accidents events types. Both event types have "Environmental impact" as underlying contributing factor with percentages 8,5% and 20% respectively. Nevertheless, we have no further data available in order to deduce an explicit relationship between "Environmental impact" contributing factor and the weather conditions (wind force and significant wave height) as division criteria of recreational craft design categories. Moreover, even from the more detailed US Cost Guard Boating Safety Statistics Report (USCG, sd) we see that human factor is again the primary contributing factor in six out of the ten top contributing factors of accidents (operator inattention, operator inexperience, improper lookout, excessive speed, navigation rules violation and alcohol use). From table 11 which analyses the weather and water conditions as contributing factor, we observe that 84% of accidents and 77% of deaths occurred in less than 0,6 m H_s and 89% of accidents and 84% of deaths occurred in less or equal of BF 4. By transferring this to RCD II specifications, around 84% of accidents occurred at physical conditions of category D and at the lower limits of category C.
- No benefit to European industry competitiveness.

Following the exploration of possible effects, the following cost- and benefit components are considered the most relevant (regarding their likelihood and impact) and are therefore selected to be used as base for the (qualitative and partly quantitative) comparison of design categories scenarios.

Costs:

- Revision of harmonised standards.
- Re-design cost for updating technical file.
- Re-certification cost.
- Communication cost.
- Craft manufacturing cost.

Benefits:

- Full harmonisation of regulations between the RCD and EN ISO 12217 for a potential future target of harmonisation of regulations.
- Increase of legal certainty (liability implication) due to defined wave and wind upper limits in design category A.
- Increase of clarity to users due to defined wave and wind upper limits in design category A and a possible positive impact in the safe use of the watercraft.
- Improved distribution of categories in terms of smaller steps and also alignment with significant wave heights of WMO sea states scale which are described in the marine forecasts.
- Negative benefit due to the confusion to manufacturers and consumers related to a changed categorization of design categories.

It should be noted that all costs and benefit mentioned are additional (incremental) to the base case scenario of no action.

6.4.2 Scenario 1 – Subdivision category D

In this sub section the following is presented, related to scenario 1 of design categories: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to "doing nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- Subcategorization of design category D into D1 and D2. The limit of H_s of the "new" category D1 is 1,5 m, higher than the H_s limit of the "old" category D with ≤0,3 m (0,5 m max), whilst the limit of Beaufort Force is remaining the same. For "new" category D2, the limit for H_s remains the same as for the "old" category D, whilst the limit for Beaufort Force decreases to ≤2. As a consequence, all crafts included in the "old" category D will meet the criteria for category D2, but not automatically these of category D1.

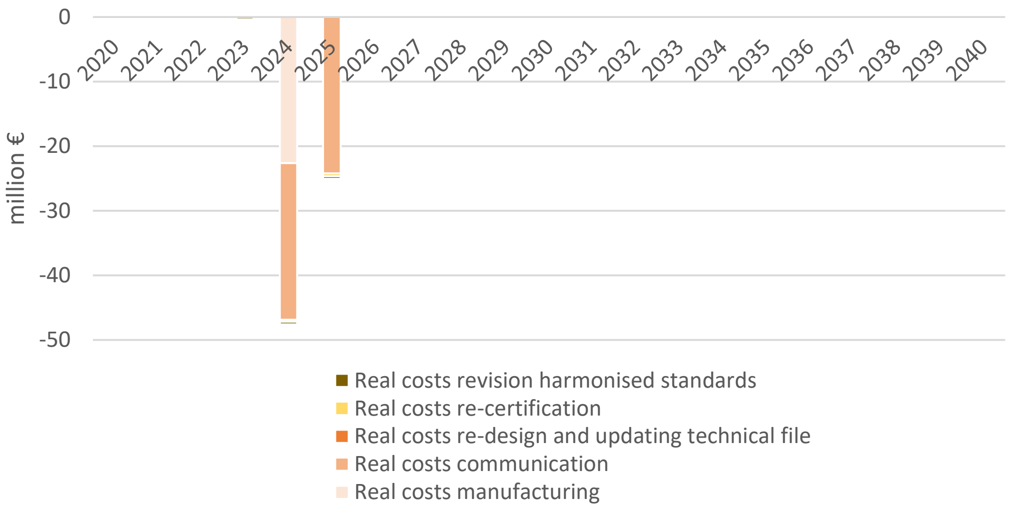
Cost overview

An overview of the main cost components is presented in Figure 6-15, which are:

- Revision of 23 ISO standards (€1,1 million), allocated to the government / industry, distributed over the years 2023-2025.
- Re-design for updating technical file of a part (5%) of the craft model types in design category D (€3000 per model type, total costs €0,34 million), allocated to the industry (manufacturers) in the year 2024.
- Re-certification of a 5% part of the craft model types in design category D (€4000 per model type, total costs €0,45 million), allocated to the industry (manufacturers) in the year 2025.
- Communication cost (€10000 per manufacturer, total costs ~€50 million), including training, booklets, brochures, excluding boat shows, allocated to the industry (manufacturers), distributed over the years 2024-2025.
- Manufacturing cost for the manufacturers who are willing to bear the cost of modifying 5% of craft models due to increased hull and stiffeners thickness (€1000 per craft, total costs €22,6 million), allocated in the year 2024.

For an elaboration on the cost definitions of the main components relevant to this scenario is referred to Chapter 5.

Figure 6-15 Cost overview (yearly) scenario "Subdivision of category D"



Benefits overview

Main benefits of this scenario are:

- No positive benefits.
- Negative benefit: confusion at manufacturers and users due to changed categorization.

Economic performance

The ENPV of the quantified costs is **€**-65 million. It should be noted that this only includes the cost components: the benefits are not quantified. An inclusion of the benefits however, will not result in a more positive ENPV, since there is only a negative benefit.

Recommendation for action

Since this scenario has a clear negative ENPV, which in reality is even more negative if also the negative benefit would be included in the calculations, it is recommended not to aim for realization of this scenario.

6.4.3 Scenario 2 – Subdivision category C

In this sub section the following is presented, related to scenario 2 of design categories: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to "doing nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- Subcategorization of design category C into C1 and C2.
- The upper limits for Beaufort Force and H_s of the "new" category C1 are similar to the "old" category C (≤6 Beaufort Force and ≤2 m H_s). The limits of "new" category C2 are lower: respectively ≤5m for the Beaufort Force and ≤1,25 m for H_s. Therefore, all crafts previously classified in design category C automatically meet the criteria of "new" category C1.

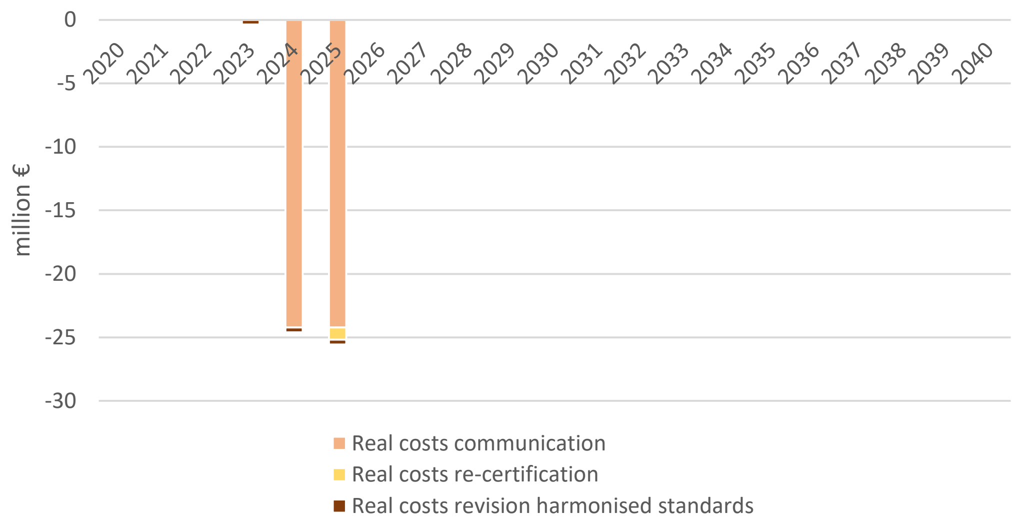
Cost overview

An overview of the main cost components is presented in Figure 6-16, which are:

- Revision of 23 ISO standards (€1,1 million), allocated to the government / industry, distributed over the years 2023-2025.
- Re-certification of a part (10%) of the craft model types in design category C (€500 per model type, total costs €0,96 million), allocated to the industry (manufacturers) in the year 2025.
- Communication cost (€10000 per manufacturer, total costs ~€50 million), including training, booklets, brochures, excluding boat shows, allocated to the industry (manufacturers), distributed over the years 2024-2025.

An elaboration on the cost definitions of the main components relevant to this scenario is referred to in Chapter 5.

Figure 6-16 Cost overview (yearly) scenario "Subdivision of category C"



Benefits overview

Main benefits of this scenario are:

- No positive benefits.
- Negative benefit: confusion at manufacturers and users due to changed categorization.

Economic performance

The ENPV of the quantified costs is **€**-45 million. It should be noted that this only includes the cost components: the benefits are not quantified. An inclusion of the benefits however, will not result in a more positive ENPV, since there only is a negative benefit.

Recommendation for action

Since this scenario has a clear negative ENPV, which in reality is even more negative if also the negative benefit would be included in the calculations, it is recommended not to aim for realization of this scenario.

6.4.4 Scenario 3 – Subdivision category C and revised ranges

In this sub section the following is presented, related to scenario 3 of design categories: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to "doing nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- Subcategorization of design category C into C1 and C2 and changing of limits in all categories to improve scientific soundness in terms of smaller steps of Beaufort wind forces and alignment with significant wave heights of WMO sea states scale and also smaller steps of H_s.
- The upper limit for Beaufort Force in the "new" category C1 (Beaufort Force 5) is lower than the "old" category C (Beaufort Force 6), whilst the H_s for the "new" category (2,5 m) is higher than the H_s of the "old" category C (2 m).
- Upper limits are set for category A: the maximum Beaufort Force is ≤9 and the maximum H_s is ≤7 m. Furthermore, addition of technical information at the explanatory notes concerning wind speed, gusts sound and maximum wave height.
- The limit of Beaufort Force of the "new" category B is BF 7, whilst the "old" category B had a limitation of BF 8. The limit for H_s for category B is not changed.
- The limit of Beaufort Force of the "new" category D is BF 2, whilst the limit of the "old" category D is BF 4. The limit H_s of category D is changed from 0,3 m with

occasionally waves of 0,5 m max to 0,5 m in order to be aligned with WMO sea state 2 (smooth).

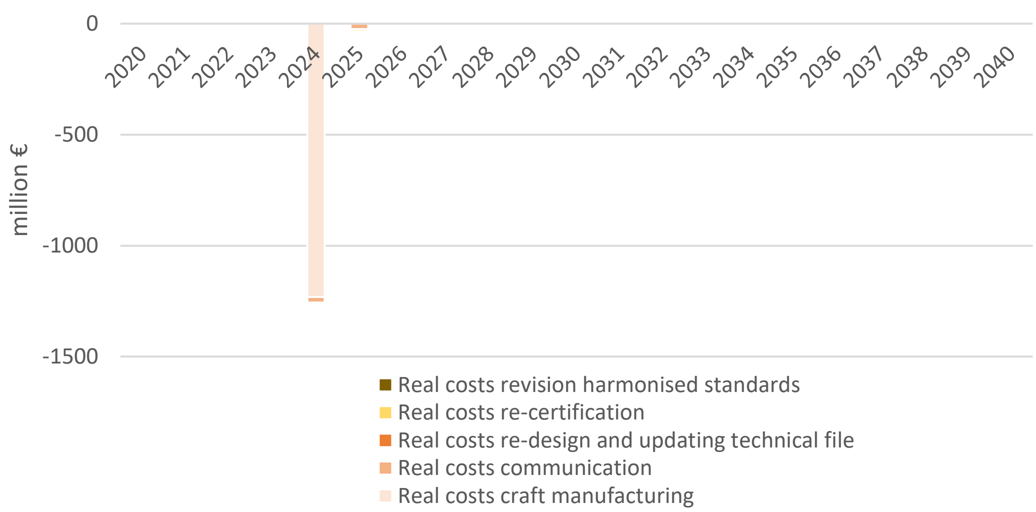
Cost overview

An overview of the main cost components is presented in Figure 6-17, which are:

- Revision of 23 ISO standards (€1,1 million), allocated to the government / industry, distributed over the years 2023-2025.
- Re-design for updating technical file of a part of the craft model types in design category C (10%) and water scooter model types (5%) (€3000 per model type, total costs €5,8 million), allocated to the industry (manufacturers) in the year 2024.
- Re-certification of a part of the craft model types in design category B, C and D and PWCS, which are assumed to be 100%, 10%, 5% and 5% respectively (€4000 per model type of category C, €500 per model type of category D, B and PWC, total costs €10,3 million), allocated to the industry (manufacturers) in the year 2025.
- Communication cost (€10000 per manufacturer, total costs ~€50 million), including training, booklets, brochures, excluding boat shows, allocated to the industry (manufacturers), distributed over the years 2024-2025.
- Manufacturing cost for the manufacturers who are willing to bear the cost of modifying the corresponding number of 10% craft models in category C, no manufacturing cost for PWCs since there are no available data and they are claimed to already comply with the higher H_s (€3200 per craft, total costs €1,23 billion), allocated in the year 2024.

An elaboration on the cost definitions of the main components relevant to this scenario is referred to in Chapter 5.

Figure 6-17 Cost overview (yearly) scenario "Subdivision of category C and revised ranges"



Benefits overview

Main benefits of this scenario are:

- An increase of legal certainty due to the upper limits set.
- An increase of clarity on the information provided to users due to the upper limits set and additional technical information with a possible positive impact in the safe use of the watercraft.
- Improved distribution of categories in terms of smaller steps in Beaufort scale and also alignment with significant wave heights of WMO sea states scale and also smaller steps of H_s.
- Negative benefit: confusion at manufacturers and users due to changed categorization.

Economic performance

The ENPV of the quantified costs is €-1,175 billion. It should be noted that this only includes the cost components: the benefits are not quantified. An inclusion of the benefits however does not necessarily lead to a more positive result of the ENPV, since in addition to the three positive benefits, there is also a negative benefit. It is believed however that an inclusion of the positive- and negative benefits is unlikely to result in a positive ENPV, also since the ENPV has a high negative value.

Recommendation for action

Since this scenario has a clear negative ENPV and since that is believed that an inclusion of the positive- and negative benefits within the ENPV is not resulting in a positive value, it is recommended not to aim for realization of this scenario.

6.4.5 *Scenario 4 – Harmonisation upper limits with ISO standard*

In this sub section the following is presented, related to scenario 4 of design categories: (1) the technological specifications, (2) an overview of the costs, (3) an overview of the benefits, (4) the economic performance of the scenario compared to "doing nothing" scenario and (5) a recommendation for action.

Technological specifications

The proposed measures and specifications of this scenario are:

- Setting upper limits for design category A of ≤9 Beaufort Force and ≤7 m H_s, in line with the upper limits set in the harmonised ISO stability standard. Furthermore, addition of technical information at the explanatory notes concerning wind speed, gusts sound and maximum wave height.

Cost overview

There are no costs related to the implementation of this scenario.

Benefits overview

Main benefits of this scenario are:

- An increase of legal certainty due to the upper limits set.
- An increase of clarity on the information provided to users due to the upper limits set and additional technical information with a possible positive impact in the safe use of the watercraft.
- Full harmonisation of regulations between the RCD and ISO 12217 for a potential future target of harmonisation of regulations.

Economic performance

The ENPV of the quantified costs is €0 million: this is excluding any benefits. Since the benefits are only positive in this scenario, the ENPV is expected to be positive.

Recommendation for action

This scenario only has positive benefits with no costs, therefore, it is recommended to aim for realization of this scenario compared to "doing-nothing" (also since there are no other scenarios with a positive outcome).

6.4.6 *Comparison of design categories scenarios*

Table 6-7 shows an overview of the most relevant economic performance indicator for the comparison of the scenarios, which is according to the Guide to Cost-Benefit Analysis the ENPV (followed by the ERR and the B/C ratio). The table also shows the existence of positive- and negative benefits per scenario.

Concluding the results and considering the "ENPV" as most important indicator whilst also taking into account the existing benefits, it is clear that scenario 4 "Harmonisation upper limits with ISO standard" has the most positive outcome, since there are no costs, whilst there are positive benefits.

Therefore, considering the options for design categories, scenario 4 is recommended.

Table 6-7 Economic impact per design categories scenario

Economic performance indicator	*Unit*	*Scenario 1 Subdivision cat. D*	*Scenario 2 Subdivision cat. C*	*Scenario 3 Subdivision cat. C and revised ranges*	*Scenario 4 Harmonisation upper limits with ISO standard*
ENPV investments	million €	-65	-45	-1175	0
Existence positive benefits	-	No	No	Yes	Yes
Existence negative benefits	-	Yes	Yes	Yes	No

6.5 Scenarios overview and comparison

Table 6-8 shows an overview of all scenarios and their specifications. Table 6-9 shows an overview per scenario of the most important economic performance indicators ENPV, ERR and B/C, as well as the ENPV values for industry costs, environmental benefits and other benefits specifically for design categories (a = benefits harmonisation of regulations, b = benefit of increased legal certainty, c = benefit clarity on information to users and d = benefit of improved distribution of categories).

Following the comparison of scenarios per topic of exhaust emissions, evaporative emissions and design categories in respectively sections 6.2,5, 6.3.6 and 6.4.6, it can be concluded that for each of the topics there is a scenario which is more cost beneficial than the base case ("do nothing"), if using the ENPV as most important indicator.

It should be noted that the implications in terms of the net present value of costs and benefits are generally much higher for the exhaust emission scenarios (order of magnitude hundreds of millions) than for the evaporative emission- and design categories scenarios (order of magnitude millions to tens of millions, except for design categories scenario 3 – hundreds of millions). In other words, the impact of changing exhaust emission related legislation is generally higher than changing other the evaporative- and design categories legislation (except for the change proposed in design categories scenario 3).

The implications of the scenarios in summary:

- Exhaust emissions - All exhaust emission scenarios score better than the "do nothing" base case scenario, since all ENPV values are larger than 0 (the base case reference ENPV). Although scenario 2 scores best on the ENPV, the difference between the scenarios is very minor (also considering the possible overestimation of the ENPV of scenarios 2 and 3 – see subsection 6.2.5). Scenario 1 "Harmonisation and best practices" scores best on the ERR, B/C, payback period and ENPV costs industry, however, scenario 3 "Best available technology version 2" scores best regarding the benefits of emission reduction (ENPV benefits environment). Scenario 2 scores in between regarding the ERR, B/C, payback period, ENPV costs industry and ENPC benefits environment. Noted is for scenario 2 and 3, a wide availability of low-sulphur diesel is required. The preferred option depends on the priorities of the Commission (environmental priorities, expected return on investment on the short term and the willingness to allocate costs to the industry).
- Evaporative emissions - All scenarios show positive results regarding the ENPV. Considering the scenario with the largest ENPV, scenario 4 "Implementation of both diurnal and permeation control" is preferred. When looking at the individual measures as presented separately in scenarios 1, 2 and 3, scenario 2 "Hose permeation control" is preferred: compared to scenario 1 and 3, scenario 2 has the largest ENPV, the highest ERR, the best B/C ratio and the shortest payback time. If focusing on the environmental benefits, scenario 3 (after scenario 4, which shows the most positive results with regard to environmental benefits) is preferred.

- Design categories - Design categories scenario 1 "Subdivision category D", scenario 2 "Subdivision category C" and scenario 3 "Subdivision category C and revised ranges" each lead to costs with a *negative* ENPV. Whilst all have the negative benefit of confusion of the industry, scenario 1 and 2 do not have any positive benefits: scenario 3 has the positive benefits of increased legal certainty and clarity on information to users, as well as the benefit of improved distribution of categories. Due to the large negative value of the ENPV of scenario 3 (€-1175 million), it is expected the positive benefits do not weigh up against the major costs. Scenario 4 "Harmonisation upper limits ISO" is preferred since it results in positive benefits only (including the benefit of harmonisation of regulations) and it does not require investment.

It should be noted that if the growth of electrification and hybridization would fall below the level that is assumed, the impact of both exhaust and evaporative emission scenarios would become larger, resulting in an improved economic performance (higher ENPV).

Table 6-8 Overview specifications per scenario

Scenario	*Specifications*
Exhaust emission scenario 1 **"Harmonisation and best practices"**	Application of best practices and currently available technologies (lower R&D costs) and harmonisation (partial) with US legislation
Exhaust emission scenario 2 **"Best available technology version 1"**	Application of best available non-aftertreatment technology to further reduce pollutant emissions compared with best practices
Exhaust emission scenario 3 **"Best available technology version 2"**	Application of best available technology for maximum reduction of pollutant emissions using catalytic SCR-aftertreatment
Evaporative emission scenario 1 **"Diurnal control"**	Control of diurnal emissions by the application of an activated carbon canister and a pressurized fuel tank
Evaporative emission scenario 2 **"Hose permeation control"**	Control of hose permeation emissions by the application of barriers
Evaporative emission scenario 3 **"Tank permeation control"**	Control of fuel tank permeation by layering fuel tanks
Evaporative emission scenario 4 **"Implementation of diurnal and permeation control"**	A combination of all measures proposed in scenarios 1, 2 and 3
Design categories scenario 1 **"Subdivision category D"**	Subcategorization of design category D into D1 and D2, of which D1 has higher limits than category D
Design categories scenario 2 **"Subdivision category C"**	Subcategorization of design category C into C1 and C2, of which C1 has the same upper limits with category C
Design categories scenario 3 **"Subdivision category C and revised ranges"**	Subcategorization of design category C into C1 and C2, of which C1 has upper H_s than category C, definition of upper limits for category A and revised ranges for categories B and D as well
Design categories scenario 4 **"Harmonisation upper limits with ISO"**	Definition of upper limits for category A, in line with the upper limits set in the harmonised ISO stability standard

Table 6-9 Overview economic performance indicators per proposed scenario (ENPV in million €, ERR in %)

	ENPV	*ERR*	*B/C*	*ENPV costs industry*	*ENPV benefits environment*	*Positive benefits*
Exhaust emission scenario 1 **"Harmonisation and best practices"**	490	51	6,7	-74	463	
Exhaust emission scenario 2 **"Best available technology version 1"**	520	19	2,1	-247	658	
Exhaust emission scenario 3 **"Best available technology version 2"**	489	14	1,3	-391	739	
Evaporative emission scenario 1 **"Diurnal control"**	2	7	0,3	-6	8	
Evaporative emission scenario 2 **"Hose permeation control"**	13	18	1,7	-8	20	
Evaporative emission scenario 3 **"Tank permeation control"**	12	11	0,9	-14	25	
Evaporative emission scenario 4 **"Implementation of diurnal and permeation control"**	27	12	1,0	-28	54	
Design categories scenario 1 **"Subdivision category D"**	-65	n.a.	n.a.	-65	n.a.	none
Design categories scenario 2 **"Subdivision category C"**	-45	n.a.	n.a.	-45	n.a.	none
Design categories scenario 3 **"Subdivision category C and revised ranges"**	-1175	n.a.	n.a.	-1175	n.a.	b,c,d
Design categories scenario 4 **"Harmonisation upper limits with ISO"**	0	n.a.	n.a.	0	n.a.	a,b,c

7 Conclusions and recommendations

This chapter presents an overview of all points that need to be evaluated according to the Terms of Reference, and problems encountered, and includes conclusions and recommendations. The results are presented in tables that show the evaluation questions as defined in the Terms of Reference. In doing so, we pay attention to conclusions and recommendations regarding the feasibility of these scenarios. We also address the research questions underlying this study.

7.1 Exhaust emissions

7.1.1 Answers to the questions of this study

	Question	*What is found*
1	What is the share of exhaust emissions produced by recreational craft engines in the EU compared to exhaust emissions produced by boats in general as well as comparing to absolute number of transport exhaust emissions?	It should be noted that the exhaust emission levels estimated in this study should be considered as upper estimate, since the calculations do not account for engine replacement before dismantling the craft (theoretically the engine lifetime is similar to the lifetime of the craft assumed, but this is not always the case in practice). As a result, the calculations consider relatively old engines (with higher emission factors, assumed based on the engine production year and emission legislation in force) with relatively high emission levels compared to newer (often cleaner) engines (in case of replacement by cleaner engines). The estimated shares presented therefore are considered maximum shares. The share of exhaust emissions produced by recreational craft engines compared to the EU transport sector is 0,4%, 0,5%, 0,6%, 4,4% and 11,6% for the substances CO_2, PM, NO_x, HC (NMVOC) and CO respectively. The share of exhaust emissions produced by recreational craft engines compared to all EU sectors together is 0,1%, 0,1%, 0,3%, 0,3% and 2,4% for the substances CO_2, PM, NO_x, HC (NMVOC) and CO respectively. The shares of recreational craft exhaust emissions of the shipping sector are more challenging to estimate. It is unknown to what extent recreational craft emissions are included in the shipping sector, following the targeted stakeholder consultation. It is stated emissions of recreational craft are accounted for in the national inventories via emissions calculations based on the national fuel consumption, but it is unknown to what extent the recreational craft (petrol) emissions are included in the shipping sector or another sector: it is stated the petrol emissions are (often) included in the road transport calculations. A proper comparison of recreational craft emissions with the shipping sector therefore cannot be made. However, if assuming the petrol emissions to be accounted for in the road transport sector, a comparison can be made by adding the estimated petrol recreational craft emissions to the shipping sector. The estimated share of recreational craft emissions would in this case be 2%, 1%, 1%, 24% and 57% for respectively CO_2, PM, NO_x, HC (NMVOC) and CO.
2	Is further reduction of exhaust emissions of recreational craft propulsion engines technically feasible?	A reduction of exhaust pollutant emissions produced by combustion engines is technically feasible.
3	Which air pollutants (including those not indicated by Directive 2013/53/EU), and greenhouse gases (GHG such as CO_2) could be reduced by either using new technologies to propulsion engines or by imposing other legislative or regulatory restrictions (such as limitation of use in certain times or limitation of speed?)	With SI engines, especially HC+NO_x and CO could be further reduced. With CI engines, especially NO_x (but also PM could in principle be reduced). The most likely paths for reduction of GHG is the (expected) market growth of purely electric (and to a lesser extent of hybrid-electric) propulsion systems for recreational craft. Limiting use is considered by respondents as a task of local authorities (not EU). The same observation can be made on the limitation of speed.
4	What options can be used to further reduce exhaust emissions of recreational craft propulsion engines?	With SI engines the major technical options are: (1) further combustion system design optimization; (2) introduction of 3-way catalyst technology for OB 4-stroke engines.

	Question	What is found
		With CI engines three technical options are available to reduce NO_x (+ HC) exhaust emissions: (1) further combustion system optimization towards lower NOx and PM emissions; (2) NO_x reduction through exhaust gas recirculation; (3) NO_x-reduction through SCR catalytic aftertreatment. Also PM reduction is in principle possible with implementation of additional catalytic aftertreatment (diesel oxidation catalyst and or diesel particulate filter) Catalytic aftertreatment with CI engines is challenging (in particular because of the volume constraints and because of their typical wet engine exhaust configuration).
5	Would further restriction of exhaust emission limits as set out in the Directive 2013/53/EU reduce overall exhaust emissions produced by recreational craft propulsion engines?	Yes, this is the case.
6	Are there other testing procedures or test cycles than those required by Directive 2013/53/EU which could be applied to recreational craft propulsion engines and would result in lower (real-world) emission factors?	The most straightforward modification to the current emission legislation will be to add NTE-legislation (as is currently already implemented in the US). The current test cycles that are used for CI/IB engines (E1/E3/E5) do not take into account that these engines tend to spend significant part of their time at (low speed, load load) conditions. The corresponding emission test results will not reflect the low efficiency of catalytic systems in that operating area. Also they will not allow to estimate the possible positive impact of hybridization on fuel consumption and emissions. Preferably the engine test area should be extended. This could be through addition of additional test modi or by an extension to the current NTE-areas/limits.
7	Would further reduction of exhaust emission limits (including those not required by Directive 2013/53/EU), and target values of GHG emissions (such as CO_2) enable reduction of fuel/energy consumption?	Pollutant emission reduction tends to increase energy consumption. Exception to this is the implementation of SCR technology on CI/IB engines and implementation of 3-way catalyst technology on SI/OB engines. Introduction of target GHG emissions is considered to be difficult to realize in practice at this moment.
8	Propose options to further reduce exhaust emissions of recreational craft propulsion engines and provide the cost/benefit analysis of the proposed options.	Three different scenarios have been identified. All of them focus on a reduction of NO_x+HC (and of CO with SI engines). No further PM reduction is assumed. Scenario 1 considers further combustion system optimization with technologies that have reached a high TRL and that have a correspondingly low-cost impact. These technologies are compatible with current fuel qualities. Scenario 2 aims at further reducing emissions by implementing catalytic aftertreatment to OB engines and EGR technology to CI SD/IB engines with P > 75 kW. Scenario 3 considers applying SCR technology to the latter group of engines instead of EGR. These technologies are mainstream in other markets but new to recreational craft. Practical implementation of SCR could be difficult (packaging constraints and real-world temperature levels). Both scenario 2 and 3 require ULSD fuel. All three scenarios give comparable ENPV results. Scenario 1 “Harmonisation and best practices” scores best on the B/C ratio, the ERR and payback period, and it has no uncertainties like the availability of ULSD fuel (this is only used in scenarios 2 and 3). It neither has uncertainties regarding the possible space limitations at some crafts types when implementing proposed technologies (this could be the case in scenario 2 and 3). On the other hand, the environmental benefits are highest in scenario 3 and scenario 2 scores in between.
9	Propose options to introduce the target values on CO_2 emissions and provide the cost/benefit analysis of the proposed options.	No short-term realistic options have been identified. GHG emission should preferably be regulated on craft-level. A VECTO-like approach is in principle possible, but further investigation is needed on solving challenges with practical implementation (e.g. engines being sold separately from boats) of such approach.

7.1.2 Conclusions

The results of this study for the part of exhaust emissions are:

- The share of emissions of recreational craft (CO_2, NO_x, HC (NMVOC), CO, PM) is very limited compared to the transport sector and compared to all other sectors together, except for CO, which is relatively large compared to the other substances. Regarding the economic impact of the emissions however, NO_x and CO_2 contribute the most (CO the least). CO is, next to recreational crafts, mainly emitted by passenger cars, mopeds and motorcycles within the transport sector and by the residential, commercial and institutional sector, as well as the construction and manufacturing sector. The estimated high emissions for CO specifically (and not for other substances) are in line with the few available publications: in the Informative Inventory Report of the Netherlands for example (Wever, et al., 2021), recreational craft is marked as key contributor to CO (next to passenger cars, mopeds and motorcycles, which mainly have (small) petrol engines), whilst (other) shipping activities are not marked as key contributor to CO (other shipping activities are mentioned as key source of NO_x and PM). This conclusion is also in line with the very high emission factors presented in the EMEP/EEA guidebook for recreational crafts compared to other (mainly diesel) engines (e.g. engines of marine vessels).
- The technologies that have been identified for reducing exhaust emissions are mature technologies that are already being applied in other markets (automotive for SI engines, NRMM for CI engines). They are in principle applicable also to recreational craft.
- Application of three-way-catalyst technology for SI engines and of EGR technology and SCR catalytic aftertreatment for CI engines is associated with challenges to solve volume constraints packaging) as well as adapting exhaust thermal management. EGR and SCR in addition require the availability of ultra-low-sulphur diesel. SCR further requires distribution and on-board storage of a second fluid (urea-water mixture).
- Three main scenarios for reducing exhaust emissions are assessed in this study: (1) the application of current best practices and partial harmonisation with US legislation, (2) the application of best available non-aftertreatment technology to further reduce pollutant emissions compared to best practices and (2) the application of best available technology for maximum reduction of pollutant emissions using catalytic SCR-aftertreatment.
- To realize an idealistic scenario of maximum electrification and/or hybridization, possible options are: (1) the exemption of VAT for electric craft (thus reducing the higher upfront investment cost of these craft), (2) supporting the roll-out of charging infrastructure in marinas/harbours, (3) increasing the number and size of zero-emission areas, (4) introducing regular emissions inspection of recreational craft (as is current practice with cars and mopeds) and (5) increasing the cost of fossil fuels e.g. through the introduction of a carbon tax on these fuels. The first four options are expected to contribute the most, because fuel costs are only a minor part of the total cost of ownership of recreational crafts. The biggest driver for electrification will however be the expected further improvement (lower cost, higher energy and power density) in battery technology. Of course, electrification could also be imposed on some classes of craft (in line with a scenario recently suggested by CARB). This would result in a further considerable reduction of CO emission.
- Although scenario 2 "Best available technology version 1" scores best regarding the ENPV, all three scenarios are comparable (in reality, the ENPV of scenario 2 and 3 "Best available technology version 2" will be slightly smaller, due to the expected increased costs for smaller manufacturers). In fact, in scenario 2 and 3 some small (CI IB) manufacturers may disappear from the market. Regarding the B/C ratio, the payback period, the ERR and the required investment by the industry, scenario 1 "Harmonisation and best practices" scores best. This scenario also has the least uncertainties: there is no dependency on the wide availability of low-sulphur diesel fuel and also there are also no uncertainties regarding the implication of the implementation of the proposed technologies (as in scenario 2 and 3) on volume limitations. On the other hand, scenario 3 scores best on environmental benefits. Scenario 2 scores in between on all economic indicators (except for the ENPV). In other words, the preferred scenario is depending on the priorities of the Commission (environmental priorities, willingness of cost allocation to the industry, quick return on investment).

7.1.3 Recommendations

The recommendations regarding the exhaust emission topic are:

- Depending on the priorities of the Commission (as mentioned in the conclusion part: e.g. environmental priorities, willingness to allocate cost to the industry and a quick return on investment), one of the exhaust emission scenarios can be selected as "preferred scenario".
- It is recommended to further study uncertainties regarding realizing the wide availability of low-sulphur diesel fuel (and second fluid distribution in case of SCR).
- It is recommended to further detail the implications of technologies on volume limitations of crafts.
- The proposed scenarios for exhaust emission reduction apply to newly produced crafts. If aiming for emission reduction of the recreational craft sector, it is recommended to explore the possibilities of emission reduction of older engines, which have relatively high emissions compared to newer ones (for example, by replacement).

7.2 Evaporative emissions

7.2.1 Answers to the questions of this study

	Question	*What is found*
10	Are there technologies which would enable to limit evaporative emissions from fuel systems of recreational craft?	The EMEP/EEA air pollutant emission inventory guidebook contains description of emissions control technologies used in road vehicles (passenger cars, vans, mopeds, scooters, motorcycles). Many of these are also applicable to recreational crafts as well. The Final Regulatory Impact Analysis of the US EPA (Control of Emissions from Marine SI and Small SI Engines, Vessels, and Equipment) also contains detailed descriptions of emissions control measures to reduce evaporative emissions from including recreational crafts. The technologies that are most suitable for the recreational craft sector include carbon canisters, pressurized fuel tanks, low-permeability (multi-layer) fuel tanks and fuel hoses.
11	Is there a set of evaporative emission rules from engines in other EU/international legislations which could apply for fuel systems of recreational craft propulsion engines covered by the Directive 2013/53/EU?	Evaporative emissions are already regulated by the US EPA. Emission standards are set out for fuel line permeation, tank permeation, and diurnal emissions for portable tanks, PWC, and other installed tanks.
12	Propose options to regulate evaporative emissions from fuel systems of recreational craft and provide the cost/benefit analysis of the proposed options.	Based on CBA results, the most cost-beneficial policy option is to regulate hose permeation emissions (Scenario 2) and/or fuel tank permeation (Scenario 3). Diurnal control (Scenario 1) has no economic benefits in the short to medium term (30 years). Regarding the ENPV, the combined scenario (Scenario 4) is preferred, since this scenario has the highest value.

7.2.2 Conclusions

The outcome of the review study on Recreational Craft Directive (RCD) 2013/53/EU is summarized below:

- Evaporative emissions are an important source of NMVOC emissions from the recreational craft sector, at comparable levels to (although lower than) exhaust emissions.
- Permeation from fuel tanks, hoses and lines are responsible for about 80% of total evaporative emissions, whereas diurnal emissions contribute another 20%. Hot soak and running losses are rather insignificant, being responsible for about 1% of the total evaporative emissions.
- The technologies for reducing evaporative emissions are already mature and are successfully implemented in the road transport sector, such as in cars, mopeds and motorcycles. The same technologies, with proper sizing and adjustments are also applicable in the recreational craft sector.

- Carbon canisters, pressurized fuel tanks, low-permeability (multi-layer) fuel tanks and fuel hoses are already used in the recreational craft sector in the US, where emission limits apply for diurnal, fuel tank and fuel hoses emissions.
- Three main scenarios for controlling evaporative emissions are examined in the present study: diurnal emissions (scenario 1), fuel tank permeation (scenario 2), and fuel hoses permeation (scenario 3). A fourth scenario, combining all the above emissions controls, is also assessed.
- In view of a possible harmonisation of emission limits with other jurisdictions, the respective emission limits already applied in the US have been considered for the above scenarios.
- All scenarios will deliver benefits in the long run. From a cost-benefit perspective, controlling permeation emissions from fuel hoses and lines will deliver the highest benefits in the shortest period of time. Scenario 4 scores best regarding the ENPV.

7.2.3 Recommendations

The recommendations regarding the evaporative emission topic of this study are based on the cost benefit analysis results and are summarized below:

- Setting a permeation emissions limit of 15 g/m^2/day for fuel hoses and lines is the most cost-beneficial option for reducing evaporative emissions from the recreational craft sector. This scenario has the shortest payback time (17 years) from all other policy options considered.
- All other options have a payback time of more than 20 years, make them less appealing compared to permeation control.
- An emissions limit of 1,5 g/m^2/day for fuel tank permeation is the second most cost-beneficial option, with a payback time of 23 years.
- The payback time increases considerably for diurnal emissions control (33 years).

7.3 Watercraft design categories

7.3.1 Answers to the questions of this study

	Question	*What is found*
13	Are the current specifications of watercraft design categories satisfactory and appropriate for the manufacturers?	They are satisfactory according to the results of explanatory interviews, public consultation and targeted consultation, in which all industry associations which participated, declared their position that the market is running smooth with the current set-up of design categories.
14	To what extent are sectorial end-users satisfied with current specifications of watercraft design categories?	They are satisfactory to a certain extent according to the results of public consultation and explanatory interview with European Boating Association (EBA), an association of end-users. To be more specific, even though there is a general admittance that many end-users don't have clear understanding of significant wave height definition and also of Beaufort force in terms of confusing wind speed values with gust values, this is rather a matter of improving seamanship through training and provision of clearer information than changing the specifications.
15	Do the current division criteria of boat design categories (resistance to wind force and significant wave height) provide for a sufficient and clear information to manufacturers and end-users?	Current division criteria of Beaufort force and significant wave height provide clear and sufficient information for the categorization of watercrafts since they combine the two main physical parameters that are encountered in all weather and water conditions: wind and wave. Nevertheless, there are missing technical information such as average wind speed, maximum gust speeds and maximum wave height that could improve understanding and sufficiency of information for both manufacturers and end-users, increasing the possibility of the safe use of the boat by the end-users.
16	Does international standardisation output provide for different division of boat design categories than the one set out in the Directive 2013/53/EU?	No, because the relevant International Standard for stability and buoyancy assessment and categorisation, which is harmonised Standard EN ISO 12217-1,2,3: 2017 (ISO 12217-1,2,3:2015), sets the same divisions of design categories enriched with some more technical information. One of the technical additions is the setting of upper limits in Category A. The majority of public and targeted

	Question	What is found
		consultation respondents agreed that a potential transposition of these upper limits (less or equal than BF 9 and approx. 7 m H_s) to a next revision of RCD, would improve the clarity of information for both manufacturers and end-users.
17	What are the possibilities for additional specifications and/or further sub-divisions of current boat design categories?	The possibilities are very limited, if not existing, for the time being, according to the results of the consultations and of the cost benefit analysis. Every subdivision, even the slightest one, incurs costs for re-design, revision of all relevant harmonised ISO standards, re-certification, manufacturing and communication cost. Scenarios 1 and 2 create millions of € costs without benefits. Scenario 3 creates ENPV of more than a billion cost with three qualitative benefits that can't outweigh the cost. On the top of this, is also the argument of creation of confusion through the introduction of new categories after five years of establishing good understanding of RCD II and consensus within the market.
18	Would additional specifications and/or further sub-divisions of current boat design categories provide clearer information for the end-users on the types of risks connected with the use of recreational craft with different boat design categories?	The problem of misunderstanding of the current four design categories by many end-users in terms of confusing average wind speed with gusts and also the definition of significant wave height in relation to maximum wave height, won't be resolved with further subdivision leading to more design categories. Nevertheless, as described in scenario 4, keeping the current status of RCD design categories and transposing category A upper limits from harmonised Standard EN ISO 12217 and in the same time adding more and simple technical information concerning maximum average wind speed, gust speeds and maximum wave height, will provide more clarity to end-users and will help safer use of the recreational craft.
19	Would additional specifications and/or further sub-divisions of current boat design categories allow the manufacturers (in particular SMEs) to better differentiate the categories of boat design?	The results of cost benefit analysis showed that subdivision of category D (scenario 1), to differentiate risks from H_s 1,5 m which is indicative wave height of BF 4 scale and subdivision of C (scenario 2), affecting 68% of the market, but without any sense if the upper limits remain the same, create millions of costs (ENPV of -65 m€ and -45 m€ respectively) without benefits. Scenario 3 with subdivision of category C and re-adjustment of ranges for total five categories is a technical or scientific improvement that differentiates categories in a way that reduces the steps of wind forces and aligns with WMO sea states which are announced in marine forecasts. Nevertheless, the extremely high cost with ENPV -1,175 billion €, makes it not appealing at all, especially for the SMEs which represent 97% of the sector (EBI, n.d.). Moreover, all this cost will be transferred to the consumers.
20	Provide the cost/benefit analysis for modification of current specifications and/or introduction of further sub-divisions of boat design categories	The results of cost benefit analysis showed that subdivision of categories D (scenario 1) and C (in scenario 2), cost millions of €, without providing benefits for the market. Subdivision of category C in scenario 3 and re-adjustment of ranges, costs 20 times more, reaching more than a billion, with three qualitative benefits that are not enough to call it cost beneficial. Only scenario 4 has zero cost and the qualitative benefits of clarity of information for safer use of the watercraft, legal certainty and full alignment with the international standardization for the potential future target of harmonisation of regulations and therefore is the preferred one.
21	To what extent do the stakeholders support the modification of current specifications and/or introduction of further sub-divisions of boat design categories?	According to the results of all consultations and interviews, stakeholders do not support any change or modification of current design categories set-up but the majority of them do support the setting of upper limits in category A. Additionally EBI supports the addition of maximum average wind speed, of gusts values as written in stability standard and of maximum wave height value in relation to significant wave height.

7.3.2 Conclusions

Based on the results of the desk research, all consultations and interviews and of the cost benefit analysis, the following conclusions can be drawn:

- All stakeholders are satisfied and they didn't criticize the current set up of RCD design categories, not because they are perfect or optimum, but based on the experience of five years implementation since the last amendment of the Directive, they confirmed that the main strength of the current set-up is that the market is running smooth with a high percentage of familiarity and consensus.
- The weakness of not having upper limits for category A, can be fixed by transposing the upper limits of harmonised stability Standard EN ISO 12217.
- The weakness of the unequal distribution of the design categories, can be fixed by increasing the total number of categories, but no tangible benefits can be substantiated in terms of safety and advanced stability or watercraft strength. Regarding proofs for safety benefits, there are no investigation reports from EMSA that report weather or environmental conditions as the causal factors for the accident in cases that the watercraft was sailing at the wind force and wave height of its assigned design category.
- There is no point in subdividing any category in half and keeping the same upper limits because it creates cost without benefits and also makes no sense since all boats will be assigned to the upper one.
- The possibility of subdivision of category D to differentiate risks in non-sheltered or inland waters in case of 1,5 m significant wave height, creates costs without any benefits. Moreover, according to information obtained from interviews, the maximum H_s rarely observed in Finland inland waterways is 0,9 m in winter period, so H_s of 1,5 m, which is the indicative probable maximum wave height in the Beaufort scale, is rather unlikely to occur in European inland waterways.
- There is technical or scientific improvement in subdivision of category C which covers more than two thirds of the market in combination with re-adjustment of ranges in most categories (see scenario 3). Although this distribution reduces the steps or increments of specified Beaufort forces and provides better alignment of categories with WMO sea states which are known from the marine forecasts, there is no evidence at all to prove it economically beneficial. It creates very high cost (ENPV of -1,175 billion €), extremely high for the 97% of the SMEs (EBI, n.d.) with qualitative benefits that can't outweigh the cost. The same negative cost benefit outcome is expected in similar cases of further subdivisions of categories resulting in six or seven or eight categories.
- The reality of the misunderstanding of Beaufort force and significant wave design categories by many end-users as explained in 5.2.7, will remain even with more or different design categories, because division criteria will be again the same.
- The choice of leaving the current status unchanged due to zero cost must be accompanied with slight modifications of transposing upper limits of category A (explained above) and enriching of explanatory notes with technical information (as described in scenario 4) in order to have the qualitative benefits of clarity of information for the end-user aiming at safer use of the watercraft, legal certainty and full harmonisation with international standardisation.

7.3.3 Recommendations

In order to implement the cost beneficial scenario 4 exactly in line with the last statement of the conclusions, the minor amendments of RCD are the following:

- Proposed amendment to the Annex I table for the category A, as shown in Table 7-1.

Table 7-1 Proposed change design categories legislation

WATERCRAFT DESIGN CATEGORIES		
Design category	Wind force (Beaufort scale)	Significant wave height (H 1/3, metres)
A	**up to, and including, 9**	**up to, and including, 7**

- Proposed revisions to the explanatory notes - modification of note A and addition of notes E and F:

A. A recreational craft given design category A is considered to be designed for a wind force up to, and including, 9 and significant wave height up to, and including, 7 m.

E. Maximum average wind speeds for categories A, B, C and D are 24,4 m/s, 20,7 m/s, 13,8 m/s and 7,9 m/s respectively. These values are taken from WMO No 306 Vol I.1 Part A 2019 edition. They depict the wind speed averaged over a period of 10 minutes at 10 meters above sea level. Depending on atmospheric conditions, gusts may temporarily increase the wind speed by about 30% to 50%.
F. The significant wave height is the mean height of the highest one-third of the waves, which approximately corresponds to the wave height estimated by an experienced observer. Maximum wave height may be double the significant wave height.

For the future, when technological developments in crafts design, propulsion means and in material technology will cause re-evaluation of stability and scantlings standards, the issue of the sufficiency of design categories may open again, giving enough time to all stakeholders and standardization organizations to reach to a consensus through elaboration of detailed impact assessments for all different types of recreational crafts. In the meantime, efforts should be focused in the objective to promote amendments in the European regulations to establish EMSA annual overview of accidents and incidents with a chapter exclusively for the recreational crafts' accidents, aiming at achieving gradually the same level of detailed information like the USCG reports. We must not forget that the vast majority of revisions of rules, regulations and standards do occur after fatal accidents and these kind of data will be valuable in any future impact assessment concerning safety issues of the watercrafts.

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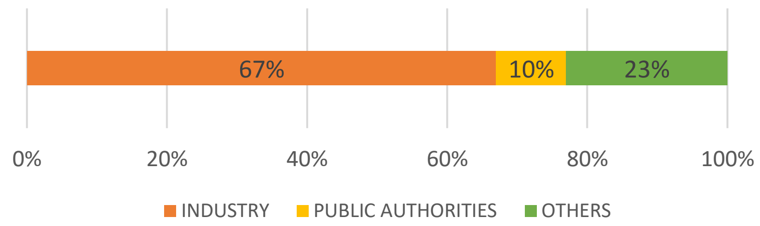
Annex 1 - Public consultation

The public targeted consultation on exhaust emissions focused on the feasibility of introducing requirements for air pollutant emissions and greenhouse gas emissions. The survey lasted for 8 weeks and was opened until March 14, 2021. The questionnaire was available in 6 languages (EN, GE, FR, IT, ES, PL).
A total of 32 responses were received, of which 2 responses were non-identified. All responses have been transferred to an Excel worksheet. These have been grouped and analysed by type of respondent (industry, public authorities, others), whereupon the replies of each question have been represented as stacked bar charts.

Figure A 1 Allocation of stakeholders participated in consultation

Stakeholder category	Sector	Survey Responses
Industry	Business association	10
	Company/business organization	9
	Other (Federation)	1
Public authorities	ministries, trade inspectorates etc.	3
Others	Notified Bodies/Technical Services	2
	Non-governmental organizations	1
	Academic/research institution	1
	EU citizens	1
	Non-EU citizens	2
	Non identified	2
Total		**32**

Figure A 2 Percentage of responses by respondent category



General observations are:

- In the answers all classes of recreational craft and all types of propulsion systems (excluding fuelcell based systems) are covered.
- The "INDUSTRY" group consists of two boat manufacturers, five engine manufacturers (3 of them producing outboard engines, the other 2 producing inboard or sterndrive engines). Ten boating industry organizations answered the questionnaire, 6 of which are members of EBI. Finally, also Euromot and ICOMIA filled in the questionnaire.
- In the "INDUSTRY" group 6 out of total 19 respondents were member of EBI (European Boat Industry) and provided answers that were almost identical to the response of that organization. In the "Others" group one respondent (EMCI) provided exactly the same answers as EBI. This is no surprise as EMCI is also member of EBI, although it is a Notified Body. As a result, the position of EBI is reflected in 9 of a total of 30 responses.

Exhaust emissions

General approach and organisation

The public targeted consultation on exhaust emissions focused on the feasibility of introducing requirements for air pollutant emissions and greenhouse gas emissions.

Figure 1 presents an indicative screenshot of a how the grouped questions by type of respondent have been analysed. This screenshot shown is for the responses by public authorities (as the number of respondents for the other groups were too large to retain visibility).

Figure A 3 Example of Excel worksheet indicating the organizational approach of the public consultation results analysis on the topic of exhaust emissions

	A	B	C	D	E	G	H	I	J	K	L	M
1	Public Authorities											
2		Organisation	Staatliches Gewerbeaufsichtsamt Cuxhaven	Ministry of Sustainable Infrastructure and Mobility	Swedish agency for marine and water management							
3		Resondent	Doris Hudtwalcker	Fabio Scotto	Fredrik Lindgren							
4		Position	Authorised Representative of Federal Council of Germany	Technical officer	Analyst	Numbers - corrected in red						
5	Question					Completely Agree	Somewhat agree	Neutral	Somewhat disagree	Completely disagree	Answers	No answer
34	1.11.2.1	*Justification*	No Answer	No answer	No answer							
35	1.11.3	*New fleet average CO2-emission levels*	No Answer	No answer	No answer	0	0	0	0	0	0	3
36	1.11.3.1	*Justification*	No Answer	No answer	No answer							
37	1.11.4	*Exempt some craft (in terms of power or type of engine) from CO2 regulation*	No Answer	Completely disagree	Somewhat disagree	0	0	0	1	1	2	1
38	1.11.4.1	*Justification*	No Answer	No answer	No answer							
39	1.11.5	*CO2-tailpipe emission label comparable to situation with passenger cars (Labels A to G)*	No Answer	Completely agree	Completely agree	2	0	0	0	0	2	1
40	1.11.5.1	*Justification*	No Answer	It is an instrument that can be immediately understood by the user	No answer							
41	1.11.6	*Introducing renewable fuels is more efficient than setting tailpipe emission limits*	No Answer	Somewhat disagree	Neutral	0	0	1	1	0	2	1
42	1.11.6.1	*Justification*	No Answer	The manufacture of renewable fuels has an energy cost	I think you should work with both solutions to lower the CO2 emissions from recreational crafts							
43												
44	Comment		Looks like private reaction. Not public authority reaction. Maybe ask for confirmation									
45												

Industry | Public Authorities | Others | Visualization tool

Analysis of the responses and main findings

The questionnaire included both closed and open format questions to cover the exhaust emission topic. Exhaust emissions in this questionnaire related both to emission of (air) pollutants as well as to emission of greenhouse gases, in particular CO_2.
Closed format questions have the form of multiple-choice questions, using a scale for rating (i.e., completely agree, somewhat agree, neutral, somewhat disagree, completely agree). Each closed format question was followed by one or more open ones to ensure that the opinions of respondents are accurately reflected. In the following, the results of the closed format questions are presented as stacked bar charts, while open format responses, due to their dispersion, cannot be presented quantitatively. However, these are used as arguments to justify the qualitative results.
This section describes the analysis of the responses to the questionnaire. First, general observations are given. After that, a more detailed analysis of the response to each the different answers is discussed separately.

General observations are:

- Not-identified responses have been retained in the questionnaire statistics.
- In the "INDUSTRY" group, one manufacturer (Yamaha NV) filled the questionnaire twice, with same/ very similar answers. For this reason, only one response was retained in the statistics.
- Some responses showed some contradictions. Where it was possible, the response was corrected in line with the justification of that respondent. In some responses 2 different boxes were ticked when answering the same multiple-choice question. Rather than excluding these responses, one of the selections was retained (while aiming to be as good as possible in line with the justification or other info in that questionnaire.

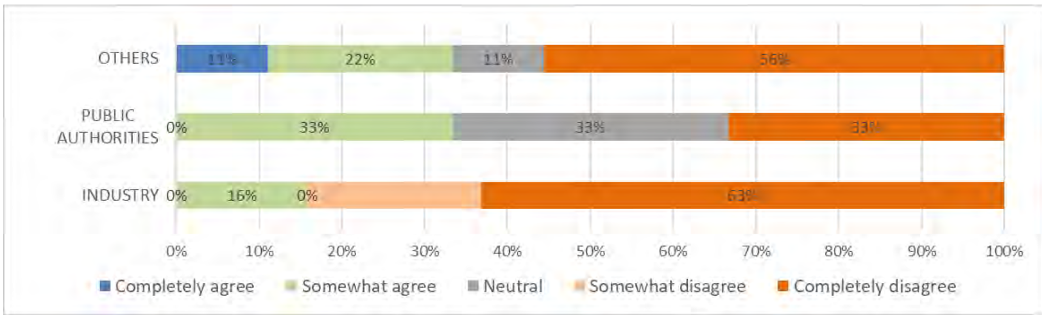
Below the different questions of the questionnaire are analysed one by one.

Q 1.1 "Often, the same type of engines used in recreational craft are also used in other on-road or non-road applications. In these other applications, lower pollutant emission levels are achieved. Sometimes, even additional pollutants are limited. Do you agree that a further pollutant emission

reduction with new recreational craft propulsion engines is possible without increasing the TCO?

Q 1.1.2 "Please indicate the kind of emission reduction technology you are planning to use, as well as the level"

Figure A 4 Response of question 1.1 for the three groups of respondents



It is clear that the majority of "INDUSTRY" and "OTHERS" respondents do not agree that a further pollutant emission reduction is possible without increasing the TCO of that craft. Focus in these answers was on the possible application of catalytic aftertreatment systems. Members of the boating industry organizations in general considered this to be not feasible because of increase in weight and volume of the engine. Further they mention issues with exhaust system durability and restrictions imposed by the application of a wet exhaust system in all recreational craft. Euromot agrees with this (but suggests aligning with US on CI engines with P < 37 kW). Only two respondents (not engine manufacturers) consider SCR/DPF resp. SCR aftertreatment for CI engines. Three respondents (out of which two sterndrive engine manufacturers) suggest 3-way catalytic aftertreatment for outboard engines (with an expected emission reduction between 40 and 70 %). This vision is not shared by the three outboard engine manufacturers
"PUBLIC AUTHORITIES" gave no justification for their responses. In the "OTHERS'' group technologies for emission reduction mentioned were mainly hybrid and electric propulsion (4 out of 7), SCR aftertreatment as well as limiting the performance envelope of recreational craft. One respondent in that group further disagreed with the premise in question 1.1. (i.e., that lower pollutant emissions are achieved in other application) on the basis that these other applications have a different use-profile (suggesting that their lower emissions follow from this use-profile).

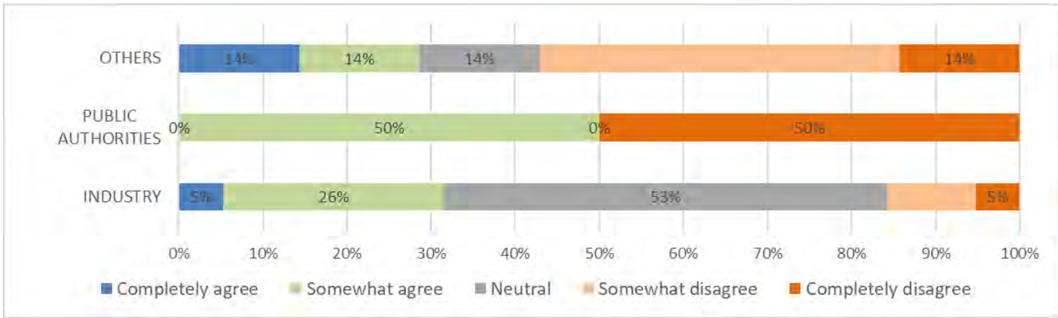
Q 1.2 "How much time do you think would be needed to introduce this technology onto the market? Please justify your answer?"

"INDUSTRY" mentions 5 to 10 years as time need for implementation of exhaust aftertreatment technology with large CI engines (P > 37 kW). Less for smaller ones. There is more variation in the time needed for implementing 3-way catalytic aftertreatment with outboard engines. Estimates vary in the range 2/3 years, 3 – 5 years (based on time needed for introduction of 3-way catalytic aftertreatment on inboard and sterndrive engines), respectively 5 – 10 years (outboard engine manufacturers estimate).
"PUBLIC AUTHORITIES" provided no additional info. "OTHERS" respondents mention up to 15 years for aftertreatment with CI engines and 5 to 10 years for the introduction of hybrid technology.

Q 1.3 Would you agree with pollutant emission reduction measures that increase the TCO of recreational craft, but where this cost increase is fully compensated by reduction of negative effects on a third party from the use of a product (e.g., an increase in life expectancy)?

Q 1.3.1 Please explain why you would (not) support this.

Figure A 5 Response of question 1.3.1 for the three groups of respondents



From the statistics it seems that most responses are either positive or neutral. However, some respondents mistook third party life expectancy as that of other parts of the recreational craft. Also, many "INDUSTRY" respondents filled in 'Neutral' but continued (as part of Q1.3.1) to categorize exhaust aftertreatment as disproportional (given the low number of recreational craft operating hours). The limited possibility to increase vessel retail price was an additional argument for not supporting the premise in Q 1.3. This was confirmed by one member of the "OTHERS" group who claimed that emission reduction technology would result in a major redesign and more costly and heavier craft (where higher weight in turn results in higher fuel consumption).

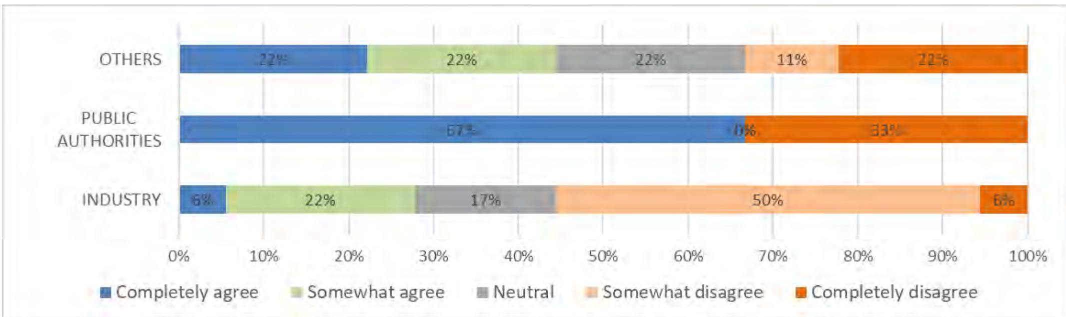
Q 1.3.3 "If you support a reduction of pollutant emissions, what TCO increase (in %) would be acceptable to?"

Q 1.3.4 "What kind of emission reduction technology would you consider using to reduce pollutant emissions?"

Question 1.3.3 only received two widely varying values ("OTHERS") for an acceptable TCO increase (+ 5 % respectively 50 %). "INDUSTRY" and "PUBLIC AUTHORITIES" did not answer. Reactions to question 1.3.4. (where given) were more or less a repetition of the answer to Q 1.1.2.

Q 1.4 Using technologies to reduce emissions (of pollutants and/or greenhouse gases) might result in a propulsion system that takes up more volume. This would reduce the space available for other purposes (e.g., storage or accommodating occupants), but would be offset by cleaner air and water. Under these circumstances, would you still agree to a reduction of emissions?
Q 1.4.1 How much volume (in litres) would you be prepared to give up in order to introduce such technologies? Please justify your answer.

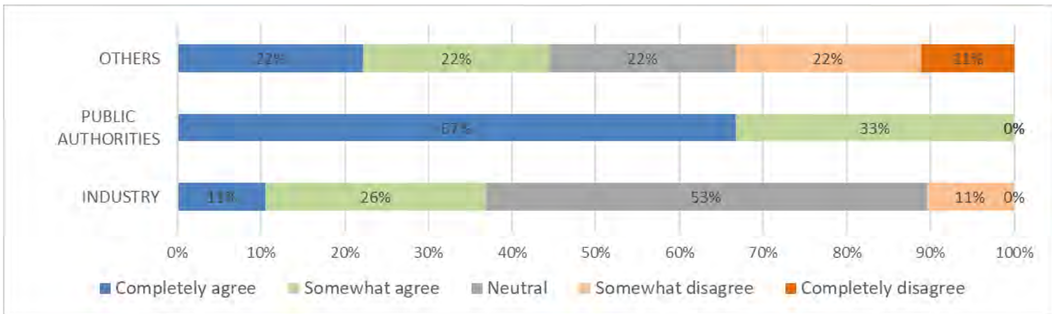
Figure A 6 Response of question 1.4 for the three groups of respondents



"INDUSTRY" answers to Q 1.4 are predominantly negative, whereas "PUBLIC AUTHORITIES" and "OTHERS" are slightly in favour. As to Q 1.4.1, no indication was given by "INDUSTRY" and "PUBLIC AUTHORITIES" on the volume that they would be prepared to give in return for lower emissions. Amongst the "OTHERS", one respondent (active in boat design) suggested that for pleasure craft larger than 35 ft. (10,67 m) with sterndrive propulsion (< 200 kW) the engine room could be enlarged with 10 % to allow for hybridization of the propulsion system.

Q 1.5 "Noise and pollutant exhaust emissions from recreational craft could be reduced if national or local authorities impose maximum speed limits (in certain areas/zones and/or during parts of the day). Do you agree that such tailor-made measures are more efficient than setting general limits?"
Q 1.5.1 "And would this be a sufficient option? Please justify your answer."

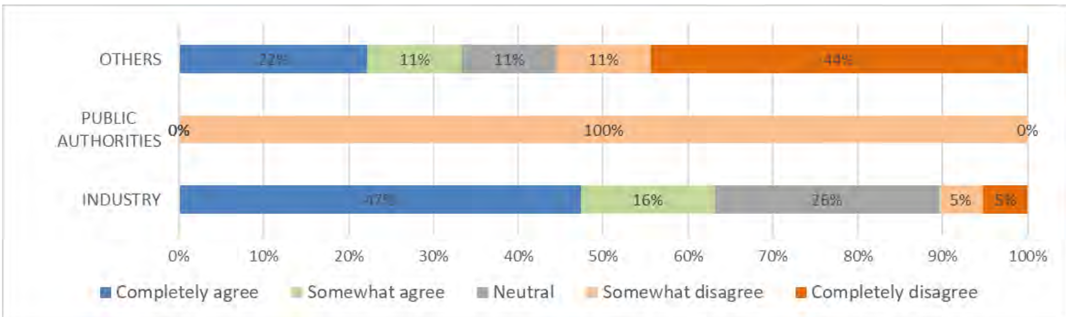
Figure A 7 Response of question 1.5 for the three groups of respondents



The majority of "INDUSTRY" stakeholders take a neutral position or seem to agree with local limitations towards recreational craft use. However, most of these stress that they do not consider this as a part of a future recreational craft directive (as such directive is aimed at taking measures on a European level). One respondent points out that limiting power will result in lower exhaust system temperatures, which in turn may result in low efficiencies of catalytic systems.
"OTHERS" stakeholders are more divided on that issue. In their reactions some "OTHERS" stakeholders also point out that such limitations are not part of a recreational craft directive and that such limitations are already in place in many places. One stakeholder suggested that limiting speed may result in larger consumption.
"PUBLIC AUTHORITIES" tend to be positive towards imposing local limitations (but it is not mentioned that they see this as an alternative to a regulation in a recreational craft directive).

Q 1.6 "Current pollutant emission limits for engines of a given maximum power vary for different driveline configurations (e.g., limits are different for outboard engines/engines for personal watercraft (PWC) compared to limits for engines located inside the boat). In addition, these limits can be different depending on what engine type is being used (for instance spark ignited or diesel, two-stroke or four- stroke). Therefore, the emission legislation is not technology neutral. Do you agree that the current emission legislation, which is not technologically neutral, should be continued?"
Q 1.6.1 "Please justify your answer?"

Figure A 8 Response of question 1.6 for the three groups of respondents



It is clear that "INDUSTRY" stakeholders are very much (63 %) in favour of sticking to the current approach where different limits apply to different engine technologies. The arguments that are mentioned to support this position are that this is necessary to retain a harmonisation of legislation with the US. Further it is pointed out that different propulsion systems have different advantages (without specifying these advantages) and that unifying limits could even discourage innovation. Further it is argued that imposing the same limits for outboard engines as for other engines would spoil these advantages. There are however also dissenting industry stakeholders. ICOMIA states

that it is important not to favour one technology over another. And one engine manufacturer states that (in recent years) SI outboard and CI sterndrive engines have proliferated disproportionally being allowed a price advantage due to lack of necessity for exhaust aftertreatment systems.
The answers in "PUBLIC AUTHORITIES" and "OTHERS" tend to be more in favour of a technologically neutral approach. Several of these stakeholders stress the importance of a level playing field.

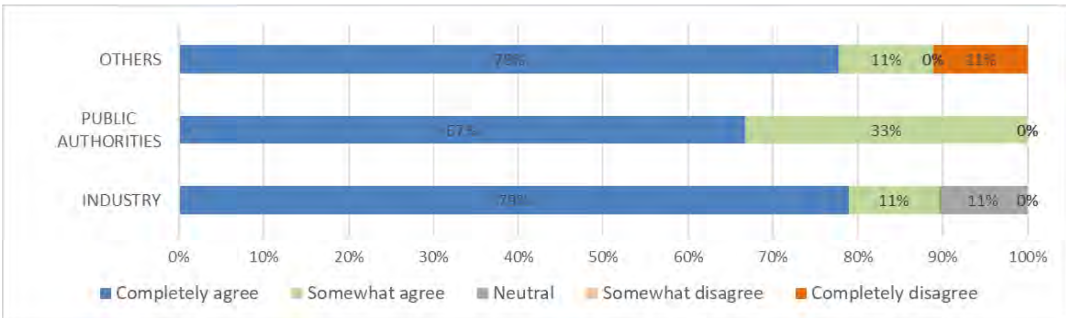
Q 1.6.2 "In your opinion, what would be the consequences of a possible switch to technology-neutral pollutant emission legislation for different driveline configurations and engine types? Please justify your answer."

Only some "INDUSTRY" stakeholders have answered this question. The majority of these answers give the message that a technologically neutral emissions limitation would likely result in the phasing out of certain engine types. Such approach would be different from that followed in the US. This would result in product development for the EU market alone. Such development would be uneconomical because of the higher product cost. With the phasing out of some engine types also the corresponding employment would be lost. Only a small number of these answers welcome tech-neutrality as a means to rebalance the market.
'PUBLIC AUTHORITIES" did not answer this question.
Amongst the "OTHERS" stakeholders tech-neutrality is not so much seen as a threat. Only one respondent mentions the ensuing challenge for SME. Another respondent points out that sufficient time should be allowed for new technology to be introduced (e.g., for electrification).

Q 1.7 "The Recreational Craft Directive should anticipate the appearance of new driveline technologies, such as hybrid propulsion systems. Do you agree that the impact of these new driveline technologies on pollutant emission test and certification procedures should be investigated?"
Q 1.7.1 Do you have any suggestions in this respect?

From the results shown in Figure A 9 it is clear that almost all stakeholders support to investigate the impact of new driveline technologies on pollutant emissions test and certification procedures. When looking into the additional info in the answers to Q 1.7.1 it is clear that not only hybrid but also electric propulsion systems are considered as near-term candidates. In fact, 4 "OTHERS" stakeholders claim that electric solutions are better than hybrid ones.

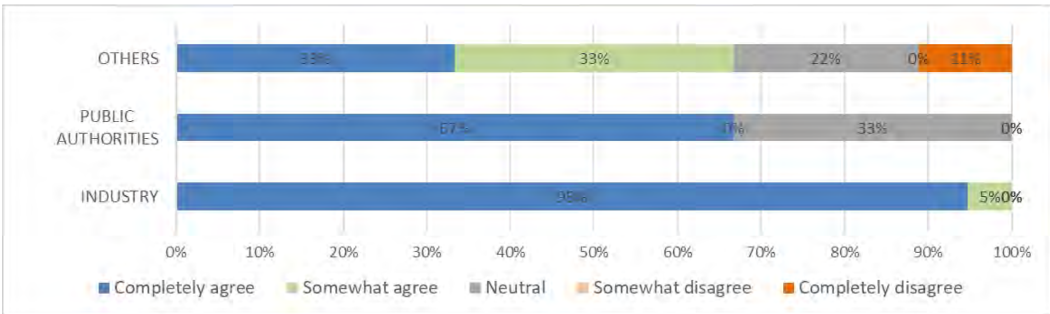
Figure A 9 Response of question 1.7 for the three groups of respondents



There are also some critical observations on the implementation of hybrid driveline technology for recreational craft: (1) hybrid systems weigh more, (2) unlike with automotive applications, brake energy recuperation is not feasible, (3) the cost-effectiveness of implementing hybrid propulsion systems is questioned.
In the answers to Q 1.7.1 no suggestions are presented on how current tests or procedures should be adapted. In the majority of the answers, it is not clear whether they believe that such testing should be on propulsion system level or on engine level. However, ICOMIA points out that they are working together with Euromot to accommodate hybrid propulsion systems in the recreational craft directive. Their ideas very likely go in the line of a modified engine test and certification procedure, since Euromot mentions that engine emission certification should be driveline-independent (inclusive of hybrid propulsion systems).

Q 1.8 The EU regulates exhaust emission of air pollutants in the recreational craft sector. Regulations also exist elsewhere in the world, but the limit values and corresponding test procedures can differ. Do you agree that the EU regulation should be harmonised with those elsewhere in the world?
Q 1.8.1 Please justify your answer.

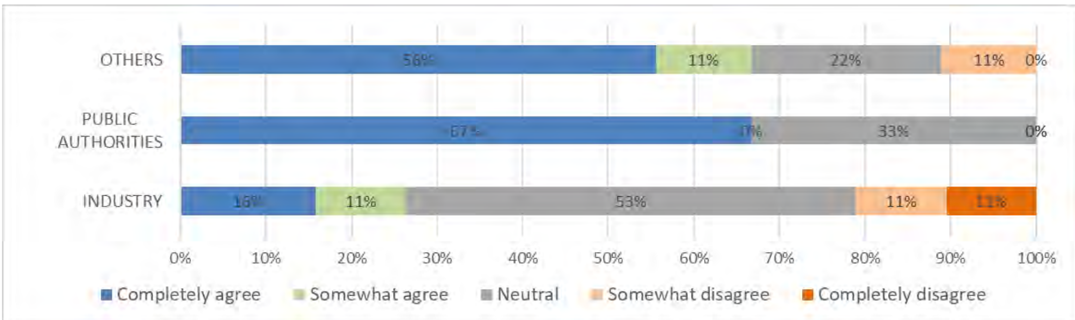
Figure A 10 Response of question 1.8 for the three groups of respondents



The "INDUSTRY" stakeholders are unanimous in their support for a harmonised emissions regulation. The arguments for such harmonisation are that this is needed to remain cost-effective as an industry given the small production numbers of recreational craft. Only one (not identified) "OTHERS" stakeholder disagrees without giving arguments.

Q 1.9 "Do you agree that the EU should aspire to lead the efforts to reduce emissions in the sector?"
Q 1.9.1 "Please justify your answer."

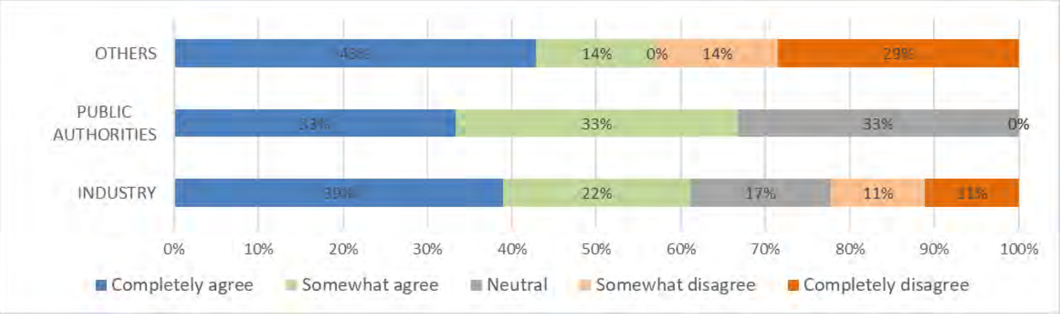
Figure A 11 Response of question 1.9 for the three groups of respondents



The majority of "INDUSTRY" stakeholders take a neutral position, with in addition more positive than negative responses. At first this seems somewhat surprising as taking a lead in imposing further (pollutant) emissions limitation would be in conflict with the objective of maintaining a harmonised legislation. When looking at the justification comments in answer to Q 1.91.1 it seems that these stakeholders look for the EU to take the lead outside of the recreational craft directive framework. In fact, some answers again stress the all importance of harmonisation. Only a few respondents believe that EU should also take the lead in imposing stricter emissions legislation. "PUBLIC AUTHORITIES" did not answer Q 1.9.1, and answers in "OTHERS" again mention the need to take action in cooperation with EPA (US).

Q 1.10 "Would you agree with the introduction of an emission label to stimulate the implementation of technologies that reduce the emission of pollutant gases?"
Q 1.10.1 "Please justify your answer."

Figure A 12 Response of question 1.10 for the three groups of respondents



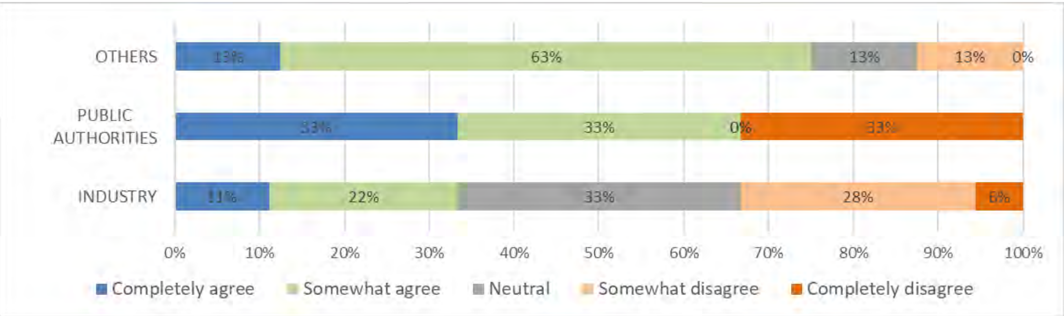
Although the majority of "INDUSTRY" stakeholders indicate a positive attitude towards the idea of an emissions label, in their justification (where given) most mention reasons for not completely agreeing. These reasons are listed below.

- Instead of regulating tailpipe emissions, overall life-cycle emissions should be regulated
- Introducing an emissions label for every recreational craft would be challenging. Because the industry is not vertically integrated and because of the small series numbers the effort of introducing such a label would lead to an excessive cost increase to the boat manufacturer. As one respondent put it: "the effort is not in line with the size of the market".
- In line with the above statement: one should start with engine labels. Reference is made to the Emission Control Information (ECI) labels that are in use in the US (EPA and CARB).
- These engine labels should discriminate between engine types.

"PUBLIC AUTHORITIES" again provided no answers to Q 1.10.1. Answers of "OTHERS' were in-line with the comments listed above. Only one stakeholder supported the idea of labelling craft and not engines.

Q 1.11 "Do you agree that CO_2 emissions from recreational craft should be regulated?"
Q 1.11.1 "Please justify your answer."

Figure A 13 Response of question 1.11 for the three groups of respondents



Overall, both "INDUSTRY" and "PUBLIC AUTHORITIES" take a balanced position with as many stakeholders agreeing as disagreeing. In their responses to Q 1.11.1 it is clear that the majority expects some form of CO_2 regulation in the future (for fairness in comparison to other sections of industry), although it is stressed that recreational craft only have a limited contribution to the overall greenhouse gas emission. Further a number of challenges and suggestions are mentioned by "INDUSTRY" stakeholders. The main points that were raised by them are summarized below:

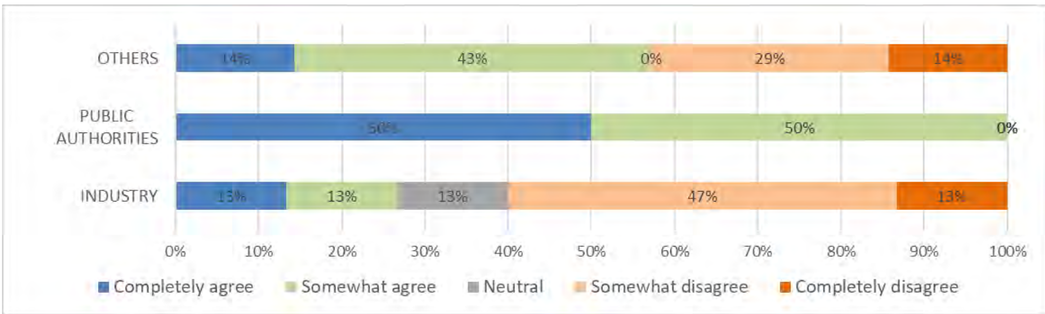
- Regulating CO_2 emission (on craft-level) is impractical/disproportionate given the large variety in craft design and use cases (and even driver behaviour).
- Imposing fleet-average CO_2-emission limits will be difficult to achieve as industry is not vertically integrated (in meeting CO_2 targets, boat manufacturer will depend on the performance of supplier engines) and will add considerably to the costs (of boat manufacturing).

- Alternatively, regulation could be done on engine level (GHG emission per kWh)
- Action should be coordinated with the US.
- The members of EBI propose the introduction of other technology (electric propulsion and renewable fuels) as a better alternative.

The responses of the "OTHERS" show more support of the idea; especially the idea of recreational craft contributing its share to the global GHG reduction is – in different forms/phrasing- mentioned several times.

Q 1.11.2 "Do you agree that a regulation of CO_2 emissions should apply to all types of recreational craft and in the same way?"
Q 1.11.2.1 " Please justify your answer."

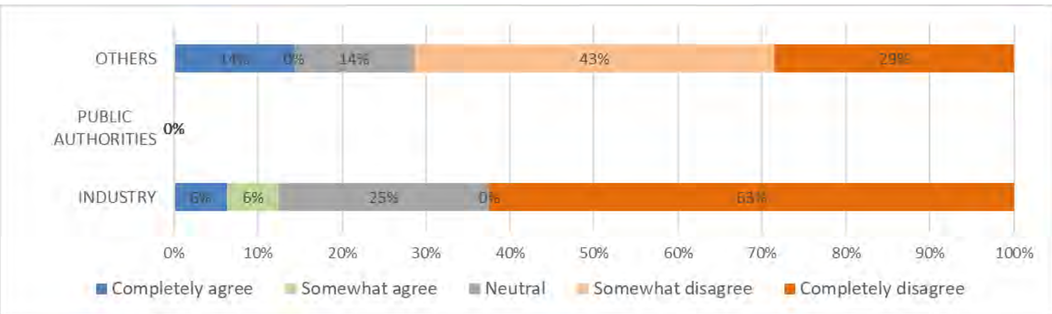
Figure A 14 Response of question 1.11.2 for the three groups of respondents



The majority of stakeholders from the "INDUSTRY" disagree with the premise in Q 1.11.2. The main arguments raised to explain this (as part of Q 1.11.2.1) are that it is difficult to regulate on craft level (consistent with the reactions to Q 1.11.1), and that a standard procedure is lacking. One boat builder expressed his concerns that exemptions will only lead to loopholes to not implement changes.
"PUBLIC AUTHORITIES" again provided no answers to Q 1.11.2. One stakeholder in the "OTHERS" group suggested that a CO_2 emission regulation may be something for luxury yachts (implying other craft should be exempt).

Q 1.11.3 "Do you agree that new fleet average tailpipe emission levels for CO_2 emissions should be set for recreational craft?"
Q 1.11.3.1 "Please justify your answer."

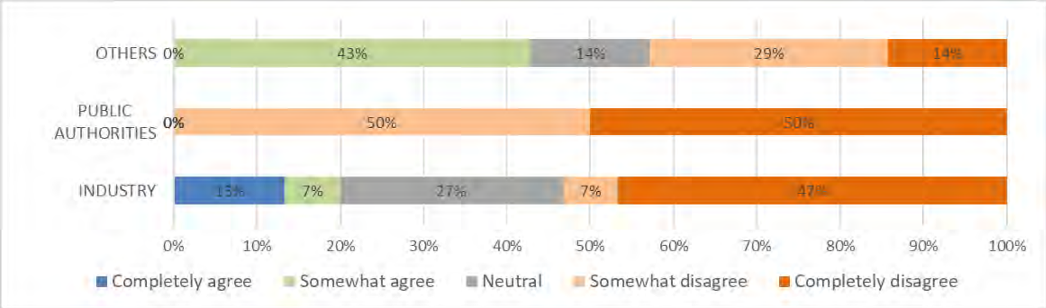
Figure A 15 Response of question 1.11.3 for the three groups of respondents



Most respondents clearly oppose the idea of imposing fleet-average CO_2-limitations. Arguments brought in by "INDUSTRY" are in line with the comments made in Q 1.11.1, or directly refer to those answers. In addition, the members of EBI feel that such measure is not suitable for the recreational craft directive.
"PUBLIC AUTHORITIES" have not replied to this question. "OTHERS" are also in majority opposing but provided only a limited number of justifications. One stakeholder was concerned about the impact of import/export on such numbers.

Q 1.11.4 Do you agree that there is a need to exempt some recreational craft – in terms of power range (in kW) or type of engine - from such CO_2 emission legislation?
Q 1.11.4.1 Can you please justify your answer?

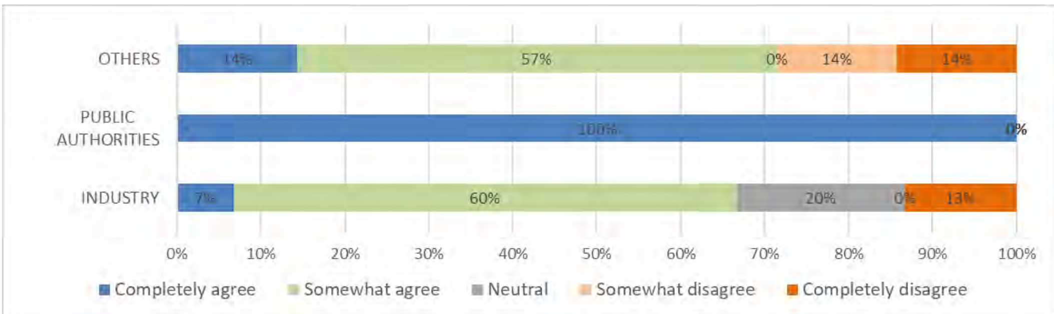
Figure A 16 Response of question 1.11.4 for the three groups of respondents



Seven out of 32 respondents did not answer to Q 1.11.4. Of the remaining 15 answers by "INDUSTRY" stakeholders, the majority are seen to oppose exemption of some craft. They give however little extra arguments. In responding to Q 1.11.4.1 they almost all refer to previous answers. One boat builder indicated that an exemption to meet with CO_2 limitations should be on the basis of total installed power, in order to avoid the application of several small engines – each of which with exemption to CO_2 limitation – on one boat.
Both "PUBLIC AUTHORITIES" that reacted oppose exemption. In the group of seven "OTHERS" stakeholders that reacted, there was more support for exemption.

1.11.5 "New passenger cars on sale display a CO_2 emission label. This label indicates that the CO_2 emission of that car falls in one of seven (subsequent) ranges (called A to G). Do you agree that a similar CO_2 tailpipe emission label should be introduced for recreational craft?"
1.11.5.1 "Please justify your answer."

Figure A 17 Response of question 1.11.5 for the three groups of respondents



Again 7 out of 32 respondents did not answer to Q 1.11.5. From Figure A 17 it is clear that there is considerable support for the idea of an CO_2 emission label with the ones that did respond. For a justification by the 15 "INDUSTRY" stakeholders for not completely agreeing with this idea, they refer to their previous answers, i.e. concerns about the impact of variation in boat type and use cases (in setting targets on craft-level).
Of the "PUBLIC AUTHORITIES" only one provided a justification for his complete agreement, indicating that it would be an instrument that can be immediately understood by the user.
The justifications of the 7 stakeholders in the "OTHERS" group that reacted included the suggestion that this should be done on engine (and not craft) level. One respondent pointed out fuel consumption is not a major issue with recreational craft (contrary to range).

Q 1.11.6 Do you agree that introducing renewable fuels for recreational craft would be more efficient than setting tailpipe CO_2 emission limits in decreasing the amount of CO_2 emissions emitted by recreational craft?
Q 1.11.6.1 Please justify your answer?

Figure A 18 Response of question 1.11.5 for the three groups of respondents

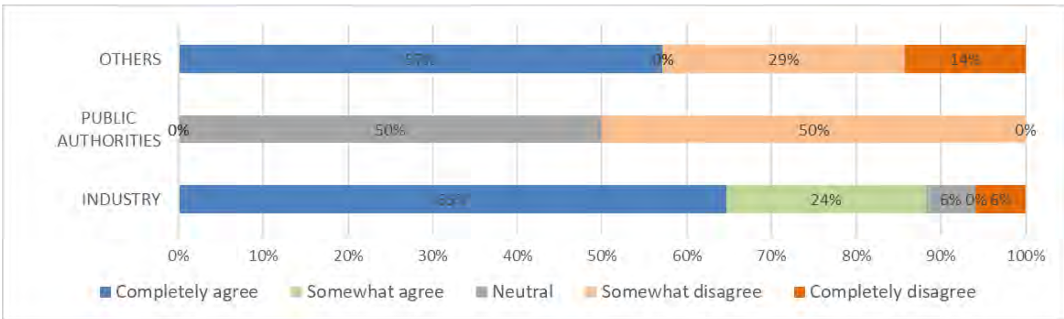


Figure A 18 illustrates that "INDUSTRY" stakeholders are very much in favour of this. The main argument that they raise in justifying this (in response to Q 1.11.6.1) is that renewable fuels would address greenhouse gas emissions for both existing and future fleets. Further one boat builder raised a concern about infrastructure falling behind. "OTHERS" were in majority also positive. Reasons for not agreeing was that the production of renewable fuels was not a pleasure craft issue but an energy supply issue. One public authority explained his neutral position by stating that introducing renewable fuels should come on top of measures to reduce CO_2 emissions. Another public authority pointed out that producing renewable fuels comes at an energy cost.

Evaporative emissions

General approach and organization

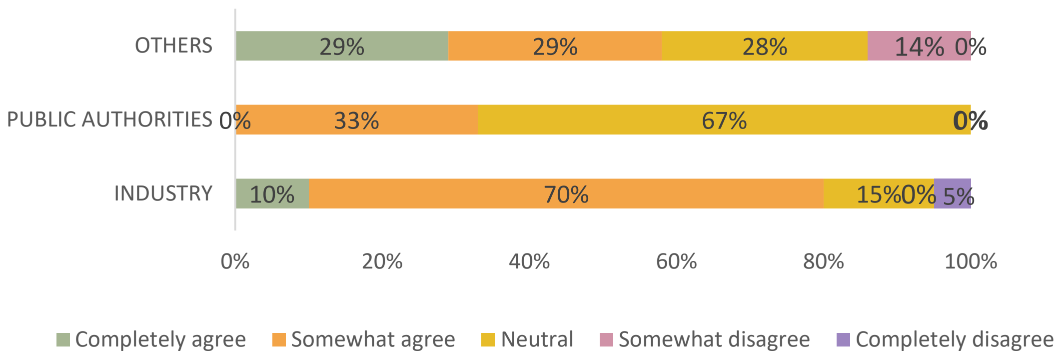
The public targeted consultation on the evaporative emissions topic focused on the feasibility of introducing requirements for evaporative emissions, the necessity of regulating all or part of the different evaporative emission sources in the EU environment, the available technologies to achieve the desired emissions reductions, as well as the associated costs.

Analysis of responses and main findings

The questionnaire included both closed and open format questions to fully cover the evaporative emission topic. Closed format questions have the form of multiple-choice questions, using a scale for rating (completely agree, somewhat agree, neutral, somewhat disagree, completely agree). Each closed format question was followed by an open one to ensure that the opinions of respondents are accurately reflected. In the following, the results of the closed format questions are presented as stacked bar charts, while open format responses, due to their dispersion, cannot be presented quantitatively. However, these are used as arguments to justify the qualitative results. The main conclusions of the targeted consultation are summarized in the following.

Q 2.1. "The evaporative emissions on recreational craft are not currently regulated at the EU-level. Do you agree that they should be regulated?
Q 2.1.1. "Please justify the answer of Q2.1.

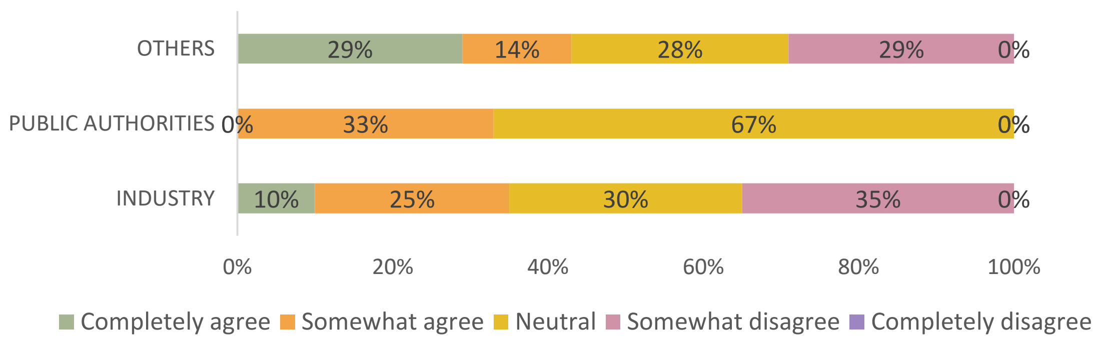
Figure A 19 Response of question 2.1 for the three groups of respondents.



The vast majority of "industry" and "others" respondents strongly support the evaporative emissions regulation in the EU. Nevertheless, a number of stakeholders raise objections to adopt US EPA regulations arguing that the latter are not necessarily suited to tackle the environmental challenges in Europe. In addition, they support finding suitable solutions to address evaporative emissions with a bottom-up approach looking at the main sources of evaporative emissions in the European environment for recreational crafts. On the other hand, some stakeholders strongly recommend EU evaporative emissions regulations should be harmonised with the current US EPA limits with the same compliance methods.
Two thirds of "public authorities" respondents have expressed a neutral position and the rest suggest including future provisions.

Q 2.1.2." Do you think that provisions for evaporative emissions should be applied to all recreational craft covered by the Recreational Craft Directive (e.g., sailboats / yachts, inboard / sterndrive motorboats, outboard motorboats, inflatable boats, PWCs, etc.)?"
Q 2.1.3." Is there any recreational craft category that should be excluded? Please justify your answer."

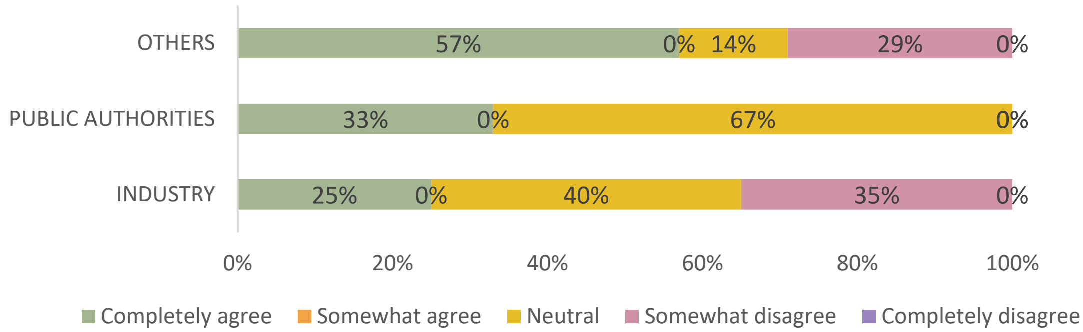
Figure A 20 Response of question 2.1.2 for the three groups of respondents.



About 35% of "industry" stakeholders support the implementation of provisions for all recreational craft boat categories covered by the Recreational Craft Directive (RCD), while the same percentage argue that several boat categories should be excluded to avoid disproportional impact, as boats with permanent installed fuel tanks, sailing boats using as main propulsion system wind or electricity, considering the size and category.
More than two thirds of "others" stakeholders are in favour of introducing evaporative emissions provisions, while they suggest exclusion of several types of crafts, such as sailing boats due to their limited petrol-powered propulsion systems in EU.
Two thirds of "public authorities" respondents do not have an opinion, while the rest one third express a positive orientation.

Q 2.1.4." Do you agree that provisions for evaporative emissions should be applied to all petrol engine types (stern-drive, inboard, outboard and PWC) and engine power classes covered by the Recreational Craft Directive?"
Q 2.1.5." Is there any petrol engine type or engine power class that should be excluded? Please justify your answer."

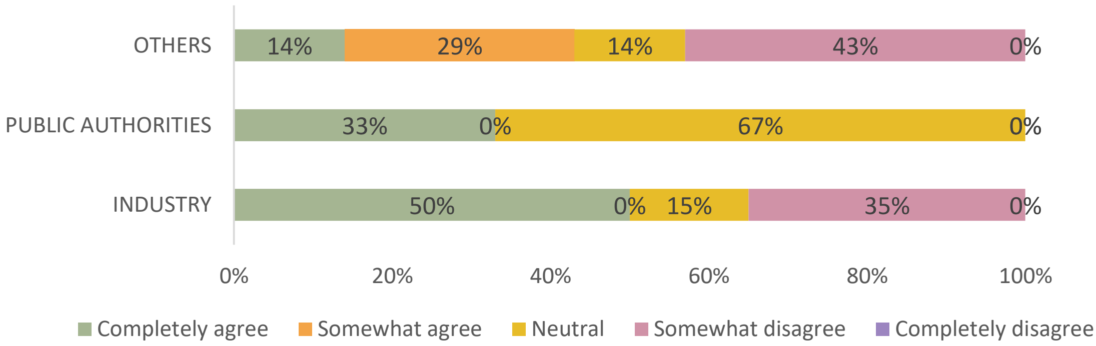
Figure A 21 Response of question 2.1.4 for the three groups of respondents.



The overall responses concerning the introduction of provisions for all petrol engine types do not show a clear preference. More specifically, the majority of "industry" respondents express a neutral position with a percentage of about 40%, a 35% is strongly against the inclusion of all petrol engine types without first conducting an impact assessment and the remaining 25% is positive to the total inclusion.
Concerning "others" group, more than half of them embrace future provisions for all petrol engine types. Others suggest excluding outboard engines which have fuel tanks on the engine due to their really small size, such as these, whose power output is below 10 kW.
Two thirds of "public authorities" respondents does not express a clear position, while the rest follows a further positive orientation.

Q 2.2." If evaporative emission standards were to be introduced in the Recreational Craft Directive, do you agree that they should be harmonised with other global values for the sector, for example such as those in US legislation?"
Q 2.2.1 "Please justify the answer of Q2.1."

Figure A 22 Response of question 2.2 for the three groups of respondents.

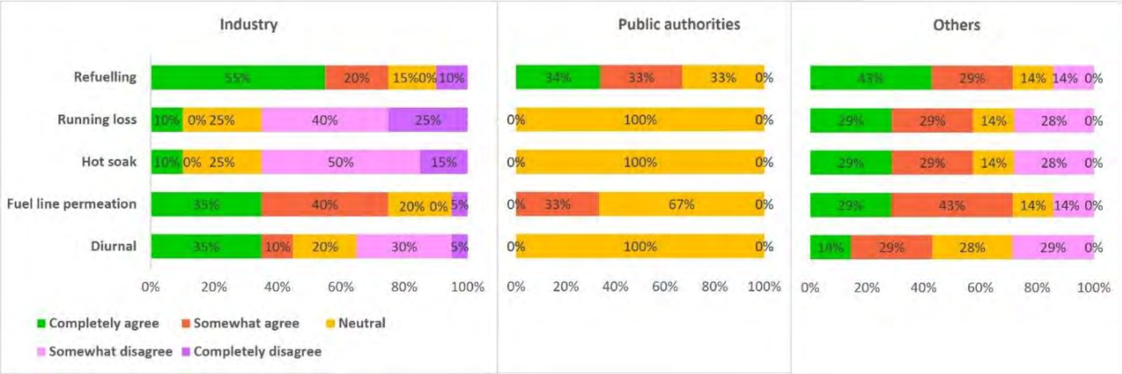


The majority of "industry" stakeholders are in favour of harmonisation with the US legislation to minimize the costs of new requirements or compliance's implementation, to simplify product exports to the US as well as to avoid single-handed development costs by recreational marine engines sold in Europe. On the contrary, they have raised concerns on the full introduction of evaporative emission requirements from the US Code of Federal Regulations, as they might not be necessarily appropriate to the EU conditions.
Not a clear preference is observed by "others" on harmonisation with US regulations. Approximately 43% of them agree with US harmonisation, as a key to trade, while the same percentage supports that the US conditions are different and thus no applicability to the EU is feasible.

The vast majority of "public authorities" respondents preserve a neutral position and the remaining of them tend to be positive on global harmonisation.

Q 2.3 "Do you agree that the below evaporative emission sources should be regulated?"
Q 2.3.1 "Please justify the answers of Q2.3."

Figure A 23 Response of question 2.3 for the three groups of respondents



The responses on which evaporative emission sources should be regulated are analysed as follows:

- About 45% of "industry" stakeholders recommend not only the regulation of diurnal emissions but the adoption of EPA/CARB regulation also. On the other hand, for 35% of them, the EU diurnal emissions are likely of a smaller magnitude, as boats tend to stay in-water during the season and are then taken out of the water and winterized, avoiding significant temperature fluctuations. This position is reinforced by the use of ventilation systems for both inboard and outboard crafts, which leads to lower evaporative emissions.
  A 43% of "others" group agree with diurnal emissions regulations, while about 29% express their disagreement and the remaining 29% are neutral to this issue.
  Totally, neutral position is held by "public authorities" respondents on diurnal emissions regulation.
- More than 70% of "industry" and "others" respondents consider fuel tank and fuel line permeation emissions must be regulated. In particular, the majority of respondents recommend following the US EPA regulation, while others support only the regulation of fuel hose permeation emissions through new standards set for the materials used. This perspective is enforced by the small size of the EU tanks due to their use for outboard applications, which consequently establish fuel tank permeation irrelevant for the EU conditions.
  "public authorities" respondents have expressed a neutral position on fuel tank and/or hose emissions regulation.
- Approximately 65% of "industry" respondents are not in favour of regulating hot soak emissions as they consider that recreational crafts are not an important source of evaporative emissions due to their extremely short operation time compared to the time not being used. The rest 35% of them strongly recommend adopting the existing US EPA regulation on hot soak emissions topic.
  The majority of "others" group agree with hot soak emissions regulation.
  "public authorities" do not have a strong opinion on hot soak emissions regulation.
- The majority of "industry" stakeholders are opposed to the running loss emissions regulation in the EU, underlining their small contribution to evaporative emissions of recreational craft sector.
  The same aspect is supported by one third of "others" stakeholders, while the remaining two thirds are in favour of running loss emissions regulation.
  "public authorities" do not have a strong opinion on running loss emissions topic.
- About 75%, 66% and 72% of stakeholders from "industry", "public authorities", and "others", respectively, agree with refuelling emissions regulation. A common request is to follow the same levels and the existing US EPA regulation.

Q 2.4 "In your opinion, which emission control technologies can be used to regulate evaporative emission levels and what emission levels can these technologies achieve?"

Table A 1 Overall responses of question 2.4

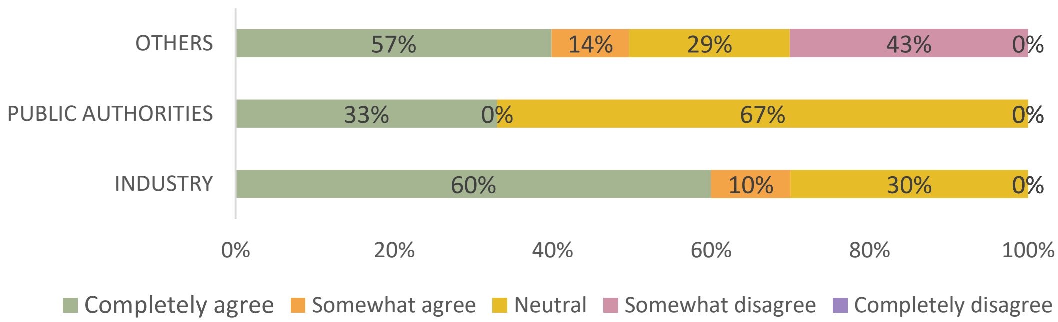
Recreational craft category	*Technology*	*Emission levels achievable (e.g., in grams/day)*	*Current costs of this technology (€/recreational craft)*
	Fuel line permeation with specific material that reduces permeation. Refuelling requirement for fuel stations for automatic shut-offs. Boat-builders to consider refuelling emissions during design. Minimum tank capacity for evaporative emissions requirements.	US requirements have limit value of 15 g/m2/day	
Outboard motorboats	Diurnal: canister and/or pressure valve for fuel tank Permeation from fuel tank/ hose: addition of a barrier layer.	EPA / CARB regulated level	confidential information
outboard motorboats, inflatable boats	Pressure relief valve Canister Cap torque stabilizer		10 €/recreational craft

Q 2.5 "If evaporative emissions provisions were to be introduced, please indicate any additional costs you would incur related to basic investment, engine calibration, certification, warranty, or other production costs related to recreational craft."

Responses on costs appear to be poor or not specific, possibly, due to confidentiality issues. Although, the majority of respondents agree that the introduction of evaporative emissions provisions will incur additional costs. More specifically, the installation costs of fuel tank as well as of fuel system are estimated to be 2.5-3 times higher than the current price in order to make each craft compliant. Additionally, it is stated that the subdivision of fuel tanks, carbon canisters, filler caps, hose clamp standards, etc. are relatively cost effective and within the scope of their developments, thus any step beyond this might have impact on retail price and development time schedules. Another argument is that if the emission control parts must be monitored like EPA's warranty, the cost of management for warranty and service will increase. In general, costs related to basic investment, engine calibration, certification, warranty, or other production costs should be considered.

Q 2.5.1 "Do you agree that these additional costs would increase the final price and/or affect the competitiveness of the product?"

Figure A 24 Response of question 2.5.1 for the three groups of respondents



Based on these cost-relative responses, about 70% of "industry" and "others" stakeholders, indicate that the final price will be increased, introducing these additional costs, and consequently will affect the competitiveness of the product.
The majority of "public authorities" stakeholders do not have an opinion on this issue.

Watercraft design categories

General approach and organization

The public targeted consultation, on watercraft design categories topic, focused on how the current set-up of watercraft design categories affects manufacturers and consumers; it provided with the opportunity to suggest additional specifications and sub-categories of watercraft design categories, if needed. Four questions were based on desk research results providing specific suggestions on additional subdivisions of design categories D and C.

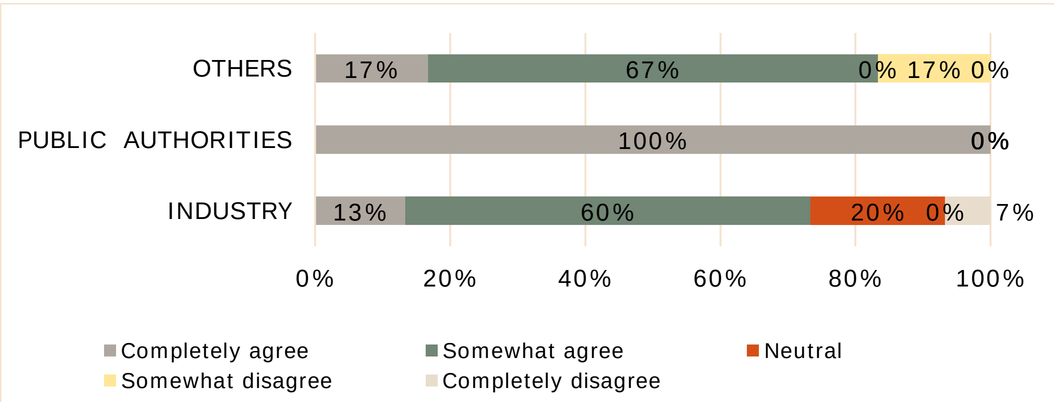
Analysis of the responses and main findings

The questionnaire included both closed and open format questions in order to cover the design categories topic. Closed format questions have the form of multiple-choice questions, using a scale for rating (completely agree, somewhat agree, neutral, somewhat disagree, completely disagree). Some closed format question was followed by an open one to ensure that the opinions of respondents are accurately reflected. In the following, the results of the closed format questions are presented as stacked bar charts, while open format responses, due to their variety, cannot be presented quantitatively. However, these are used as arguments to justify the qualitative results. One general observation is the absence of end-users' associations as respondents, causing the results to be dominated by the Industry.
To be noted that since we had "no answer" to all questions by seven stakeholders (five engine manufacturers from "industry", one public authority and one individual from "others", probably due to no expertize on the subject, these responses were excluded from the charts.

The main conclusions of the targeted consultation are summarized in the following:

Q3.1: Do you agree that the current specifications (wind force and significant wave height) and/or divisions (A, B, C, D) of watercraft design categories provide sufficient and clear information to manufacturers?

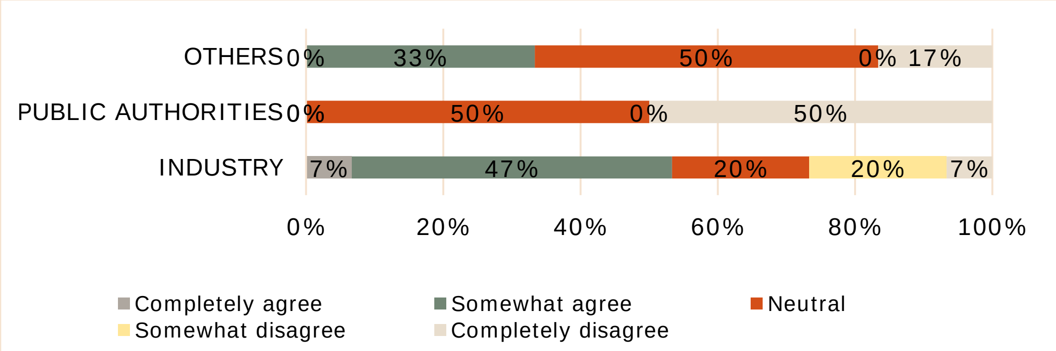
Figure A 25 Response of question 3.1 for the three groups of respondents.



The vast majority of "industry", "public authorities" and "others" respondents strongly support (78% in total) the current divisions and specifications of the watercraft design categories in relation to manufacturers' point of view. The total disagreement is 9% whereas 13% is the percentage of neutral positions.

Q3.2: Would you agree that additional or different specifications and/or further sub-divisions could provide clearer and more sufficient information to manufacturers (in particular SMEs)?
Q3.2.1: If you agreed with the previous statement, please suggest different specifications and/or further sub-divisions.
Q3.2.1: Please explain what cost and benefits the different specification(s) or further sub-division(s) would bring.

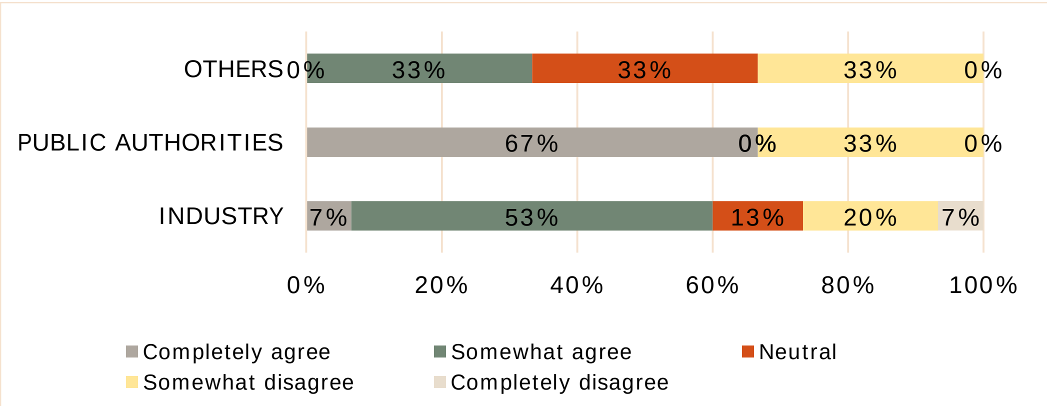
Figure A 26 Response of question 3.2 for the three groups of respondents



In this question we have 44% agreement, 26% disagreement and 30% neutral positions. These results may lead to wrong interpretation, because this agreement is not accompanied with proposals for different subdivisions and/or specifications, but with proposals for adding technical information in the current set-up of design categories in order to provide more clarity and better understanding to end-users concerning weather conditions or definitions or assessment procedures. In other words, all respondents agree with the current set-up, whereas part of "industry" respondents, including ICOMIA, suggests to be left exactly as is (27%), and another part (54%), including EBI, proposes modifications by adding technical information. Six "industry" stakeholders and one from "others" fully support EBI's position paper which proposes to add maximum average wind speed, maximum gust speeds and potentially maximum wave height (after further consultation and assessment) to the RCD Annex I table which describes the specifications of each category. Another stakeholder from "industry" proposes steepness of waves, capability of operator and vessel speed to be appropriately defined in order to bring clarity for customers. Additionally, a stakeholder from "others" recommends the splitting of the categories in two, one that has been tested and verified and includes every documentation and one that relies on manufacturers' self-assessment, so that customers know the product quality and standards. Concerning self-assessment, he recommends that the first boat of a production line (for every design) should be approved and verified by conducting sea tests.

Q3.3: Do you agree that the current specifications (wind force and significant wave height) and/or divisions (A, B, C, D) of recreational craft design categories provide sufficient and clear information to end-users on the types of risks connected with using watercraft?

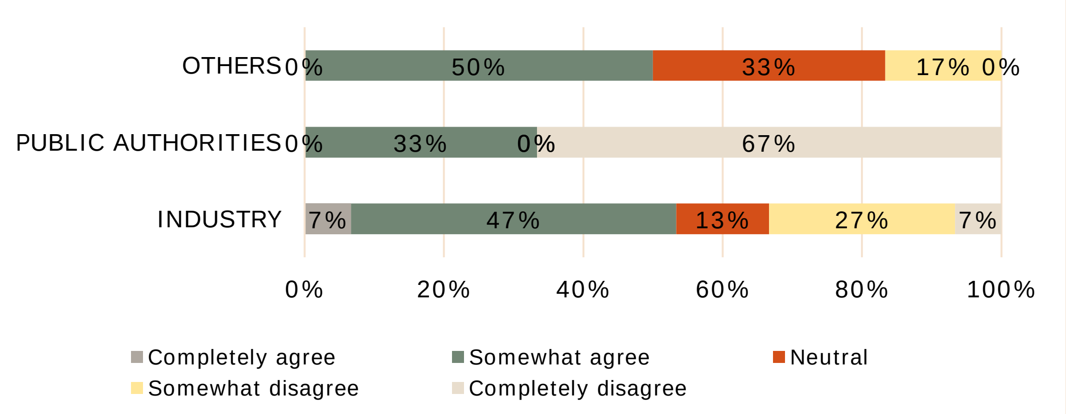
Figure A 27 Response of question 3.3 for the three groups of respondents



The majority of "industry", "public authorities" and "others" respondents (54% in total) support the current divisions and specifications of the watercraft design categories in relation to sufficiency and clarity of information given to end-users. The total disagreement is 29% whereas 17% is the percentage of neutral positions.

Q3.4: Would you agree that additional or different specifications and/or further sub-divisions could provide clearer and more sufficient information for the end-users?
Q3.4.1: If you agreed with the previous statement, please suggest different specifications and/or further sub-divisions.
Q3.4.2: Please explain what cost and benefits the different specification(s) or further sub-division(s) would bring.

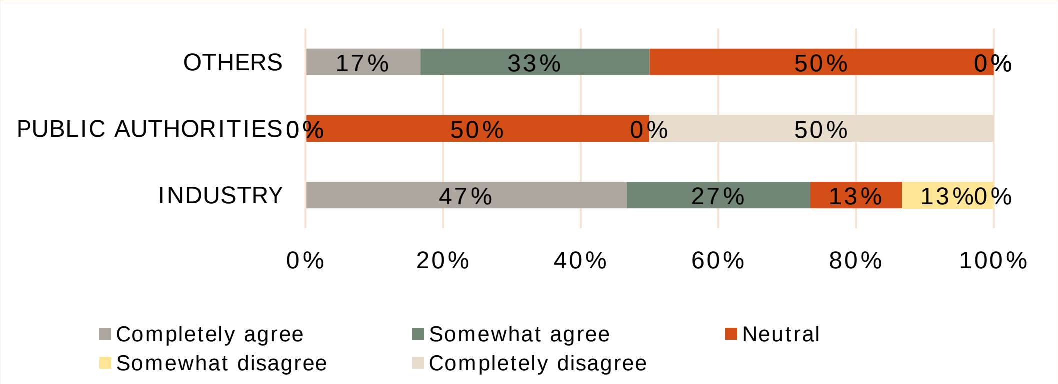
Figure A 28 Response of question 3.4 for the three groups of respondents



In this question we have 51% agreement, 32% disagreement and 17% neutral positions, as aggregated results. Exactly as in question 3.2, these results may lead to wrong interpretation, because this agreement is not accompanied with proposals for different subdivisions and/or specifications, but with proposals for adding technical information in the current set-up of design categories in order to provide more clarity and better understanding to end-users concerning weather conditions or definitions, in order to avoid wrong interpretation of the RCD. Again, all respondents agree with the current set-up, whereas part of "industry" respondents, including ICOMIA, suggests to be left exactly as is (34%), and another part (54%), including EBI, proposes modifications by adding technical information. Six "industry" stakeholders and one from "others" fully support EBI's position paper which proposes to add maximum average wind speed, maximum gust speeds and potentially maximum wave height (after further consultation and assessment) to the RCD Annex I table which describes the specifications of each category. Another "industry" stakeholder states that the classification system is acceptable and he proposes the use of "more specific cycle information" in order to remove interpretation and allow direct comparisons across manufacturers and crafts. He also proposes guidance on good seamanship that may prompt to a more responsible understanding from customers.

Q3.5: Do you agree that the Recreational Craft Directive should specify any upper limits of wind force and wave height for category A?
Q3.5.1: To what extent would the transposition of the upper limits, set in the harmonised standards related to stability and buoyancy assessment and categorization EN ISO 12217-1,2,3: 2017 (less than 10 wind force and approx. 7 metres significant wave height), improve the clarity of information for manufacturers and end-users?

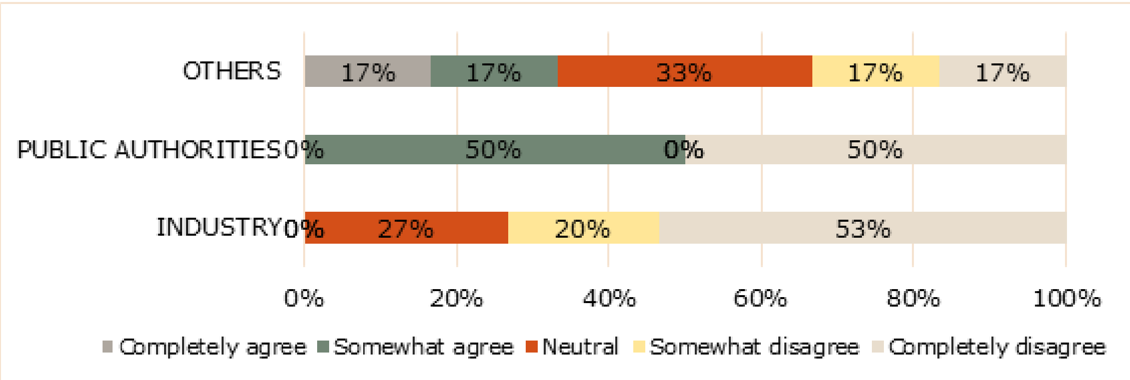
Figure A 29 Response of question 3.5 for the three groups of respondents



The majority of "industry", "public authorities" and "others" respondents support (61% in total) the transposition of the upper limits of the harmonised stability standards EN ISO 12217-1,2,3: 2017 (less than 10 wind force and approx. 7 metres significant wave height) to the RCD Annex I table. The disagreement is 13% whereas there is 26% is the percentage of neutral positions. The disagreements had no justifications. ICOMIA although somewhat agrees with the transposition, presented the argument "that current RCD already currently excludes "abnormal conditions" and gives some example of these for Category A craft".

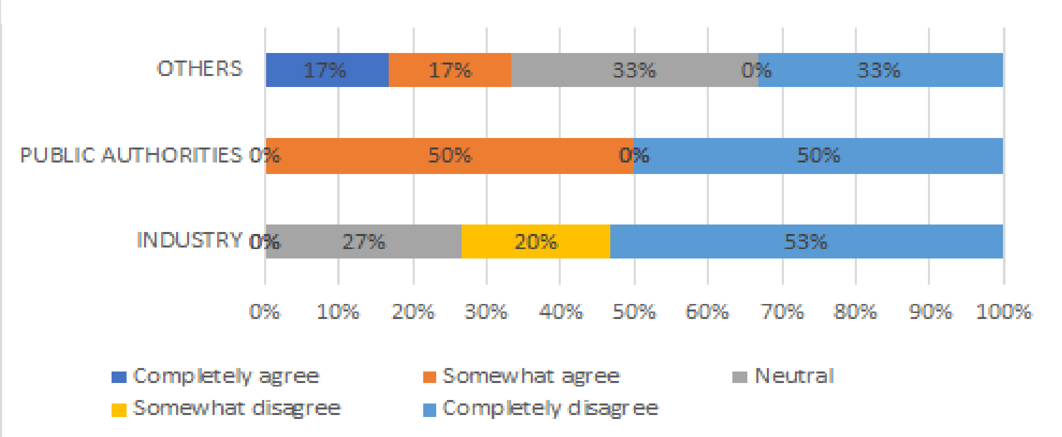
Q3.6: Do you agree that a further subdivision of category D into two parts (one with a wind force up to and including 2 with a significant wave height up to 0,3 metres and another with a wind force up to and including 4 with a significant wave height up to 1,5 metres, leaving category C as is) would allow manufacturers to bring more clarity and logic into the classification of the design categories?
Q3.6.1: Please explain your answer.

Figure A 30 Response of question 3.6 for the three groups of respondents



Q3.7: Do you agree that a further subdivision of category D into two parts (one with a wind force up to and including 2 with a significant wave height up to 0,3 metres and another with a wind force up to and including 4 with significant wave height up to 1,5 metres, leaving category C as is) would provide end-users with clearer information on the types of risks connected with using recreational crafts?
Q3.7.1: Please explain your answer.

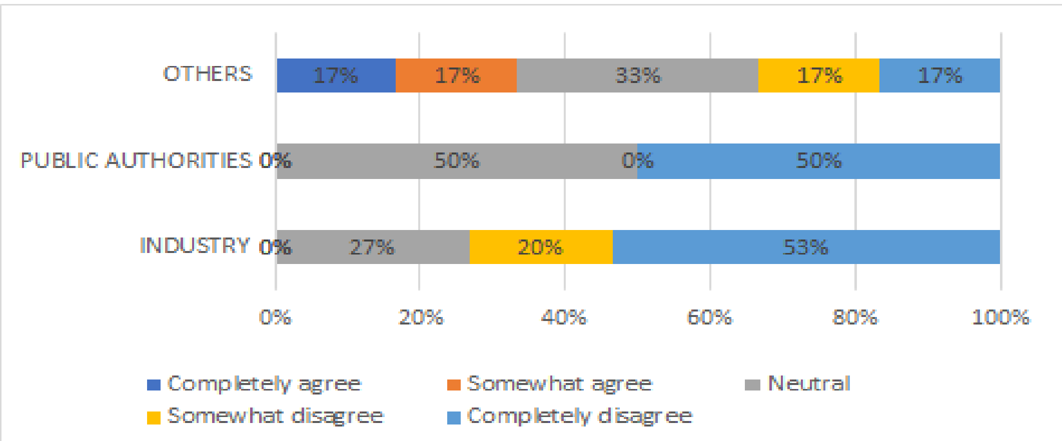
Figure A 31 Response of question 3.7 for the three groups of respondents



For both questions 3.6 and 3.7, the majority of "industry", "public authorities" and "others" respondents disagree (61% in total) with the proposed subdivision of design category D estimating that there will be no benefit either for manufacturers or for end-users respectively. Only 13% agrees whereas 26% expressed neutral position. The basic argument for this disagreement by "industry" respondents is that it will not improve the current situation and on the contrary will cause confusion and increased costs from design, revision of all relevant harmonised ISO standards, updating of all the existing certificates, reassessment costs and communication efforts. Additionally, one public authority states no gain by the proposed subdivision and only one public authority states that it could be a solution for those builders who produce pleasure craft exclusively for inland waters or for water roads of limited size.

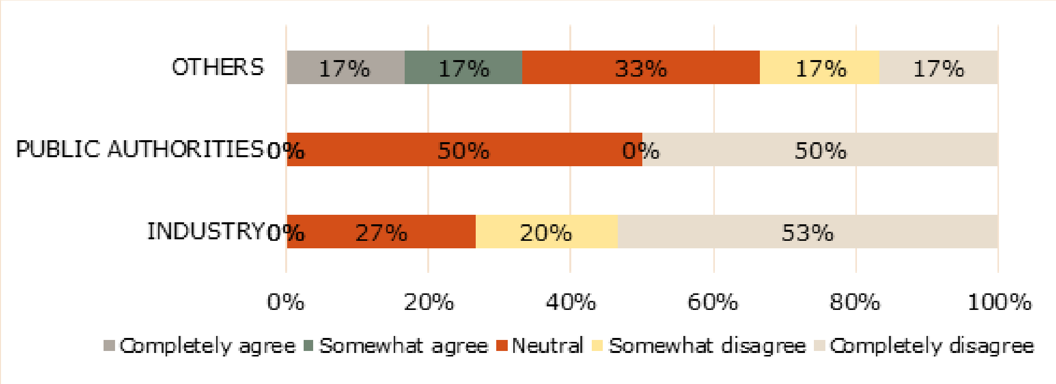
Q3.8: Do you agree that a further subdivision of category C into two parts (one with a wind force up to and including 5 with a significant wave height up to 1,25 metres and another with a wind force up to and including 6 with a significant wave height up to 2.5 metres, leaving categories D and B unchanged) would allow manufacturers to bring more clarity and logic into the classification of the design categories?
Q3.8.1: Please explain your answer.

Figure A 32 Response of question 3.8 for the three groups of respondents



Q3.9: Do you agree that a further subdivision of category C into two parts (one with a wind force up to and including 5 with a significant wave height up to 1,25 metres and another with a wind force up to and including 6 with a significant wave height up to 2,5 metres, leaving categories D and B unchanged) would provide end-users with clearer information on the types of risks connected with using recreational crafts?
Q3.9.1: Please explain your answer.

Figure A 33 Response of question 3.9 for the three groups of respondents



For both questions 3.8 and 3.9, the majority of "industry", "public authorities" and "others" respondents disagrees (61% in total) with the proposed subdivision of design category C estimating that there will be no benefit either for manufacturers or for end-users, respectively. Only 9% agrees whereas 30% chose neutral position. The basic argument for this disagreement by "industry" responders is that it will not improve the current situation and on the contrary will cause confusion and increased costs from design, revision of all relevant harmonised ISO standards, updating of all the existing certificates, reassessment costs and communication efforts. Additionally, one public authority states no gain by the proposed subdivision and only one stakeholder from "others" suggests that very small touristic boats for daily excursions that are currently in C category would go to Cb, while other boats that go daily fishing would be assessed as Ca.

Q3.10: If you proposed sub-divisions of design categories or additional specifications, please provide information on any additional costs (e.g., investments, production costs, certification costs, etc.) and other possible impacts (e.g., on manufacturer productivity, safety, standardisation, etc.) related to your proposal.

Since there were no proposals for sub-divisions or alternative divisions of the current four design categories, there were no information concerning additional costs. EBI's proposal which is supported by seven more associations, keeps the current set-up as is, while providing additional technical information to consumers and manufacturers. It brings no additional costs either to manufacturers or to end-users.

Annex 2 - Evaporative emissions – Tables and Figures

Appendix 2 contains tables used as input for evaporative emissions estimations as well as more detailed figures and results.

Input for emission estimations:

Table A 2 Monthly DVPE values for the EU Member States (EEA, 2019)

DVPE per month (kPa)	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Austria	90	90	90	90	90	90	90	60	60	60	60	60
Belgium	90	90	90	90	90	90	90	60	60	60	60	60
Bulgaria	60	90	90	90	90	90	60	60	60	60	60	60
Cyprus	60	90	90	90	90	90	60	60	60	60	60	60
Czech Republic	90	90	90	90	90	90	90	60	60	60	60	60
Germany	90	90	90	90	90	90	90	60	60	60	60	60
Denmark	90	90	90	90	90	90	90	60	60	60	60	90
Estonia	90	90	90	90	90	90	90	60	60	60	60	60
Spain	90	90	90	90	90	90	90	60	60	60	60	60
Finland	90	90	90	90	90	90	90	90	60	60	60	90
France	90	90	90	90	90	90	90	60	60	60	60	60
Croatia	90	90	90	90	90	90	90	60	60	60	60	60
Greece	90	90	90	90	90	90	90	60	60	60	60	60
Hungary	90	90	90	90	90	90	90	60	60	60	60	60
Ireland	90	90	90	90	90	90	90	90	60	60	60	90
Italy	90	90	90	90	90	90	90	60	60	60	60	60
Lithuania	90	90	90	90	90	90	90	60	60	60	60	60
Luxembourg	90	90	90	90	90	90	90	60	60	60	60	60
Latvia	90	90	90	90	90	90	90	90	60	60	60	90
Malta	90	90	90	90	90	90	90	60	60	60	60	60
Netherlands	90	90	90	90	90	90	90	60	60	60	60	60
Poland	90	90	90	90	90	90	90	60	60	60	60	60
Portugal	90	90	90	90	90	90	90	60	60	60	60	60
Romania	90	90	90	90	90	90	90	60	60	60	60	60
Sweden	90	90	90	90	90	90	90	60	60	60	60	60
Slovenia	90	90	90	90	90	90	90	60	60	60	60	60
Slovak Republic	90	90	90	90	90	90	90	60	60	60	60	60

Table A 3 Monthly average inimux and maximum temperatures for the EU Member States (Climatestotravel.com, 2019)

min, max average temperature per month[°C]	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Austria	7	3	-1	-2	-1	2	6	11	14	16	16	12
	14	8	4	3	5	10	16	21	24	26	26	20
Belgium	8	4	2	1	1	3	5	9	12	14	13	10
	15	10	6	6	7	10	14	18	21	23	23	20
Bulgaria	8	3	-2	-3	-2	1	6	11	15	17	17	13
	19	13	6	5	7	13	18	24	28	31	32	26
Cyprus	7	3	-1	8	7	9	12	16	20	22	23	20
	14	8	4	17	17	19	23	27	30	32	33	31
Czech	5	1	-3	-4	-4	0	3	8	11	13	13	9
	13	6	2	1	3	8	14	19	22	24	24	19
Germany	6	2	0	-1	-1	1	3	7	11	13	13	10
	13	8	5	4	4	8	12	18	0	22	22	18
Denmark	7	4	1	-1	-1	1	4	8	12	14	14	11
	13	8	4	3	4	6	11	16	19	22	21	18
Estonia	3	-1	-5	-7	-8	-4	0	5	10	12	12	7
	9	3	0	-1	-2	2	8	15	19	21	20	15
Spain	11	12	7	3	10	9	7	10	17	14	22	17
	21	19	16	9	18	19	18	21	25	26	29	32
Finland	4	-1	-4	-6	-7	-4	1	6	11	14	13	9
	9	4	0	-1	-2	2	8	14	18	22	20	15
France	10	6	4	3	3	5	7	11	14	16	16	13
	19	14	11	10	12	15	17	21	24	27	27	24
Croatia	15	11	8	7	6	9	11	15	19	22	22	19
	21	17	13	12	12	14	17	21	25	28	29	25
Greece	15	11	8	7	7	8	12	16	20	23	23	19
	24	18	14	13	14	16	21	26	31	33	33	29
Hungary	7	2	-2	-4	-2	2	6	11	14	15	15	12
	16	8	3	1	5	10	16	21	24	27	26	22
Ireland	7	5	3	2	2	3	5	7	10	12	12	10
	14	10	8	8	8	10	12	15	18	20	19	17
Italy	14	10	8	7	7	9	11	15	18	21	21	18
	21	16	14	13	13	15	17	21	24	27	27	24
Lithuania	6	2	-2	-3	-4	-1	3	7	11	14	14	10
	12	6	3	1	1	4	10	16	18	21	21	17

min, max average temperature per month[°C]	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*
Luxembourg	6	2	0	-2	-1	2	4	8	11	13	13	10
	13	7	4	3	5	9	13	18	21	23	23	18
Latvia	6	2	-2	-3	-4	-2	2	7	11	14	14	10
	11	6	2	-1	1	4	10	15	18	21	21	16
Malta	18	15	12	10	9	11	12	16	19	22	23	21
	25	21	17	16	16	17	20	24	29	32	32	28
Netherlands	8	4	2	1	1	3	5	8	11	13	13	11
	15	10	7	6	7	10	14	18	20	22	22	19
Poland	6	1	-2	-4	-3	-1	3	8	11	14	13	10
	13	6	2	1	2	6	11	17	20	22	22	18
Portugal	15	12	10	8	9	10	12	13	16	18	18	17
	22	18	15	14	16	18	19	21	25	28	28	26
Romania	10	5	0	-1	-1	3	7	12	17	19	19	15
	17	11	6	4	6	9	14	20	25	27	27	23
Sweden	6	2	-2	-3	-4	-1	2	7	11	13	12	9
	12	6	3	1	1	5	10	16	20	21	21	16
Slovenia	12	7	4	3	3	6	9	13	16	19	19	16
	18	12	8	6	8	11	15	19	23	26	26	22
Slovak Republic	7	2	-2	-3	-1	3	6	10	13	16	16	12
	16	8	3	2	4	11	17	20	24	27	27	21

EU average emission factors by month and craft type:

Uncontrolled fleet							Controlled fleet					
Diurnal Emission factors	**sailing boats**	**others**	**yawls and cabin boats**	**speedboats outboard**	**speedboats inboards & sterndrive**	**water scooters**	**sailing boats**	**others**	**yawls and cabin boats**	**speedboats outboard**	**speedboats inboards & sterndrive**	**water scooters**
Oct	3,1	2,6	3,1	3,1	2,6	3,4	1,3	1,0	1,3	1,2	1,0	1,4
Nov	1,5	1,2	1,5	1,5	1,2	1,7	0,6	0,5	0,6	0,6	0,5	0,7
Dec	1,0	0,8	1,0	0,9	0,8	1,0	0,4	0,3	0,4	0,4	0,3	0,4
Jan	0,8	0,6	0,8	0,8	0,6	0,9	0,3	0,3	0,3	0,3	0,3	0,3
Feb	1,0	0,9	1,0	1,0	0,9	1,1	0,4	0,3	0,4	0,4	0,3	0,5
Mar	1,6	1,3	1,6	1,6	1,3	1,8	0,6	0,5	0,6	0,6	0,5	0,7
Apr	2,7	2,2	2,7	2,6	2,2	3,0	1,1	0,9	1,1	1,1	0,9	1,2
May	2,8	2,3	2,8	2,7	2,3	3,0	1,1	0,9	1,1	1,1	0,9	1,2
Jun	2,7	2,2	2,7	2,7	2,2	3,0	1,1	0,9	1,1	1,1	0,9	1,2
Jul	3,7	3,0	3,7	3,6	3,0	4,1	1,5	1,2	1,5	1,4	1,2	1,6
Aug	3,6	2,9	3,6	3,5	2,9	3,9	1,4	1,2	1,4	1,4	1,2	1,6
Sep	3,0	2,5	3,0	2,9	2,4	3,3	1,2	1,0	1,2	1,2	1,0	1,3

Hose permeation Emission factors	Uncontrolled fleet sailing boats	others	yawls and cabin boats	speedboats outboard	speedboats inboards & sterndrive	water scooters	Controlled fleet sailing boats	others	yawls and cabin boats	speedboats outboard	speedboats inboards & sterndrive	water scooters
Oct	4,4	0,5	4,4	7,4	8,9	1,4	1,0	0,1	1,0	1,7	2,1	0,1
Nov	3,2	0,5	2,7	4,6	5,5	1,4	0,6	0,1	0,6	1,1	1,3	0,1
Dec	2,7	0,0	1,8	3,1	3,7	0,0	0,4	0,0	0,4	0,7	0,9	0,0
Jan	2,5	0,0	1,5	2,6	3,1	0,0	0,3	0,0	0,3	0,6	0,7	0,0
Feb	2,6	0,0	1,7	2,9	3,5	0,0	0,4	0,0	0,4	0,7	0,8	0,0
Mar	3,1	0,5	2,5	4,3	5,2	1,4	0,6	0,1	0,6	1,0	1,2	0,1
Apr	3,8	0,5	3,8	6,4	7,7	1,4	0,8	0,1	0,8	1,5	1,8	0,1
May	5,0	0,5	5,0	8,5	10,2	1,4	1,1	0,1	1,1	2,0	2,4	0,1
Jun	6,3	1,0	6,3	10,7	12,8	2,9	1,4	0,2	1,4	2,5	3,0	0,2
Jul	7,6	1,0	7,6	13,0	15,7	2,9	1,7	0,2	1,7	3,0	3,7	0,2
Aug	7,5	1,0	7,5	12,8	15,4	2,9	1,6	0,2	1,6	3,0	3,6	0,2
Sep	5,9	1,0	5,9	10,0	12,1	2,9	1,3	0,2	1,3	2,3	2,9	0,2

Fuel tank permeation Emission factors	Uncontrolled fleet sailing boats	others	yawls and cabin boats	speedboats outboard	speedboats inboards & sterndrive	water scooters	Controlled fleet sailing boats	others	yawls and cabin boats	speedboats outboard	speedboats inboards & sterndrive	water scooters
Oct	5,6	3,7	5,6	5,7	4,7	4,4	1,0	0,6	1,0	0,9	0,8	0,7
Nov	3,5	2,3	4,1	3,5	2,9	2,7	0,6	0,4	0,7	0,6	0,5	0,5
Dec	2,3	1,5	3,4	2,3	2,0	1,8	0,4	0,2	0,6	0,4	0,3	0,3
Jan	2,0	1,3	3,2	2,0	1,7	1,5	0,3	0,2	0,6	0,3	0,3	0,3
Feb	2,2	1,4	3,4	2,2	1,9	1,7	0,4	0,2	0,6	0,4	0,3	0,3
Mar	3,3	2,1	3,9	3,3	2,8	2,5	0,6	0,3	0,7	0,6	0,5	0,4
Apr	4,8	3,2	4,8	4,9	4,1	3,8	0,8	0,5	0,8	0,8	0,7	0,6
May	6,4	4,2	6,4	6,5	5,4	5,0	1,1	0,7	1,1	1,1	0,9	0,8
Jun	8,0	5,3	8,0	8,2	6,8	6,3	1,4	0,9	1,4	1,4	1,2	1,1
Jul	9,8	6,4	9,8	9,9	8,3	7,6	1,7	1,0	1,7	1,7	1,4	1,3
Aug	9,6	6,3	9,6	9,8	8,1	7,5	1,6	1,0	1,6	1,6	1,4	1,3
Sep	7,5	5,0	7,5	7,7	6,4	5,9	1,3	0,8	1,3	1,3	1,1	1,0