

Roadmap for the Decarbonisation of the European Recreational Marine Craft Sector



Roadmap for the Decarbonisation of the European Recreational Marine Craft Sector

Acknowledgments

The Carbon Trust wrote this report based on an impartial analysis of primary and secondary sources, including expert interviews.

The Carbon Trust would like to thank everyone that has contributed their time and expertise during the preparation and completion of this report. In particular, we would like to thank interviewees who provided time and information.

This report was sponsored by the UK Foreign, Commonwealth & Development Office with support from the UK Department for Transport. For the avoidance of doubt, this report expresses independent views of the authors.

Who we are

Established in 2001, the Carbon Trust works with businesses, governments and institutions around the world, helping them contribute to, and benefit from, a more sustainable future through carbon reduction, resource efficiency strategies, and commercialising low carbon businesses, systems and technologies.

The Carbon Trust:

- works with corporates and governments, helping them to align their strategies with climate science and meet the goals of the Paris Agreement;
- provides expert advice and assurance, giving investors and financial institutions the confidence that green finance will have genuinely green outcomes; and
- supports the development of low carbon technologies and solutions, building the foundations for the energy system of the future



The Carbon Trust's mission is to accelerate the move to a sustainable, low carbon economy. It is a world-leading expert on carbon reduction and clean technology. As a not-for-dividend group, it advises governments and leading companies around the world, reinvesting profits into its low carbon mission.

Headquartered in London, the Carbon Trust has a global team of over 200 staff, representing over 30 nationalities, based across five continents.

Authors:

Olivia Burke

Manager

olivia.i.burke@carbontrust.com

Giulia Rado

Senior Analyst

giulia.rado@carbontrust.com

David Plunkett

Associate

david.plunkett@carbontrust.com

Mary Harvey

Analyst

mary.harvey@carbontrust.com

Contents

1. Introduction	2
2. Market overview	3
2.1 Market Status	3
2.2 Market segments	5
2.2.1 Recreation vessel types	5
2.2.2 Boat parks	7
2.2.3 Mooring recreational vessels	9
2.3 Country profiles	12
2.3.1 United Kingdom (UK)	12
2.3.2 France	13
2.3.3 Netherlands	13
2.3.4 Greece	14
2.3.5 Cyprus	14
2.3.6 Malta	15
3. Sectoral Growth	16
3.1 Growth predictions	16
3.2 Growth drivers and challenges	17
4. Sectoral emissions	19
4.1 Emissions from recreational vessels and sector environmental trends	19
4.1.1 Lifecycle emissions	19
4.1.2 Operational emissions	20
4.1.3 Materials and end-of-life emissions	22
4.2 Current regulation and legislation	23
4.2.1 International shipping regulation	23
4.2.2 European policies	24
4.2.3 Recreational vessels-specific national strategies	28
4.3 Initial decarbonisation roadmaps	31

5. Decarbonisation technologies overview and assessment of barriers and enablers	33
5.1 Hull materials and boat recycling	34
5.1.1 Technology overview	34
5.1.2 Barriers and enablers to uptake.....	37
5.2 Technical design and performance measures	37
5.2.1 Hull design optimisation	37
5.2.2 Hydrofoils.....	38
5.3 Alternative energy sources.....	42
5.3.1 Marine solar power systems.....	42
5.3.2 Marine wind generators	43
5.3.3 Hydro-generators.....	44
5.4 Drive train hybridisation/electrification	45
5.4.1 Technology overview	45
5.4.2 Barriers and enablers to uptake.....	48
5.5 Alternative fuels	50
5.5.1 Hydrogen.....	51
5.5.2 Biofuels	52
5.6 Summary of decarbonisation technologies	54
6. Supply chain assessment.....	59
7. Recommendations to enable decarbonisation	67
7.1 Lifecycle assessment (LCA)	67
7.2 Electrification & alternative fuels	69
7.3 Marinas.....	71
7.4 End-of-life	73
7.5 Nautical tourism	75
7.6 Roadmap	76
8. Summary of findings.....	78
9. References	80

Figures

Figure 1: Global recreational vessels revenue	4
Figure 2: Global Boat Park. Boat park refers to the number of vessels in use. <i>Data from ICOMIA 2019 World Boat Park</i>	8
Figure 3: Split of vessel type at European boat parks.	9
Figure 4: Predicted Global Boat Market by 2027. <i>Data Source: Verified Market Research</i>	17
Figure 5: Flax 27. <i>Credit Greenboats</i>	35
Figure 6: Coastal High Speed Craft. <i>Credit: The Ultimate Boat Company</i>	36
Figure 7: Foil system. <i>Credit - Princess Yachts</i>	41
Figure 8: Torqeedo inboard electric set up. <i>Credit – Torqeedo</i>	47
Figure 9: Cheetah Marine hydrogen powered craft. <i>Credit - Cheetah Marine</i>	53
Figure 10: Recreational Marine Craft Sector Decarbonisation Roadmap	77

Tables

Table 1: Typical engine types per boat category	7
Table 2: Boating facilities by country. n.b. this is not an extensive list. <i>Source: ICOMIA</i>	11
Table 3: Diesel and petrol combustion emissions	22
Table 4: Clean Maritime Plan ambitions	28
Table 5: Examples of hydro-generators outputs per specified speed	45
Table 6: Decarbonisation technology assessment by technology matureness and operational emission reduction potential	55
Table 7: Key emission reduction technologies’ applicability by vessel type and decarbonisation potential within a short – long-term timeframe	56
Table 8.1-8.6: Summary assessment of the recreational vessel supply chain	59-65

Abbreviations

CO	Carbon monoxide
CO₂	Carbon dioxide
EOL	End-of-life
EV	Electric vehicle
FRP	Fibre reinforced plastics
GDP	Gross Domestic Product
GHG	Greenhouse gas
GRP	Glass reinforced plastics
LCA	Lifecycle assessment
N₂O	Nitrous oxide
NO_x	Nitrogen oxides
PM	Particulate matter
PWC	Personal water craft
R&D	Research and development
RIB	Rigid inflatable boat
SME	Small and medium-sized enterprise

Executive Summary

The recreational craft sector encompasses many different types of sports and leisure vessels including cruising, water sports, fishing, sailing and inland waterway crafts. The UK is one of the leading markets within the sector, particularly in relation to export sales in Europe, as well as globally. The recreational craft sector is an important contributor to the UK's economy, representing around £2.7 billion in revenue and over £1 billion in Gross Value Add (GVA).

Despite the impact of the Covid-19 pandemic, the recreational craft industry is expected to recover and continue to grow globally over the coming years. One of the major challenges to the future of the recreational craft industry is the environmental impacts and associated GHG emissions footprint. The Covid-19 pandemic has further focused attention on the impacts of climate change, and early preparation for the transition to low emission vessels is key for industry growth to succeed.

While the exact total GHG emissions from the recreational craft industry are unknown, the sector only contributes to a small part of overall maritime emissions, and causes significantly less impact than the automotive industry. Nevertheless, emissions from recreational crafts need to be reduced to mitigate impacts on local coastal and inland waterway ecosystems, in addition to supporting the achievement of national climate targets. The need to reduce emissions from recreational craft will create key opportunities for the UK and other major European market players to demonstrate sectoral leadership for the development, manufacturing and servicing of low and zero emission craft.

The decarbonisation of the sector will heavily rely on policy and legislation. Current regulations focus on limiting exhaust emissions within the sector, but there is a requirement to go further and set clear targets on GHG emissions (at national and European level) and an implementation timeline for low emission technologies. A sectoral decarbonisation target should preferably consider lifecycle emissions to incentivise the abatement of a boat's upstream and downstream emissions, along with operational emissions.

At both national and European level, there is a willingness to better understand and develop strategies for addressing the environmental footprint of the recreational craft sector. Industry stakeholders have called to continue the dialogue at a European level to ensure harmonisation between standards and collaboration on technology and infrastructure development.

There is no single decarbonisation solution that can be applied across all boat types. This report explores different options including design optimisation, electrification and alternative fuels. Some solutions may be bridging technologies to full decarbonisation and it will be important to consider the full lifecycle and wider energy system pathways. The industry supply chain is dependent on consumer demand, which in turn is dependent on availability of technologies and infrastructure. To accelerate change, targeted R&D, cross-industry collaboration and regulatory and financial intervention are required to support the development and uptake of technologies.

1. Introduction

The maritime sector is a significant contributor to European economies, however, with shipping currently accounting for 2.3% of global CO₂ emissions there is a clear opportunity to reduce emissions and ensure sustainable growth of the sector. In 2019, the UK passed legislation to enshrine a net zero emissions target to be achieved by 2050 for the whole economy, and since then, the European Union's (EU) Green Deal has been announced which supports EU countries to reduce emissions across different sectors. While emissions from recreational boats are relatively small compared to those from other sectors, it is critical that the sector is supported if the UK and EU are to each become climate neutral by 2050.

The recreational marine craft sector encompasses many different types of sports and leisure vessels including cruising, water sports, fishing, sailing and inland waterway crafts. This report is focusing on vessels with a hull length between 2.5m to 24m as defined by the EU's Recreational Craft Directive. The European Union plus the UK forms the second largest market after the US and the maritime sector is dynamic, high-value and an important economic source to EU. The sector has seen significant growth and recovery since 2008, although there are concerns the Covid-19 pandemic will have a long-lasting impact on the industry, which according to the European Commission's data on the recreational craft sector consists of many small and medium-sized businesses (SMEs), employs approximately 280,000 people and generates an average annual revenue of €20 billion, see the European Commission's guidance on the [recreational craft sector](#) [1].

There are opportunities for technology transfer from complementary industries, including commercial shipping and the automotive sector, but it is necessary to consider the recreational craft market with their specific requirements for decarbonisation. Factors such as recreational vessels typically having long lifecycles, low usage hours and being bought for pleasure rather than practicality, are important to understand in the context of providing guidance on how this part of the maritime sector can decarbonise.

Recreational vessels are varied in both their construction and use, and this will require different approaches to decarbonisation with alternative technologies and fuel types. There is a perceived shift towards more sustainable practices and to support a growing consumer demand. Policies should look to encourage innovation and support a range of technologies.

This roadmap provides a summary of the market, analysis of potential technology solutions, and a discussion on potential mechanisms to support the sector decarbonise with a particular focus on the UK, Cyprus, France, Greece, Malta, and the Netherlands. These are countries with large markets for the sale of recreational craft, along with a substantial recreational craft manufacturing sector.

2. Market overview

2.1 Market Status

Europe has 43,500 miles of coastline, over 23,000 miles of inland waterways and around 36 million EU citizens who regularly participate in marine watercraft activities, see these and other statistics through the Arizton's 2020 [Recreational Boat Market – Global Outlook and Forecast 2020-2025](#) [2]. The European recreational craft industry comprises of boatbuilders, engine manufacturers, equipment manufacturers, and tourism, trade and service providers such as marinas. The industry consists of approximately 32,000 companies (97% of which are SMEs) with over 280,000 employees, and nearly 30% of employees are specific to the boat building sector, according to the European Commission's Blue Economy Report 2020, see the full [Blue Economy Report 2020](#) [3]. Within the European, as well as global recreational craft sector, the UK is among the key market players, with 26,890 industry employees, equivalent to almost 10% of the EU's total sectoral workforce and generating £2.7 billion in revenue in the 2019 financial year.

Engagement in recreational watercraft activities is popular globally, with the US and the EU together representing approximately 80% of both the world's production (boats, engines, equipment, components, accessories) and recreational vessel market. European manufacturers are the front runners with boat building predominantly taking place in Europe. The UK has maintained its position as the leading European country for the total number of boats exported, while, in total, European countries traded €16 billion in boats annually between members, see the 2019 report by ICOMIA on the [Recreational Boating Industry Statistics](#) [4].

Trade over the last decade has steadily increased following a slow recovery from the 2008 economic crisis (see Figure 1), and trade within this sector will likely be an important lever in the economic recovery of European nations post pandemic.

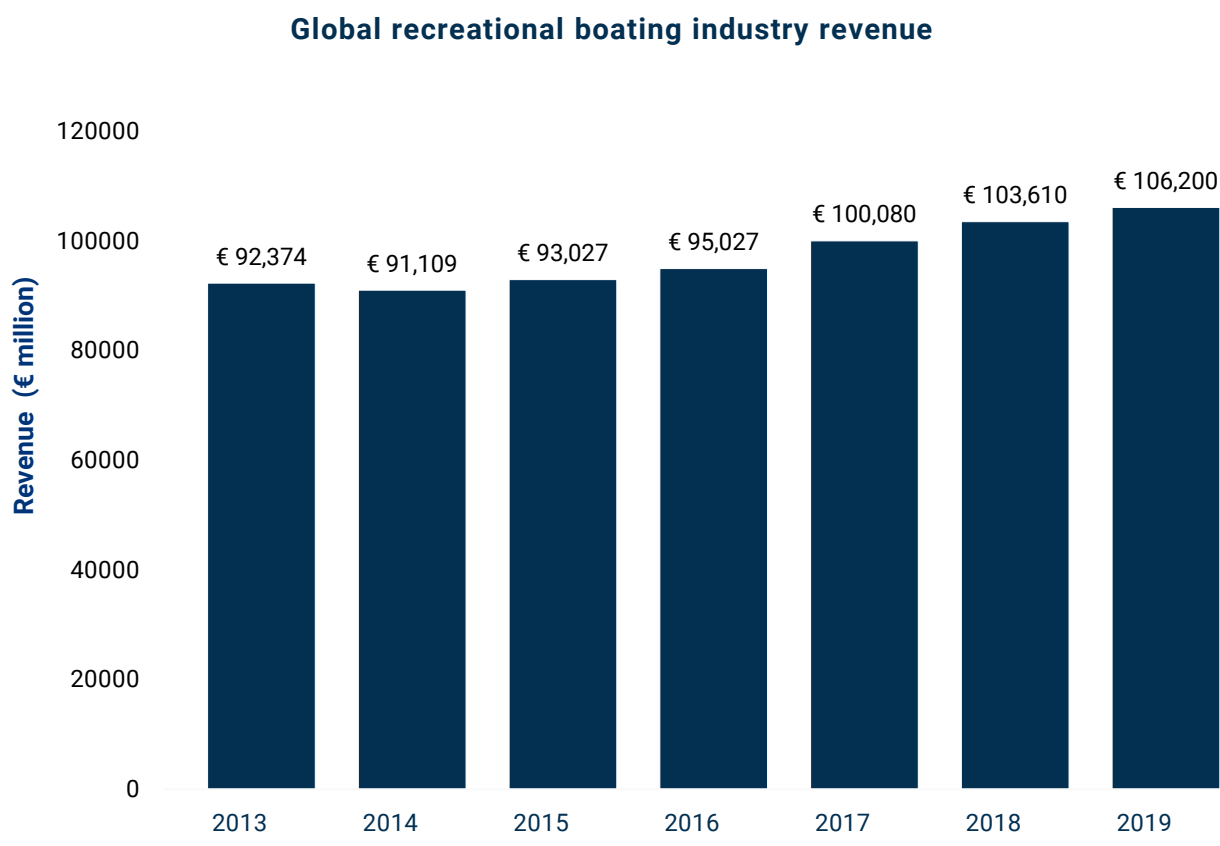


Figure 1: Global recreational vessels revenue
 See ICOMIA's 2019 report on [Recreational Boating Industry Statistics](#) [4]

A key challenge to the industry is job seasonality, with many sectors operating only through the summer months raising concerns about long-term stability. According to the Blue Economy Report, over the last decade the industry has also seen average consumer age rise from 45 to 55, raising concerns around the popularity for boat ownership with younger generations, see the full [Blue Economy Report 2020](#) [3]. The European Commission estimated six million boats are kept in European waters, out of which there are 60,000 charter boats generating approximately €6 billion each year, see the European Commission's [working document on Nautical Tourism](#) [5]. There are indications of an increasing demand for the charter sector, with new business models such as shared ownership platforms, which may widen the consumer age range.

Europe is experiencing a growing interest in sustainability, particularly among younger generations, and a marked increase in people participating in outdoor sporting pursuits in the summer of 2020 as a result of Covid-19 restrictions. Linking nautical tourism to a sustainable environment and scaling-up industry action in decarbonisation through material science, lifecycle analysis, alternative fuels and developing new technology will help the market to grow, and for the sector to positively contribute to the blue economy.

2.2 Market segments

2.2.1 Recreation vessel types

The recreational craft industry includes a wide variety of vessels types, which differ in terms of means of propulsion, usage pattern, activity type and size. The propulsion systems deployed on a boat are a key factor in determining the emissions during operation. In terms of power source used to operate boats, the sector can be divided into engine-powered, sail-propelled or man-powered. There are three main types of engines deployed on engine-powered recreational boats:

- **Outboard engines:** propulsion system made up of a gearbox, propeller or jet drive, mounted at the stern of a vessel. Given the size and weight limitations linked to outboard engines, usually outboards are spark ignition engines (or petrol engines). Two-stroke engines have historically been preferred to four-stroke engines based on the same limitations, however, improvements in engine technology have largely closed the performance gap between the two engine types and both can be taken up as outboard motors today
- **Inboard engine:** engine enclosed within the hull of the boat and connected to a drive/shaft or waterjet propulsion. Inboards can be either spark ignition (petrol engine) or compression ignition (diesel engine)
- **Sterndrive engine:** system considered to be a combination of inboard and outboard engines as the drive unit is outside the hull, while the remaining engine system is inboard. Sterndrive engines can be either spark ignition (petrol engine) or compression ignition (diesel engine)

In terms of boat types, the sector can be categorised into motorboats (inboards and outboards), sailboats, personal watercraft and inflatables. A brief summary of each boat type is presented in the subsections below and an overview of the engine types typically applied for each boat category is summarised in Table 1, see [tracking environmental pressures from recreational boating](#) [6]. Additionally, the recreational craft sector can also be categorised by type of activity (water sports, cruising and fishing).

2.2.1.1 Sailboats

Sailboats are designed to mainly be powered through sails using wind as a propulsion. However, to enable operations when wind conditions are unfavourable, as well as to facilitate manoeuvring, an engine is usually fitted on sailboats. Sailboats without inboard facilities will typically be fitted with an outboard engine. Larger sailboats/yachts with a cabin can be fitted with an inboard engine. Small sailboats such as dinghy boats are often not fitted with an engine.

2.2.1.2 Motorboats

Motorboats can be divided into open motorboats and motorboats with a cabin. Within these two categories, there are a wide range of motorboat subcategories, which can be grouped based on their hull shape (displacement boats and planning boats), as well as in length of the boat and engine power (ranging from tens to hundreds of hp). Typical motorboat usage patterns and missions are very diverse given the range of

motorboat types; these can vary from navigating inland waterways, to high performance sports boats, to fishing boats and superyachts. Open motorboats are typically used for relatively short distances, mainly for transportation or for water sports. Inboards, outboards or sterndrive engines can be fitted on open motorboats. Motorboats with cabins can be used for longer journeys or for cruising and are usually fitted with an inboard engine, although outboards may also be used, particularly on small to medium-sized motorboats.

2.2.1.3 Inflatables

Inflatables are boats characterised by a buoyant hull structure, where the shape of the hull and level of buoyancy is obtained via inflation. There are five main types of inflatable boats, including inflatable rafts, inflatable pontoon boats/catamarans, inflatable kayaks, inflatable dinghies/sports boats and rigid inflatable boats (RIBs), see further guidance by the SHM group on [the types of inflatable boats](#) [7]. Given that only the latter two are engine-powered, they are the most relevant types of inflatables for decarbonisation of operational emissions. A brief overview of these two inflatable boat types is presented below:

- **Inflatable dinghies/ inflatable sports boat:** a high-quality inflatable, mainly used as tenders for larger vessels. They are fitted with an outboard motor, normally in the lower power range and can be operated at sea to a certain extent
- **Rigid inflatable boats (RIBs):** a type of hybrid between an inflatable boat and a traditional boat, characterised by inflatable tubes to provide buoyancy, but with a rigid hull which enables them to operate at sea easily. They are fitted with an outboard motor, often in the higher power range

2.2.1.4 Personal watercraft

Personal watercraft (PWC) are powered by water jet propulsion, which is in turn powered usually by an inboard petrol engine. PWCs are usually used mainly for water sports. PWCs are often referred to based on their trade names, such as Jet Skis (Kawasaki), Waverunners (Yamaha) and Sea Doos (Bombardier Recreational Products - BRP). These three companies represent nearly 100% of the PWC market in Europe. The five main types of PWCs are categorised by the number of seats available, as well as the position of the rider, including: one seater (sit down), two seater (sit-down), three and four seater (sit-down) and stand-up PWCs, see the British Marine guidance page on [Personal Watercrafts](#) [8].

Table 1: Typical engine types per boat category
 See [tracking environmental pressures from recreational boating](#) [6]

Boat type	Typical engine type
Sailboats	Outboard engine – smaller boats Inboard diesel engine – larger boats
Motorboats	Outboard/inboard petrol or diesel engine/sterndrive petrol or diesel engines – open motorboats Inboard petrol or diesel engine/sterndrive petrol or diesel engines – cabin motorboats Outboard engine – small cabin motorboats
Inflatables	Outboard engine
Personal watercraft (PWC)	Inboard petrol engine

2.2.2 Boat parks

According to ICOMIA 2019 statistics, the total global boat park – defined as the total number of boats in use – adds up to 30.4 million boats, with 21.3 million boats for which a specific boat category can be identified (Figure 2), see the 2019 report by ICOMIA on the [Recreational Boating Industry Statistics](#) [4]. Out of these vessels, outboard motorboats constitute over half of the market in terms of number of vessels (52%), followed by inboard/sterndrive motorboats (18%), sailboats (12%), others (5%)¹, PWCs (5%) and inflatables (3%). The US’s boat park is the largest globally, accounting for 13.1 million boats, or 43% of the total global boat park. Europe accounts for the third largest boat park after Canada, at 6.4 million boats – or 21% of the market².

¹ Other boats include: vessels for pleasure sports, rowing boats and canoes other than motorboats, sailboats and inflatables.

² The total European boat park figure includes total boat parks for Germany and Croatia, which are not included in Figure 2 as categories of boats for these two countries were not available.

2019 Global Boat Park

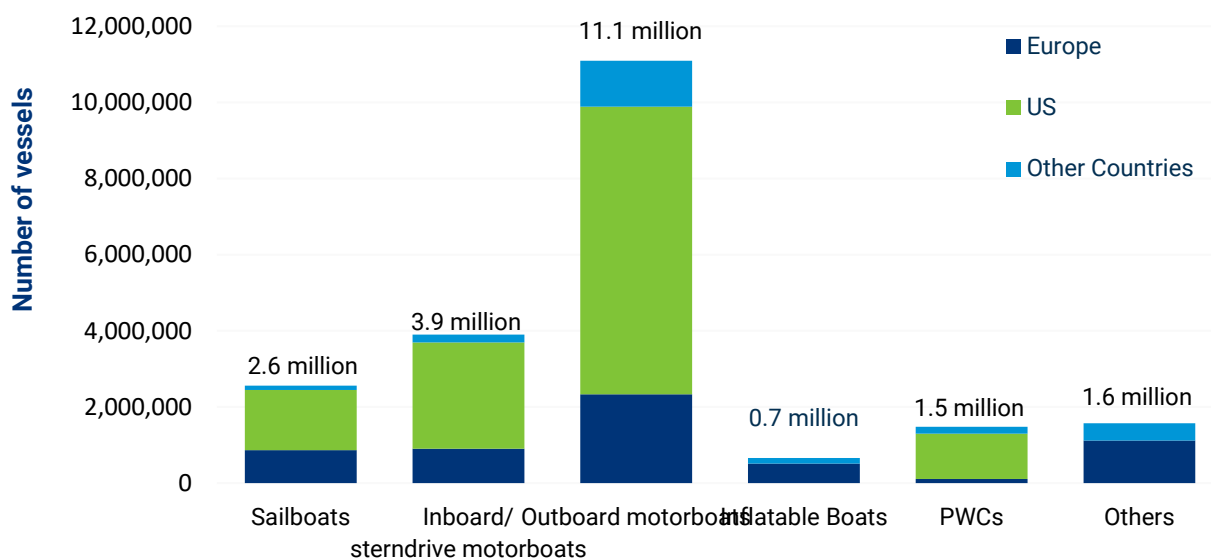


Figure 2: Global Boat Park. Boat park refers to the number of vessels in use.

Data from ICOMIA 2019 World Boat Park.

Within Europe, the breakdown of the boat park per vessel type differs slightly from the global picture (Figure 3). Outboard motorboats still represent the largest share of vessels in the fleet (40%), however other boats account for a larger share of the boat park in Europe (19%). Shares for inboard/sterndrive motorboats and sailboats are similar at around 15%, while inflatables represent a larger share compared to the global boat park at 9%. PWCs only account for 2% of the European boat park.

France has the largest boat park overall, totalling 1.13 million boats, or 18% of the total European fleet, closely followed by Finland (1.12 million boats, 18%) and Norway (0.81 million boats, 13%). Looking at fleets per boat type, Sweden, Finland and Norway are the markets with the largest number of outboard motorboats, accounting for 22%, 20% and 18% of the total number of European outboards. The three European countries with the highest number of sailboats are the UK, France and the Netherlands, representing 25%, 24% and 21% of the 0.9 million European sailboats.

In regards to inboards/sterndrive motorboats, the largest fleets in Europe are found in France (0.20 million boats, 22%), Norway (0.16 million boats, 18%), and the Netherlands (0.14 million boats, 15%). France also comes first in terms of inflatables fleet size, with 0.20 million boats (40% of European inflatables fleet), followed by Norway (33%) and the UK (12%). PWCs are allocated only to eight countries within Europe according to statistics, with France accounting for over half of the European PWC boat park, followed by the UK (13%) and Norway (12%).

European Boat Park by Country and Boat Category (2019)

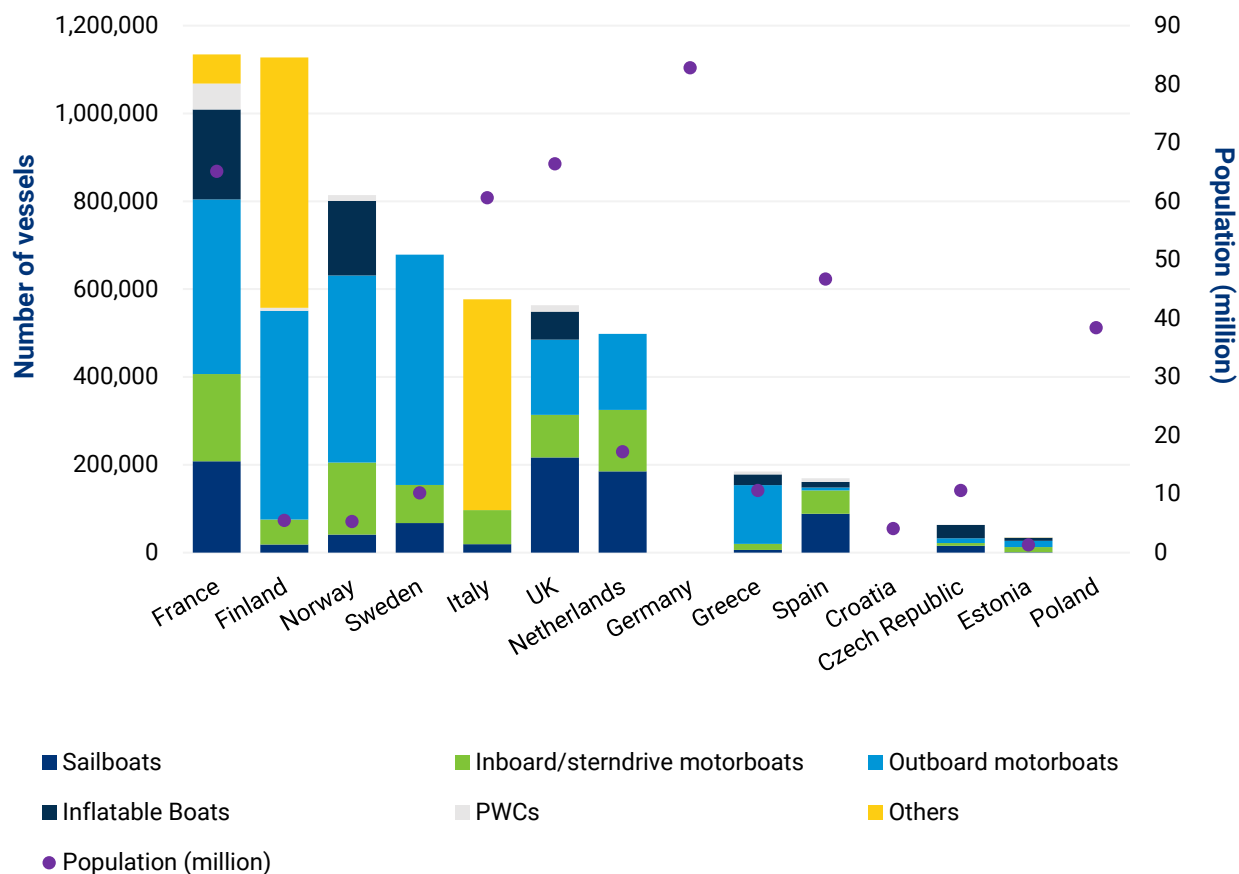


Figure 3: Split of vessel type at European boat parks.
Data from ICOMIA 2019 World Boat Park.

2.2.3 Mooring recreational vessels

There are a number of facilities where boats can moor, the largest of which are marinas. Marinas are typically part of the water/coastal area and are equipped for supplying berthing services. Other areas include berthing areas (typically a mooring buoy coastal or larger water areas), mooring sites (typically a fixed mooring stake along inland waterways) or dry facilities (for smaller boats inland, e.g. reservoirs or long-term storage of larger boats).

Though the main source of income is through berthing boats, marinas are also used as a hub for much of the rest of the supply chain including service providers, equipment sales and tourism through charters. Marinas are also known with evolving the local economy, as consumer services (restaurants and local shops) are likely to emerge with more access to the area, see the European Commission's [working document on Nautical Tourism](#) [5]. Throughout Europe the use of marinas differs: in some areas of Southern Europe with a strong tourist economy, marinas are dependent on chartered boats whereas other areas are mainly dominated with residential mooring, see the ECSIP Consortium's study on the [competitiveness of the recreational boating sector](#) [9]. It should be noted that depending on the location of the marinas, cash flow can be seasonal.

According to the ICOMIA there are over 10,000 marinas in Europe (see Table 2 for a selection), including small yacht clubs and municipal moorings. Marinas vary in size, from small canal-side marinas to larger yacht harbours for luxury superyachts, and therefore have widely differing incomes and business models.

Marina development occurs in two different ways: through private investments and as a municipal investment. The majority of privately-owned marinas are SMEs or are managed by associations that do not tend to focus on shipping or large commercial operations, see the European Commission's [working document on Nautical Tourism](#) [5] and the [Phenomenon of the Marina Development to Support the European model of Economic Development](#) [10]. There are a growing number of private owners that operate a chain of different marinas, which allows easy knowledge sharing. An example of a marina chain is "Yacht Havens Group Ltd" which operates in the UK and the Netherlands.

Therefore, there are varying degrees of funds available for infrastructure upgrades at a marina level. Larger marinas may be able to invest in new technology but the full benefit will not be realised without a network of upgraded mooring facilities. Smaller marinas generally do not have the funds to invest in newer technologies or the contact network to collaborate with other marinas to share knowledge. Infrastructure upgrades are extremely important for a low emission future, as will become apparent in this report, so marinas may require assistance from governments.

Many marinas were designed and built in the mid-to-late 1900s and require significant refurbishment or modernisation, especially since the recreational craft industry has increased in popularity and marinas now need to account for an amplified number of visitors. To prepare for future technologies, it is important marinas start to invest in the relevant technologies such as high-speed shore charging to allow for a smooth transition to low emission technologies over the coming years.

Table 2: Marine facilities by country. N.B this is not an extensive list.

Source: ICOMIA

Country	Number of individual marinas/yacht harbours ³	Number of wet berths/slips	Number of boat ramps
Sweden	2,000	500,000	200
Italy	961	187,000	2,000
UK	575	100,000	1,317
Finland	1,300	80,900	8,300
France	403	253,000	1,196
Netherlands	1,160	245,000	700
Greece	60	23,305	413
Spain	370	130,900	200
Poland	1,310	48,900	1,914
Cyprus	2	470	-

³ Note: ICOMIA's report (2020) underlines that countries have different definitions of marinas / yacht harbours, hence some numbers may appear inflated if countries are also counting small pontoons within the total.

2.3 Country profiles

Europe has a strong recreational sector both in supply and demand with countries such as France, the Netherlands, and the UK, world-renowned for their boat building capabilities. As the sector looks to decarbonise, it will be important for companies to adapt and upskill to ensure Europe does not lose its design and manufacturing capabilities. Many European countries have high boat ownership and domestic engagement in water-based activities with nautical tourism providing significant economic impact and the Mediterranean coast generating half of the sector's economic output, see the European Commission's [working document on Nautical Tourism](#) [5].

While major economies have in recent years started to put greater focus on clean growth, the Covid-19 pandemic has focused attention on investing in the green transition and building greater resilience. Nautical tourism is an important segment of the recreational craft sector, and, as with all tourism, it has suffered substantially during the pandemic. A recent call for action by the European Tourism Alliance highlights the opportunities to accelerate recovery by investing in sustainable tourism including the decarbonisation of the recreational craft sector both at a EU and national level, see the European Tourism Alliance call for action: [Accelerate Social and Economic Recovery by Investing in Sustainable Tourism Development](#) [11].

The following country profiles outline this study's geographical focus areas, providing detail on the relative importance of the recreational craft sector for each market.

2.3.1 United Kingdom (UK)



The UK has 17,381km of coastline and 3,250km² area of inland lakes and waters, with a strong maritime history. The ICOMIA 2019 Recreational Boating Industry Statistics reported that there are approximately 600,000 boats in ownership and annual boat sales are estimated at €600m,. While the domestic market grew in 2018, supported particularly by the sales of smaller vessels, export sales continue to be the important driver of growth, particularly motor yachts which accounted for 77% of all export sales in 2019 and 86% in 2018, see the 2019 report by ICOMIA on the [Recreational Boating Industry Statistics](#) [4]. Europe continues to be the key export market with approximately 27% of sales going to the rest of the world. Key players include Sunseeker, Princess and Oyster, which are recognised as global leaders in the yacht sector and continue to be sought after brands.

British Marine has estimated that the total UK recreational craft market is worth £1.4 billion annually to the UK economy, with the leisure marine market accounting for over 69% of the total sectoral gross value add at over £1 billion. The UK has seen a growth in the export market supported by the depreciation of the pound since the EU referendum according to British Marine, see British Marine [UK boatbuilding sector enjoys rising exports amid challenging industry conditions](#) [12]. In 2019, UK boatbuilders generated around £1 billion in revenue (including leisure marine, superyacht and small commercial marine sectors) with an estimated 58% of marine industry turnover centred in the South West and South East, with employees in the leisure marine sector totalling 26,890, see British Marine: [key performance indicators and industry trends research](#) [13].

In 2019, the UK government announced a Clean Maritime Plan setting out how the industry can reach net zero emissions, including all new vessels for UK waters designed with net zero emission capable technologies by 2025. Further information can be found in Section 4.2.

2.3.2 France



France has a strong recreational vessel manufacturing industry and domestic engagement in coastal activities as Europe's largest consumer market. It has 5,700km of coastline and 8,500km of inland waterways with over 1,000 marinas and harbours. France specialises in sailing boats with the manufacturing of these vessels accounting for 34% of European production in 2015, and a total production revenue of €1.3 billion in 2019, mainly driven by the sales of yachts, see the 2019 report by ICOMIA on the [Recreational Boating Industry Statistics](#) [4]. France is a world leader in sailing boat production with distinguished brands such as Bénéteau and Fountaine-Pajot driving international exports.

In 2019, it was estimated by Fédération des Industries Nautiques that 44,000 people were employed by the nautical sector. The west coast is the main employment area for pleasure boats with two thirds of the companies located in this region. Both new and second-hand yacht and motor boat sales rose in 2019, although the growth has been relatively modest (2.6% new and 3% second hand) and over 75% of boat production has been for export, according to the Boat Industry [2019 figures for the French boating industry](#) [14]. This slow-down in sales growth has been observed across the industry since 2008.

In recognition of the industry need to address the end-of-life issue, France is one of the few countries with regulations governing the dismantling and recycling of recreational vessels, having implemented the principle of extended producer responsibility by establishing eco-contributions to be paid by boat manufacturers and by boat buyers for financing recycling of boats as well as APER in 2019, a non-profit organisation set up by the French Nautical Industries Federation to manage the disposal of recreational craft. Further information can be found in Section 7.4.

2.3.3 Netherlands



The Netherlands has 400km of coastline and 7,652km² of inland fresh water lakes. The recreational craft industry employs approximately 23,000 people, with nearly 4,000 companies working in the industry. Domestic boat ownership is high and demand has grown in recent years with an estimated 12,000 recreational boats in Amsterdam. However, export sales are a significant part of the Dutch sector with overseas sales of vessels under 24m reaching €195 million in 2019, and totalling €2.9 billion including all class sizes of recreational vessels, see the 2019 report by ICOMIA on the [Recreational Boating Industry Statistics](#) [4].

As a maritime nation, the Netherlands has a strong history in boat building and has become one of the leading countries in building superyachts (defined as luxurious yachts longer than 24m). In 2018, they

ranked second globally for superyacht construction orders and since 2016 they have accounted for 25-45% of the total value of ships delivered in the Netherlands. Dutch yards catering to superyacht construction have invested in new production facilities which is strengthening their global position. According to the OECD, export sales from luxury yachts amounted to €1.7 billion in 2019, see the OECD's report on the [peer review of the Dutch shipbuilding industry](#) [15].

Activities are underway to encourage low emission vessels with the City of Amsterdam enacting a ban on boats with diesel engines operating on the city's canals by 2025. So far, around 75% of the commercial fleet have gone electric, however, it is estimated that only 5% of privately-owned boats have managed to accomplish this due to the costs involved. See Section 4.2.2.3, for more detail.

UK outline



2.3.4 Greece

Greece consists of 6,000 islands and islets with over 15,000km of coastline. As an island nation in the Mediterranean, the recreational craft industry is a priority area for growth. Nautical tourism has played an important role in the economic recovery of the country since the market collapse following the financial crisis in 2008. In 2020, the Greek Marinas Association, estimated that marinas and yachting contributed 1.4% in GDP with the expectation of significant growth. In part, this is likely to be increased by further privatisation of Greek marinas which is expected to add another 1% to the GDP.

Similarly, to other Mediterranean countries, Greece is well known for its charter operators and is a key market for imports of sailing yachts. In a survey undertaken by ICAP, the country's yacht chartering grew by an average of 3.4% between 2014 and 2018, with the charter of sailing vessels accounting for the majority of the market segment revenue which includes superyachts, see the article [Greek yachting charter market growth](#) [16]. Greece has become well known as a destination for island hopping, which helps to differentiate it from neighbouring countries, and nautical tourism will play a significant role in the recovery of the tourism sector post pandemic.

There were nearly €74 million of domestic boat sales in 2019, which is the third consecutive year of double-digit growth, and this is helping to grow the related servicing industry. Although the export market is smaller, in the same year there were nearly €16 million of exports with the largest segment associated with outboard motor boats.

2.3.5 Cyprus



Cyprus has 648km of coastline and is the third largest island in the Mediterranean. Demand for recreational vessels has grown with the major marinas typically at maximum occupancy. In recent years, Cyprus has attracted significant investment to upgrade facilities including the Ayia Napa Marina, which will be fully operational by 2023, and Larnaca port and marina upgrades due to be completed in 2037. Cyprus is an important export market for many other European countries with 95% of their imports coming from within

the EU, focused on the larger vessels – notably motorboats above 12m, see the 2019 report by ICOMIA on the [Recreational Boating Industry Statistics \[4\]](#).

2.3.6 Malta



Malta has a coastline measuring 173km. Similarly, to other Mediterranean countries, Malta is a key export market for other European countries with approximately 84% of imports coming from within the EU. This is dominated by motorboats above 12m, followed by a much smaller market for sailboats above 12m. The domestic export market is small and focused on countries outside of the EU. Malta has typically focused on the services and repair industry, see the 2019 report by ICOMIA on the [Recreational Boating Industry Statistics \[4\]](#).

There is growing recognition of the economic benefits for nautical tourism which has been supported by the development of marinas and berthing facilities. Malta has enacted legislation to make it more attractive for private and commercial yachts to register under the Maltese flag to encourage vessel charter and recreational crafts. This has enabled Malta to become the second largest maritime flag in Europe, and the eighth largest in the world. However, there is growing competition with neighbouring countries.

3. Sectoral Growth

Prior to the Covid-19 pandemic, the industry was aware of a shift in consumer habits concerning recreational craft. Various industry research has concluded that although the global pandemic has made a significant dent in the global recreational craft industry, with some areas receiving help from governments, the summer 2020 sales were on track with global growth predictions and saw a sharp increase in purchasing by recreational marine user newcomers as a result of the 'staycation' phenomenon, see the 2019 report by ICOMIA on the [Recreational Boating Industry Statistics](#) [4].

3.1 Growth predictions

Despite the ongoing Covid-19 pandemic, the industry is expected to recover and future prospects are promising for the industry. All research shows an increase in CAGR (compound annual growth rate) from 2020. Some predictions by various research bodies into the growth of the industry are:

- **Technavio's** report on [Global Boat and Yacht Transportation Market 2020-2024](#) predicts a global increase 4% CAGR between 2020-2024 [17].
- **Grand View Research** report on [Leisure Boat Market Size, Share and Trends Analysis Report 2020-2027](#): Global increase of 4.1% CAGR between 2020-2027 [18].
- **Market and Market's** report on [Recreational Boats Market – Global Forecast to 2027](#) predicts a global increase of 3.02% CAGR between 2019-2027 [19].
- **Global Market Insight's** report on [Recreational Boating Market Size and Forecast 2020-2026](#) predicts a European increase 5.5% CAGR between 2020-2026 [20].

The above research bodies each have their own definitions on what constitutes a 'boat', so the values for absolute growth rate are somewhat restricted. However, it is clear to see that the recreational craft market is still set to grow.

The market review papers mentioned above broadly agree that the North American market is expected to see the largest market growth due, in part, to their increase in per capita income, resulting in a rise of disposable income, and the increasing popularity of recreational craft and fishing. Figure 4 shows the predicted market split between regions by 2027.

Prior to the pandemic, the recreational craft industry was seeing an increase in vessels used for tourism purposes. The continued development of coastal and marine tourism in North America and other European countries like France is expected to drive the increase of recreational vessels.

Global Boat Market by Geography in 2027

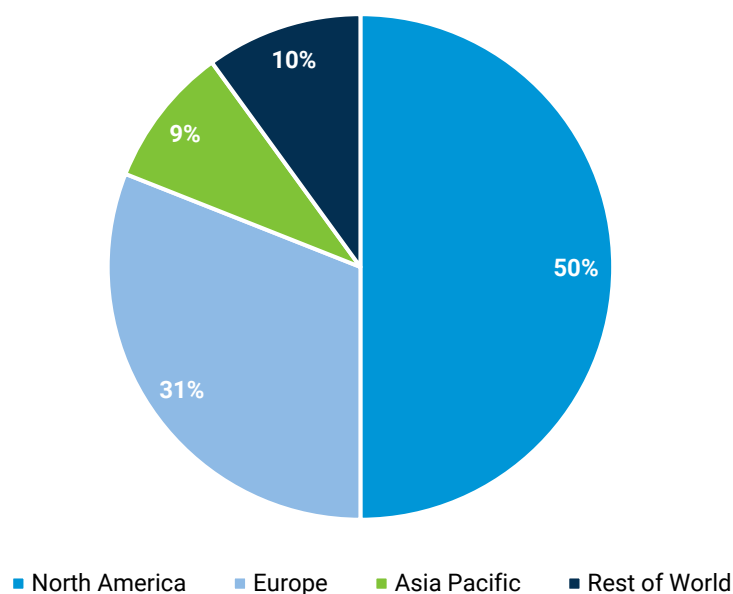


Figure 4: Predicted Global Boat Market by 2027.
Data Source: Verified Market Research [Global Boat Market Forecast](#) [21]

3.2 Growth drivers and challenges

Growth rate is affected by a range of factors: population, regional recreational craft demand, the recreational industry, water sports industry and the competitive landscape. The key drivers to the increase in demand in North America are thought to be an increase in coastal tourism and an increase in recreational activities like fishing.

Globally, manufacturers are also holding more boat shows and Expos. According to IFBSO (International Federation of Boat Show Organisers) there are 18 boat shows scheduled globally during 2021, with the first held virtually in Helsinki in February, see the IFBSO [forthcoming shows ordered by date](#) [22]. The Southampton boat show in the UK is by no means the largest, but still receives over 100,000 visitors annually. The existence of multiple manufacturers creates industry competition, which will help with industry growth as advancements in technical innovation will emerge.

Technology advancements are also expected to increase the popularity of engaging in recreational craft activities. According to Global Market Insight, manufacturers are increasingly integrating advanced technologies into boats to increase function (e.g. improving steering) but also to improve safety and security (e.g. integrating sensors), see Global Market Insight’s report on [Recreational Boating Market Size and Forecast 2020-2026](#) [20].

One of the major challenges to the future of the recreational craft industry is its environmental impacts and associated carbon footprint. The environmental impacts incorporate not only carbon emissions, but physical impacts due to anchoring and mooring, groundings and abandonments, collisions, disturbances,

propeller wash and vessel wake, see article [Boating and Shipping related environmental impacts and example management measures: a review](#) [23].

The general trend for boat ownership age has continued to rise and stakeholders note that alternative ownership models are becoming more appealing to younger generations. These include co-ownership or rental with an interest in newer models rather than second hand boats. While in the mid to long-term this will likely create opportunities for new technologies and low emission vessels, many of the existing fleet are nearing end-of-life, creating problems linked to their disposal.

Nautical tourism is an important economic growth driver for many European countries and this has helped drive growth in the recreational vessels sector. In addition, trends show greater consumer interest in environmental issues and there have been increasing numbers of visitors to Coastal Marine Protected Areas (MPA) and Marine Natura 2000. Stakeholders have noted the potential to incentivise an acceleration to low emission vessels by enacting legislation to only allow low emission vessels to enter these areas.

4. Sectoral emissions

4.1 Emissions from recreational vessels and sector environmental trends

The shipping sector as a whole, including commercial domestic and international vessels, is responsible for around 2.3% of global emissions. To date, emission inventories and regulations have focused on commercial vessels, with data related to the recreational craft industry remaining scarce. Despite the lack of data on recreational craft's total emissions, the sector is responsible for a minor share of shipping emissions.

Nevertheless, emissions from recreational craft need to be reduced to mitigate impacts on local coastal ecosystems, as well as to support the achievement of national climate targets. Additionally, the decarbonisation of recreational craft could support the decarbonisation of other maritime sectors by contributing to the development and deployment of a net zero emission technology supply chain for solutions that could be applied to other shipping segments, such as short sea shipping.

As governments seek to increase their decarbonisation efforts and as demand for more sustainable vessels increases among consumers, companies across the supply chain of the recreational craft sector face increasing pressures to improve the environmental credentials of existing and new vessels, as well as new opportunities for driving innovation and leadership within the sector.

Boat and engine manufacturers are already engaged in increasing fuel efficiency and reducing vessel emissions, with demand for zero operational emission engines increasing and companies investing in the development of new systems capable of running on alternative fuels. However, action needs to ramp up rapidly if the sector is to decarbonise at the rate outlined by regional climate targets.

4.1.1 Lifecycle emissions

A lifecycle assessment (LCA) is the approach used to determine total GHG emissions produced by a product throughout its various lifecycle stages – from resource extraction to disposal, also known as a cradle-to-grave approach. Efforts to curb the maritime sector's emissions to date have focused mainly on reducing operational emissions, particularly in commercial shipping where vessels need to comply with carbon intensity thresholds set against their actual or expected operational emissions. However, as pressures to decarbonise the maritime sector keep growing, the sector is starting to look at the LCA approach as a more comprehensive process to assess emission reductions and ensure that any emission reductions achieved for operations do not drive increased emissions either upstream or downstream.

The LCA approach, although still novel for the industry, is slowly emerging within the recreational craft sector, with LCA tools being developed to support boatbuilders in designing and manufacturing boats with an overall lower environmental impact (see example within case study below). Although it is still early stages in the industry's adoption of an LCA approach, it is critical that full lifecycle emissions are taken into account

when evaluating decarbonisation options for recreational craft to gain an overall understanding of how a boat's emissions footprint can change based on these options, and what the optimal decarbonisation solution is for a specific boat. Despite a greater focus being placed within the report on assessing the decarbonisation potential of different technologies in regards to operational emissions, further work to determine each technology's LCA impact will be required to ensure that an optimal pathway to emissions

Case study

Marine shift 360

MarineShift360 is an international partnership aiming to drive change in the marine industry by providing a comprehensive Lifecycle Assessment (LCA) tool supported by data collected by marine industry experts and backed by 11th Hour Racing. The tool enables users to compare materials, alternate materials, and drive innovation towards sustainability by measuring the environmental footprint of the boat. It is certified in accordance with the standards for lifecycle assessment: ISO 14040:2006 and ISO 14044:2006, and it measures global warming potential (kgCO₂e), non-renewable resource depletion, water consumption, marine eutrophication, energy consumption and waste production.

reductions is pursued by the recreational craft sector.

4.1.2 Operational emissions

Recreational crafts are powered generally by diesel or petrol, although some drop-in low or net zero emissions synthetic fuels or bio-fuels or electric/alternative propulsion systems already exist. The major greenhouse gas emissions from recreational craft include carbon dioxide (CO₂) and nitrous oxide (N₂O). Other airborne emissions from fuel combustion include nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter (PM) and volatile organic compounds.

Part of the emissions from the engine exhaust system can dissolve into the water, particularly when the exhaust outlet is located underwater. Hydrocarbons, which include a range of different compounds, are a key source of emissions to water from watercraft. The main hydrocarbons emitted from watercraft include:

- Benzene, toluene, ethylbenzene and xylene: made up by 20-50% petrol, hence will evaporate quickly from water
- Methyl-t-butylether (MTBE): MTBE can be added to fuels to increase the fuel's octane number. MTBE is soluble in water and high concentrations are highly toxic
- Polycyclic aromatic hydrocarbons (PAHs): generally, poorly soluble in water and with low degradability, although they can be easily absorbed by sediments due to their high affinity for particles and organic matter. Some PAHs have a higher solubility and hence pose higher risks to aquatic organisms

For more information see [tracking environmental pressures from recreational boating](#) [6].

The level of emissions and pollutants emitted by a boat when in operation will depend on several factors, including engine and fuel type, mode and duration of operation, as well as horsepower. Up until recently, there has been a clear emission performance gap between two-stroke and four-stroke engines.

In two-stroke engines, the power and exhaust processes take place within the same piston stroke and higher amounts of unburnt or partly combusted fuel can be released via the exhaust system. In a four-stroke engine this is based a four cycle process.

Research suggests that historically carburetted two-stroke engines were around ten times more polluting than four-stroke engines, see the NIWA literature review on [potential impacts of emissions from outboard motors](#) [24]. More stringent engine standards for pollutant emissions and efficiency have driven improvements in two-stroke engine technology, with modern direct injection two-stroke engines having comparable pollutant emissions and fuel consumption to four-stroke engines. However, recreational boats operating on older two-stroke engine models still emit significantly more pollutants than an equivalent four-stroke engine.

Two-stroke engines have historically been less costly, more reliable in operational behaviour and with higher power output per engine size and weight compared to four-stroke engines, which has driven their uptake particularly in the outboard engine sector. Although recent improvements on four-stroke engines have closed the performance gap between the two engine types, two-stroke engines still represent a large portion of the recreational craft fleet. Only limited upgrades to either newer two-stroke engines or to four-stroke engines have taken place to date due to the involved cost of retrofit and absence of incentives.

From a horsepower perspective, the recreational craft sector has seen engine power increases in the past decade, particularly on outboard engines. Sales of highest rated outboard engines (200hp and above) have doubled in the US and Europe since 2008 levels, and saw a 17% increase from 2018 to 2019. The move to more powerful engines is expected to drive upward trends in operational emissions, despite improvements in engine efficiency.

On the fuels front, according to BEIS' fuel emission factors (2020), diesel has higher associated combustion emissions compared to petrol, with 100% mineral petrol having around 6% lower GHG emissions compared to 100% mineral diesel. When accounting for current average biofuel blends, petrol still has 5% lower GHG emissions compared to diesel. Petrol engines are typically used on smaller boats, particularly on outboard motorboats. Larger boats, particularly seagoing vessels, usually have diesel engines.

Table 3: Diesel and petrol combustion emissions
 Figures available at BEIS: [Greenhouse gas reporting: conversion factors 2020](#) [25]

Fuel	Emissions - kgCO ₂ e/kWh (based on Net Calorific Value)
Diesel (100% mineral)	0.26891
Petrol (100% mineral)	0.2539
Diesel (average biofuel blend)	0.25568
Petrol (average biofuel blend)	0.24164

The total operating time of boats will also have an important impact on their total annual and lifetime emissions. Recreational craft have a much lower usage rate compared to commercial vessels given the nature of the sector, with higher usage rates seen in months characterised by warmer climate. Interviewed stakeholders have indicated that boats in the EU are used around 50 hours per year. This figure is expected to vary depending on specific countries climate conditions, hence an indicative range of between 25-100 hours has been assumed.

These estimates highlight that, although operational emissions are an important driver of total emissions in the recreational craft sector, sources of emissions from other lifecycle stages (e.g. manufacturing to end-of-life) should also be considered in the sector’s decarbonisation.

4.1.3 Materials and end of life emissions

The recreational craft sector is increasingly looking at how to reduce the environmental impacts related to practices for disposing of boats once they reach their end of operating life. Recreational boats have a long average lifespan, which estimates show being at around 10 years for inflatables, 20 years for motorboats and 30 plus years for sailboats, although industry stakeholders highlight that actual lifetimes of vessels can be even longer. Most vessels today are made from fibre reinforced plastics (FRPs), and particularly glass reinforced plastic (GRP), which are highly durable. For this reason, end-of-life (EOL) of boats has not been considered as a major issue to date.

However, as vessels reach their EOL or as some vessels may need to be scrapped early in the future due to retrofits to net zero emission propulsion being unsuitable, the issue of disposing of boats becomes increasingly important. According to studies from the European Composites Industry Association, composites from the marine industry will account for 10% of total composite waste streams by 2025, equivalent to 70,000 tonnes of waste, see the European Boating Agency’s [position statement on end-of-life boats](#) [26].

Currently, recycling of FRPs is challenging and costly, hence the industry has had few incentives to pursue solutions to this challenge. Disposal of FRPs to landfill is still allowed in the EU and the majority of FRP products, including boats, end up in landfill. However, some countries including Austria and Germany have already forbidden the disposal of FRPs to landfill and more member states are expected to follow suit, see

the European Commission's report on [large scale demonstration of new circular economy value-chains](#) [27]. As awareness of the issue increases, several projects have looked at boat disposal practices and recycling processes. Industry focus on the use of alternative materials for hulls to enhance the circularity of a boats lifecycle is also growing. Both of these topics are further explored in section 5.1.

4.2 Current regulation and legislation

The framework for decarbonisation is set through legislation and regulation and must be supported by appropriate financial mechanisms and incentives to develop innovation and grow ambition. The following sections outline the current landscape, while further information on potential future policies can be found in Section 7.

4.2.1 International shipping regulation

Recreational craft up to 24m in hull length fall outside the remit of the International Maritime Organization's (IMO) regulations. Although the recreational and commercial shipping sectors are fundamentally different (usage patterns, ranges, economics), understanding the developments of international shipping's GHG emission regulations provides useful background to the direction that the maritime sector is taking to achieve decarbonisation.

In 2018, the IMO adopted its Initial GHG Reduction Strategy, outlining an absolute emission reduction target of 50% by 2050 compared to 2008 levels, and to phase out sectoral emissions as soon as possible and within the century. The strategy also set out carbon intensity reduction targets of 40% and 70% by 2030 and 2050, respectively, compared to the 2008 baseline, see IMO guidance on [reducing greenhouse gas emissions from ships](#) [28]. These objectives provided the industry with guidance around the scale of decarbonisation required from the sector in the short, medium and long-term and placed new pressures for stakeholders to take action. During the Marine Environment Protection Committee's (MEPC) 75th meeting held in November 2020, the IMO approved new drafted mandatory regulations to control emissions from the international fleet, due to be officially adopted in 2021. According to these amendments, vessels will need to comply with both design and operational carbon intensity thresholds, see IMO statement on [amendments to aid emissions reduction](#) [29].

A new design efficiency metric for existing ships – the Energy Efficiency Existing Ship Index (EEXI) was approved, expanding design efficiency requirements that had been previously limited to newbuilds through the Energy Efficiency Design Index (EEDI). Similarly, to EEDI requirements, all existing vessels above 400 GT will be required to comply with EEXI thresholds, which will be provided for each ship type and size category. Recreational vessels are currently not included in the EEDI vessel categories; hence it is expected that this measure will not apply to yachts and superyachts in a first phase. However, detailed guidelines on EEXI still need to be published.

The Marpol Annex VI amendments also include enhanced Ship Energy Efficiency Management Plan (SEEMP) requirements, covering mandatory content, approval and audits. By January 2023, all ships above 400GT will be required to have an approved SEEMP on board all vessels. This will be applicable to any

recreational vessels (yachts) falling within the gross tonnage threshold, which will typically be vessels with hull lengths above 24m. Ships above 5,000GT will be subject to disclosure and monitoring of an annual operational carbon intensity indicator (CII), which will be accompanied by a rating system based on carbon intensity performance. The performance level will need to be included in the SEEMP, along with an implementation plan showcasing how CII targets will be achieved.

Although the new IMO measures signal renewed commitments from regulators to keep placing pressure on the industry to decarbonise, they have been criticised by various stakeholders as not being ambitious enough to meet the IMO's absolute reduction targets, as well as not driving the rate of decarbonisation required to align to Paris Agreement climate targets.

4.2.2 EU policies

4.2.2.1 European Green Deal policies and funding

The European Union has openly criticised the outcomes of the 75th MEPC and plans to roll out more ambitious measures to incentivise decarbonisation of its maritime sector. The European Green Deal, first presented in 2019, included shipping within the 90% emission reductions by 2050 targets for the transportation industry. In December 2020, the European Commission adopted the new Sustainable and Smart Mobility Strategy, which outlined several measures targeting shipping, including:

- Extending the EU's Emission Trading System (EU ETS) to shipping in June 2021
- The implementation of the FuelEU Maritime – Green European Maritime Space initiative, aimed at increasing the adoption of alternative fuels within the international maritime fleet, regulating access of the most polluting ships into EU ports, and mandating that docked ships reduce their emissions, including through the use of shore power
- Considering the establishment of a Renewable and Low Carbon Fuels Value Chain Alliance, aimed at supporting the development and deployment of the most promising alternative fuels for the transport sector

While these measures are directly relevant to commercial shipping rather than recreational vessels, the push to reduce emissions and shift away from conventional fossil fuel-based fuels, to alternative fuels, is expected to impact the whole sector, including leisure craft. The Recreational Craft Directive, the current key EU measure aimed at regulating emissions from recreational craft is further covered in section 4.2.2.3.

The introduction of the European Green Deal has unlocked new funding opportunities for the maritime sector also through other strategies indirectly linked to the mobility strategy, including the new Hydrogen Strategy. The Hydrogen Strategy aims at accelerating clean hydrogen production in the EU, with a target to support a minimum 6GW and 40GW of electrolyzers in 2024 and 2030, respectively, see the European Commission's [hydrogen strategy for a climate-neutral Europe](#) [30]. The production of green hydrogen is seen as a key factor required to achieve the decarbonisation of the maritime sector, including for specific types of recreational craft, as is further explored in Section 4.2.3.1 of this report.

4.2.2.2 Covid-19 recovery funding

Covid-19 recovery packages represent a key opportunity for building back greener sectors, including the recreational craft industry. In May 2020, the European Commission launched the EU Recovery Plan, including the NextGenerationEU initiative, a €750 billion temporary recovery instrument aimed at boosting immediate economic and social recovery from the Covid-19 pandemic, see the European Commission's statement on [preparing for the post-pandemic future](#) [31]. The funding will be made available to EU members via a mix of grants, loans and strengthening of existing EU programmes. It will aim to provide support to the worst hit sectors, as well as making these sectors greener, more digital and more resilient to future challenges. Stakeholders repeatedly highlighted the Covid-19 recovery package, along with the European Green Deal, as key mechanisms for accelerating decarbonisation within the recreational craft sector.

Recreational activities including tourism have been severely hit by the pandemic and the European Tourism Manifesto (an alliance of travel and tourism organisations including the European Boating Industry) have recently released a document outlining a series of concrete investment proposals to support the recovery and development of a more sustainable tourism industry for member states to consider when developing their national recovery and investment plans, see the European Tourism Alliance call for action: [Accelerate Social and Economic Recovery by Investing in Sustainable Tourism Development](#) [11]. These proposals cover several areas, including recreational craft. Ideas specifically related to the decarbonisation of the recreational craft sector include:

- Funding projects aimed at building environmental recreational vessels, including the development of criteria defining environmental performance (e.g. benchmarking eco-designs, lifecycle assessments and materials substitution)
- Funding renovations and environmental enhancements of coastal and inland marinas for recreational craft, including the development of new berths, renewable energy installations, energy storage solutions, waste disposal facilities, small scale local desalination plants and climate adaptation projects
- Funding RD&D of alternative fuels for recreational craft (including biofuels, electrification, hybrid engines and hydrogen), as well as making funding available for consumers to retrofit existing vessels with new engines able to run on alternative fuels

4.2.2.3 The Recreational Craft Directive

The Recreational Craft Directive aims at standardising design and manufacturing requirements, as well as regulating exhaust emissions and noise for watercraft (both recreational craft and personal watercraft) sold to or operating within the European Union and European Economic Area. The first version of the Directive (Directive 94/25/EC) was adopted by the Council and European Parliament in 1994 and amended in 2003 (Directive 2003/44/EC), also referred to as RCD, was applicable until 18 January 2017. Directive 2013/53/EC, also known as RCD 2, came into force in 18 January 2016 and has now entirely replaced RCD, see RYA guidance on the [Recreational Craft Directive](#) [32].

The RCD II applies to all watercraft between 2.5 and 24m of hull length built since June 1998 and used for recreational and sports purposes. The directive provides requirements for the design and manufacturing of the boats and does not currently provide operational requirements. All watercraft falling under the directive need to comply with the established essential requirements in order to be sold or operated within the EU. The directive also applies to watercraft that has undergone significant retrofits, referred to as major craft conversion and including any changes to the watercraft's means of propulsion, including major engine modifications or other modifications that may lead the watercraft to fall outside of compliance with essential safety and environmental requirements outlined by the directive.

In relation to exhaust emissions, the directive sets out limits on carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulates for both compression ignition and spark ignition engines. However, target values for greenhouse gas emissions including CO₂ are not currently covered by the directive, see the full directive on [recreational craft and personal watercraft](#) [33].

In 2019, the European Commission announced it would commence a review process of the RCD in 2020, in line with the directive's review clauses. As part of this process, a third party study is being conducted by a consortium of companies – including Panteia, TNO and Emisia – to assess the impact of the current directive. Based on the outcomes of this assessment, the European Commission is due to draft a report by January 2022, which will highlight the key findings and present any proposals for implementing changes to the directive. The proposals would be taken through the legislative process of the Council and European Parliament. To align with Europe's new climate target of achieving carbon neutrality by 2050, the RCD review will also assess potential measures to reduce GHG emissions from recreational craft, which may be included in the proposed amendments for a future revision of the RCD, see EBI 2021 [update on review of the recreational craft directive](#) [34].

As part of the ongoing review process, the European Commission launched a consultation that closed on 14 March 2021, aimed at obtaining feedback from industry stakeholders in regards to the technical and economic feasibility of introducing additional exhaust emission reduction requirements for marine propulsion engines (including GHG emissions), and for introducing new requirements on evaporative emissions, as well as checking that current watercraft design categories are appropriate, see the European Commission's 2021 [targeted consultation on the Recreational Craft Directive](#) [35].

4.2.2.4 Non-Road Mobile Machinery Regulation

The Non-Road Mobile Machinery (NRMM) Directive outlines requirements on gaseous and particulate pollutant emissions that engines used on NRMM must comply with to be placed in the EU market. Emission thresholds cover CO, HC, NO_x, PM and Particle Number (PN). While the directive only covers engines for use on inland waterways of 19kW or above, non-road engines can be marinised and used on vessels, hence requirements are expected to trickle down to the recreational craft sector.

The directive (97/68/EC) was originally adopted by the EU in 1997 and consists of several annexes which have been amended over time. The latest proposed and adopted amendment is the EU Regulation 2016/1628 and is aimed at providing more stringent emissions and particulate matter restrictions on non-road engines and equipment. The current NRMM Directive applies in Great Britain and it is expected that a GB Type Approval scheme will be developed to replace EU provisions starting from 1 January 2022, see the Vehicle Certification Agency's directive on [Non-Road Mobile Machinery](#) [36].

The RCD 2 allowed for engines certified under the NRMM Directive (97/68/EC) to be marinised and installed on boats in compliance with the RCD 2. However, with the update of the NRMM Directive (2016/1628), this option will no longer be viable as the RCD refers only to NRMM 97/68/EC and not to the new regulation. According to British Marine, the marinisation of NRMM engines now falls under the Non-Road Equipment (NRE) category of the new NRMM Regulation (2016/1628), see British Marine: [Important update on marinized engines](#) [37].

4.2.2.5 RED II directive on biofuels and alternative fuels

An important EU regulation that is expected to impact the development and uptake of alternative fuels in the maritime sector is the Renewable Energy Directive (RED). More specifically, while recreational craft is not explicitly mentioned in the directive, requirements and targets on the uptake of biofuels and alternative fuels for transportation are expected to have an impact on the availability and uptake of these fuels on recreational craft.

The RED, first adopted in 2009, is the main EU law regulating the use of renewable fuels in Europe. The 2009 RED set a target for achieving 10% of total energy for transportation to come from renewable sources by 2020. The EU has reviewed the RED and legislators have agreed on the final RED II in June 2018. The RED II sets out targets and limits for use of different renewable transport fuels in the EU, with a binding target of advanced fuels to meet 7% of transport energy consumption. Fuels for the maritime and aviation sectors are not accounted within the target, however, fuels supplied to these sectors will receive a multiplier of 1.2 – i.e. each tonne of advanced fuel supplied to shipping/aviation will count for 1.2 tonnes towards meeting the mandated targets, see the briefing from Transport & Environment on the RED II and [how member states can deliver sustainable advanced transport fuels](#) [38].

As the EU has now increased its climate ambitions and is targeting a 55% emission reduction by 2030 and climate neutrality by 2050, the RED will need to be revised to ensure it is aligned with new targets. The consultation related to the review process was opened in November 2020 and closed on 9 February 2021.

4.2.3 Recreational vessels specific national strategies

Stakeholders have highlighted the importance of harmonisation of regulations and standards across national boundaries, and while European policies provide the overarching framework for the sector, national policies can assist in accelerating change.

4.2.3.1 UK maritime sector decarbonisation strategy

In 2019, the UK Government published Maritime 2050, which outlined the country’s strategic vision for the maritime sector up to the middle of the century, see the DfT guidance on [Maritime 2050, Navigating the Future](#) [39]. This vision included the ambition of the UK to lead the transition to net zero emission vessels, positioning itself as a frontrunner compared to other countries and to international standards. In the same year, the Clean Maritime Plan was released, offering more detailed ambitions and commitments set out by the government to lead the clean maritime transition, see the DfT report on the [Clean Maritime Plan](#) [40]. Key ambitions to reach the broader Maritime 2050 objectives are summarised in Table 4, below.

Table 4: Clean Maritime Plan ambitions

By 2025	By 2035
<p>The use of energy efficiency measures is maximised across all vessels operating in UK waters</p> <p>All new builds that will be operated in UK waters have the capability of running on net zero emissions fuels</p> <p>There are net zero emission commercial ships in operation in UK waters</p> <p>Clean maritime clusters aimed at developing innovations and infrastructure to enable net zero emission propulsion technologies are being built in the UK</p>	<p>Several clean maritime clusters have been built in the UK</p> <p>Low/net zero emission fuel bunkering infrastructure is available across the UK</p> <p>The UK Ship Register is recognised as a world leader in the net zero emissions maritime sector, due to its strong export industry, leading RD&D sector, and a global centre for investments, insurance and legal services related to clean maritime growth.</p>

Although not explicitly cited as part of these objectives, it is expected that the Clean Maritime Plan’s targets and commitments will apply to the recreational vessel industry.

In December 2020, the UK’s Climate Change Committee published its Sixth Carbon Budget report, also covering specific recommendations for the shipping sector, see the CCC’s report on [The Sixth Carbon Budget: The UK’s path to Net Zero](#) [41]. As part of the report, the CCC have outlined recent developments in the UK’s support for decarbonising shipping, which are based on the commitments outlined as part of the Clean Maritime Plan, and have highlighted existing gaps to achieve 2050 objectives. The latest policy developments include:

- A commitment to investing £20 million into the Clean Maritime Demonstration Programme, aimed at supporting the design and development of clean maritime technology. This funding announcement was included as part of the government's Ten Point Plan in November 2020, with the intention of mobilising public and private investments to support the country's green recovery, see the government's report on the [Ten Point Plan for a Green Industrial Revolution](#) [42]. Expected to be launched this spring, it will include feasibility studies and technology trials in a one year 'springboard programme' that will lay the foundations for a network of real-world projects to support maritime decarbonisation in the UK.
- A commitment to exploring economic incentives for supporting the uptake of alternative fuels in the maritime sector, which includes a consultation in 2020 to review options on how to use the existing Renewable Transport Fuel Obligation (RTFO) to support these efforts. The RTFO currently applies to the road transport sector (mandatory), the aviation sector (optional), as well as to fuel suppliers within the non-road mobile machinery sectors, which include inland shipping and recreational craft not usually operated at sea. This consultation was delayed owing to the need to resource pandemic response efforts, but is due to take place in 2021
- A plan to launch a call for evidence on non-tax incentives to support the decarbonisation of the shipping sector. This call was initially planned to take place in 2020, but has now been delayed. The Government is, however, due to provide a response to HM Treasury's Carbon Emissions Tax consultation, which also covers the potential extension of carbon tax to other sectors of the economy including shipping from 2021, see the HM Treasury consultation on the [Carbon Emissions Tax](#) [43]. The newly announced guidelines for the implementation of a UK ETS do not currently cover emissions from the shipping sector, see the BEIS guidance on [UK Emissions Trading Scheme](#) [44]. However, the UK may decide to follow the EU's approach and extend the UK's ETS to also include shipping in the future

Key policy gaps highlighted by the CCC that are directly relevant to the recreational vessel sector include the lack of support measures for encouraging the uptake of net zero emission fuels at a commercial level and for developing infrastructure required to supply net zero emission fuels (from fuel production to bunkering), as well as the development of a sectoral roadmap for the deployment of net zero emission fuels with related timelines and efficiency targets.

4.2.3.2 UK MCA Safety Code for Small Commercial Vessels

The UK's Maritime and Coastguard Agency (MCA) has developed and implemented Codes of Practice for Small Commercial Vessels of up to 24m, including vessels in commercial use for sport or pleasure purposes. The requirements of these codes have been summarised into one code in 2003, referred to as the MGN 280. This code sets out safety requirements and requires vessels to undergo a stability assessment, a full out-of-the-water survey, an in-water survey and checks of its safety equipment in order to obtain an SCV certification.

The safety code currently does not cover alternative fuels, however, this may change in the near future. Stakeholder interviews have highlighted that the MCA is looking to update its Workboat Code and that this update will include a new annex dedicated to alternative propulsion technologies. The annex will initially cover batteries and hybrids, however, it is expected to expand in time to also include alternative fuels. The new Workboat Code Annex is expected to be published for consultation in the second half of 2021 and

finalised in 2022. The Safety Code for Sports and Pleasure craft is expected to be revised in 2022 and, depending on the outcome of the Workboat Code update, the new annex on alternative propulsion is expected to be integrated in the Sports and Pleasure Craft code.

The new annex will provide a framework for the uptake of alternative fuels in the small craft sector, starting from more mature technologies for which more evidence on the safety requirements is available. As additional evidence becomes available on the best approaches to meet safety requirements, official guidelines highlighting these approaches are also expected to become available, further facilitating the uptake of low/net zero carbon propulsion solutions.

4.2.3.3 The Norwegian Government's action plan for green shipping

Another example of a recent national action plan focused on decarbonising the maritime sector is the [Norwegian government's action plan for green shipping](#), published in 2019 [45]. This action plan is particularly relevant as it has a dedicated section exploring the current status and potential measures for decarbonising recreational craft. The Norwegian government's ambition is to halve emissions from domestic shipping by 2030.

Norway has been a leader in green shipping to date, with the first LNG-fuelled ferry (Glutra) entering into operations in 2000, as well as the establishment of the NO_x fund back in 2008 that spurred further uptake of LNG as a fuel among other shipowners. Since then, Norway has been at the forefront of demonstrating several alternative fuels, including biofuels and hydrogen-powered vessels. The aim of the action plan is to capitalise on the existing expertise and maintain future competitive advantage.

Norway's recreational vessel sector accounts for 53,000 tonnes of CO₂e, or around 0.4% of Norway's total transport sector emissions (2017 data), with Norwegian households owning 614,000 recreational vessels including motorboats, sailboats and jet skis. The current carbon tax applies to petrol and diesel for use as a fuel in recreational craft, which are also subject to the road use duty and the basic tax on mineral oil, respectively. The government has committed to increasing the carbon tax rate by 5% per year between 2020 and 2025, see the Norwegian government's [action plan for green shipping](#) [45].

Additionally, the government is looking to gain a better understanding of the options to reduce emissions from recreational craft and to ensure that these options become commercially available through the implementation of adequate policies.

4.2.3.4 The Netherlands

In 2013, the City of Amsterdam introduced a net zero emission status requiring smaller boats to be electric by 2020 and larger commercial vessels to be emission free by 2025. In 2017, a ban was introduced on two-stroke outboard engines older than 2007 on private boats, which was enforced on commercial vessels by 2020, see the Inland Waterways International [history on electrification of all canal traffic](#) [46] and the I Amsterdam guidance on [Boating in the city](#) [47]. This has been supported by offering a mooring licence incentive for a green vessel which is 0.3x that of a non-green vessel licence (petrol or diesel).

By March 2020, 75% of the 550 commercial vessels in the inner city of Amsterdam were running emission free. The majority of vessels are undergoing retrofitting which is adding approximately 33% to the cost of the repair bill, though this cost increases for older boats (some a century old), see the Safety 4 Sea report on [Amsterdam canal boats and the 2025 diesel ban](#) [48].

Retrofits and upgrades to electric drive trains and battery systems is easier for the commercial boats who can factor this into their business costs. The city government have worked closely with contractors to ensure all infrastructure is in place for smooth operation of commercial and recreational vessels. This includes over 100 charging stations by the end of 2021, and a floating battery on a barge, powered by renewable energy, put in place for the busiest months of the year.

4.2.3.5 France

There is industry recognition that not enough is being done to address end-of-life. France is one of the few countries which has implemented regulation to govern the dismantling and recycling of recreational vessels. As part of the French Energy Transition Act, the concept of extended producer responsibility has been implemented as a means of financing the costs of recycling or disposing of recreational craft. The deconstruction of boats is paid for from eco-contributions of pleasure boat manufacturers and a proportion of francisation tax, as established by the French government. To support and oversee the deconstruction chain of recreational craft at their EOL, the Association for Eco-Responsible Pleasure (APER), founded in 2009 in France by the Federation of Water Industries, has been made the official body in charge of managing the disposal of pleasure craft at a national level in 2019. Uptake of the disposal service is encouraged by APER funding 80% of the transport cost (for boats under 6m) to approved facilities for deconstruction. Twenty-four deconstruction facilities are now open with over 800 boats being deconstructed since September 2019.

More recently, the discussion has become more complex as the challenge is now not only about boat dismantling, but how to develop sustainable disposal alternatives for FRP waste. The remit of APER was changed in 2018 to apply as an eco-organisation and adhere to new French regulation on waste. This means APER now has an objective to deconstruct 22,500 boats by end of 2023.

4.3 Initial decarbonisation roadmaps

At both national and European level, there is a willingness to better understand and develop strategies for addressing the environmental footprint of the recreational craft sector. Decarbonisation is increasingly a topic of conversation with organisations such as the European Boating Industry, whose members include national associations, running events focusing on transnational strategies for decarbonisation. Stakeholders have communicated the role of the EU in promoting decarbonisation plans to ensure harmonisation between standards.

At a national level, there has been limited work to develop roadmaps to address the technology and policy gaps. In May 2020, British Marine published their “National Environmental Roadmap Part 1”, aimed at providing a starting point to develop solutions to tackle the industry’s environmental challenges, including air pollution, see British Marine’s [National Environmental Roadmap](#) [49]. The roadmap highlighted the following technologies as examples of solutions that can reduce air pollution and emissions: fuel additives,

alternative fuels, diesel hybrid propulsion, pure electric propulsion and alternative fuel hybrid marine propulsion.

The document also underlined the lack of data available and need for more research into the current impact of recreational craft and lifecycle assessments on potential decarbonisation solutions, especially for retrofits. British Marine are now working on part two of the road-mapping project, during which industry specific working groups will tackle existing barriers, including how to enable net zero emission vessels by 2050.

Similarly, the Royal Yachting Association is currently working on a roadmap for the decarbonisation of the recreational craft sector. The RYA roadmap will focus not only on vessel emission reduction technologies, but will also cover opportunities for supporting sectoral decarbonisation across memberships, clubs, training centres and events.

5. Decarbonisation technologies overview and assessment of barriers and enablers

There are a range of technologies that can support the decarbonisation of recreational craft, characterised by different emission reduction potentials, costs and applicability to specific boat types. This section provides an overview of the key decarbonisation technologies, discusses their main barriers to uptake, and highlights potential solutions that can enable the roll out of these technologies at the scale required to reduce the sector's emissions to net zero by 2050. Section 6, provides more detail on country specific opportunities to engage with these technologies through developing and adapting their supply chain.

The section focuses mainly on technologies to reduce operational emissions of recreational craft, although as highlighted in section 4, we recognise that taking into account the full lifecycle emissions of specific technologies, or of a whole boat, is essential to having a clear overview of total emissions being produced across all lifecycle stages. This is particularly important given the low usage profile of recreational craft and hence a potential significant impact of emissions being produced by technologies during lifecycle phases other than their operational phase.

Given the increased need for the industry to solve the issue of disposing of vessels at their EOL and increasing circularity of the sector, the first section of this chapter covers innovative hull materials and their impact on EOL processes.

Following Section 5.1, the main technologies assessed are divided into four categories:

- 1. Technical design and performance (Section 5.2)**
- 2. Alternative energy sources (Section 5.3)**
- 3. Drive train hybridisation/electrification (Section 5.4)**
- 4. Alternative fuels (Section 5.5)**

5.1 Hull materials and boat recycling

5.1.1 Technology overview

Hulls for recreational craft are mainly made out of glass reinforced plastic (GRP), with carbon fibre being deployed on some high-end/luxury vessels. Both of these materials are challenging to recycle and the industry is increasingly looking into alternatives to reduce environmental impacts associated with disposal of boats, as well as to promote a circular model for resource utilisation within the industry.

New materials being developed in the industry include natural fibres. Among these, flax fibres currently represent one of the most promising options, with comparable performance in terms of pressure, tension and kinking, see Greenboat's guidance on [material and technology](#) [50]. Flax fibre is lighter compared to GRP and cost is lower compared to carbon fibre, as well as being significantly less carbon intensive to produce compared to GRP according to industry experts, see Yachting World's article on [smart technology in the future of yachting](#) [51]. Currently, there are few examples of natural fibres being used as the sole material for hull manufacturing, however, more frequently, they are being used to develop semi-structural parts of a boat or boat moulds. Boat manufacturers including Greenboats (Germany) and Baltic Yachts (Finland) have manufactured vessels using flax fibres. Additionally, in 2019 global composite materials supplier Gurit started collaborating with Bcomp, a Swiss start-up focused on providing natural fibre-based lightweight solutions, highlighting the potential wider adoption of such materials within the industry.

Cork is another natural based solution being deployed as decking material. Along with being more sustainable, cork also provides good insulation from noise, vibration and temperature, as well as being non-slip and resisting well to scratches/deformations. Recycled materials including recycled plastic bottles are also starting to be used by some boat manufacturers for hull cores.

While natural based fibres and recycled plastics can be more easily recycled compared to FRPs, stakeholders interviewed have highlighted that these materials once recycled again will probably not be able to be used to build other boats, but will be used for products with lower performance requirements. However, there are other innovative materials being developed that can deliver similar performance characteristics to GRP and carbon fibre, and that can be recycled indefinitely back into boat hulls (see Ultimate Boats case study below).

Replacing petroleum-based epoxy resins is also an issue being looked at by the industry. While bio-resins exist, the share that can be used on boats to maintain the performance levels required is estimated to be around 30%. Linseed oil, produced from flax fibres, is an example of bio-resin being used by boatbuilders to replace part of conventional epoxy resin.

Case study

Greenboats

Greenboats is an SME based in Germany which has pioneered the use of sustainable materials in boat construction including recycled PET, bio-based resins, cork and flax fibres grown in the EU to replace fiberglass. Their 27ft cruising dayboat, Flax 27 (pictured) was the most sustainable boat shown at the Düsseldorf Boat Show in 2020 – the largest indoor European boat show.

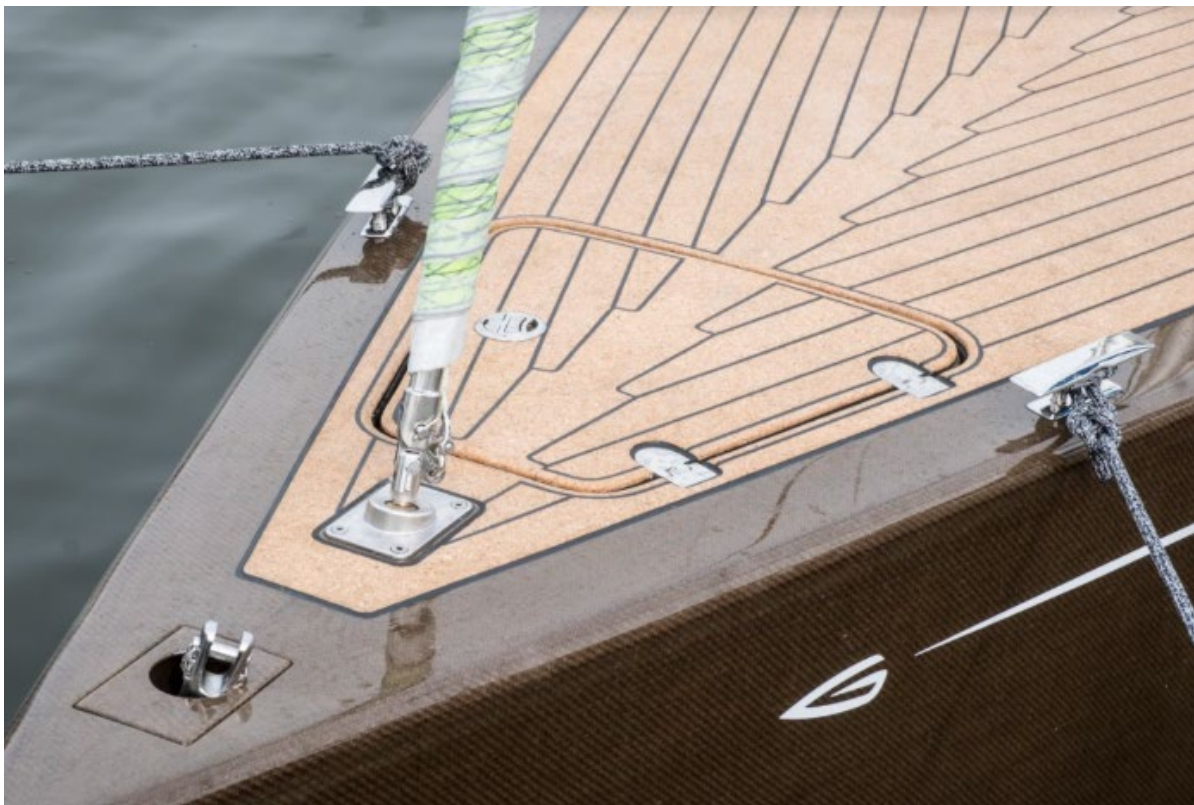


Figure 5: Flax 27. Credit Greenboats

Case study

The Ultimate Boat Company

[The Ultimate Boat Company](#), a UK-based start-up, has developed a patented alternative composite material called DANU, which enables upcycling, remanufacturing or recycling of a hull at EOL. DANU is a composite with hybrid characteristics between GRP and carbon fibre, being stronger and lighter than GRP and less brittle than carbon fibre, and is based on the same manufacturing methods as conventional composites allowing the use of existing infrastructure. See the Ultimate Boat Company's guidance on using [DANU composite in their yachts](#) [52].



Figure 6: Coastal High Speed Craft. Credit: The Ultimate Boat Company

5.1.2 Barriers and enablers to uptake

A key barrier to wider uptake of alternative, lower carbon boat materials is the higher cost associated with small scale production. The creation of manufacturing hubs/clusters was highlighted by stakeholders as an effective solution to create economies of scale for manufacturing of boats built from alternative materials, including natural and recycled fibres. The customisation of these boats would remain decentralised, taking place in-house among boatbuilders. There is also a need for training of personnel to be able to work with alternative hull materials. Supporting the upskilling of the boatbuilding workforce will facilitate the adoption of lower carbon materials.

Another means of promoting the uptake of more sustainable hull materials is through the use of lifecycle assessment tools that can provide oversight of the total emissions produced by the materials and construction processes used during boat building, as well as of emissions produced during later lifecycle stages of the vessel. Promoting the use of such tools is expected to support awareness of the environmental impact of choosing certain hull materials and to help drive adoption of alternative more sustainable materials. One example of such a tool is the MarineShift360 LCA tool, backed by 11th Hour Racing and aimed at supporting the evaluation and comparison of materials and processes used in boat manufacturing to drive sustainable innovation in design and manufacturing of the maritime industry.

Incentivising recycling of boats at their EOL will also be required, both for boats using conventional as well as alternative materials. Boat recycling today is very limited mainly due to the lack of specialised facilities, as well as the higher costs compared to disposing of a vessel by sending it to landfill, or even abandoning or sinking it. Creating the required recycling infrastructure across Europe, as well as increasing recycling rates of boats through regulation and/or financial incentives, should be among the industry's priorities.

5.2 Technical design and performance measures

5.2.1 Hull design optimisation

5.2.1.1 Technology overview

Hull design optimisation entails the development of a hull design that can optimally meet both technical and operational requirements. Optimising hull design is an important measure that can be deployed on newbuilds to reduce vessel drag, which leads to reductions in fuel consumption and improvements in range. Interviewed stakeholders have highlighted that hull optimisation can lead to 30% reduction in fuel consumption and thus operational emissions. According to interviewed stakeholders, hull optimisation can also facilitate the uptake of alternative propulsion systems that require heavier storage systems – including electric propulsion based on battery storage, as well as hydrogen – by improving the lift of the vessel considering heavier loads. Minimising fuel consumption is also expected to support the uptake of alternative fuels that may have higher prices than conventional fuels by reducing the quantity of fuel required.

Hull design optimisation is not a new concept, however, identifying the best hull design that is able to meet a range of objectives (e.g. performance, seakeeping and manoeuvrability) has long been a challenging

objective for naval architects. Hull design optimisation typically involves an iterative process, with theoretical, computational and experimental modelling techniques applied to develop and assess the performance of novel hull shapes. Generating and modifying such hull shapes is a complex task can be costly, hence usually limiting the number of hull designs that can be developed and tested for optimisation purposes, see University of Berkeley's, Yu and Wang's paper on [hull form optimization](#) [53].

To facilitate this process, there has been an increase in the research dedicated to the development of intelligent ship optimisation techniques through the use of information technology, see the ICPS conference proceedings on [key AI technology in hull optimisation](#) [54]. Some of these approaches, including machine learning and neural networks training, are already being applied by some naval architects to achieve optimal hull forms based on multiple objectives. Stakeholders have highlighted that the sailing racing sector invests significantly in hull efficiency improvements as one of the key competitiveness factors. Some large boat builders have been actively investing in improving hull efficiencies for some time. However, advanced hull optimisation approaches are still fairly limited within the sector, with most naval architects still using existing hull forms as a reference and applying modifications to these to achieve new designs.

5.2.1.2 Barriers and enablers to uptake

Hull design optimisation is considered to be one of the "low hanging fruit" that the recreational craft industry could pursue to significantly lower operational emissions of new boats, while also facilitating the uptake of net zero emission propulsion technologies. These improvements will be particularly important on larger or high-speed recreational craft (e.g. yachts towards the 24m range or speedboats), where current potential decarbonisation technologies such as batteries do not currently meet power requirements.

However, as pointed out in section 5.2.1, developing optimal hull forms can be costly as well as time consuming. Some interviewed stakeholders have flagged that small boat manufacturers have limited R&D budgets and usually prioritise efficiency improvements that lead to reduced costs for manufacturers, for example making hulls lighter and hence reducing the amount of material required for production. Lack of customer demand for optimised hulls also acts as a disincentive for boatbuilders to invest in this area.

Stakeholders have suggested that, although R&D grants for boat manufacturing from governments are already available, the launch of grants that are specifically directed towards hull efficiency innovations would incentivise further efforts in this field. Awareness raising initiatives highlighting the benefits that hull optimisation can provide, particularly when combined with the use of alternative propulsion systems, should be implemented by industry stakeholders to spur customer demand for innovative and efficient craft designs. Close collaboration between boat builders and engine manufacturers will become increasingly important to enable the optimal integration of alternative propulsion systems within craft designs. Ensuring that hull optimisation knowledge built up within the racing sector can be effectively shared with other recreational craft sectors has also been highlighted by stakeholders as an important enabler to support further design efficiency improvements.

Standardised validation systems will need to be developed to verify that specific hull designs actually lead to the expected operational efficiencies, thereby minimising the risk of large performance gaps between a vessel's predicted and actual fuel consumption and emission reductions. Such systems could be

implemented in the form of assurance or certification schemes on vessel design specs/ design models to ensure that the design credentials of a vessel are accurately reported by boatbuilders to consumers.

5.2.2 Hydrofoils

5.2.2.1 Technology overview

Hydrofoils are wind-like foils mounted under the hull with the aim of lifting the hull out of the water to reduce drag by up to 90%, according to interviewed stakeholders, and achieve higher speeds. Foiling technology was first introduced on a vessel in 1906 on a 60hp motorboat designed and built by Enrico Forlanini, an Italian inventor, see Ancasta's: [development of foiling – 100 years in the making](#) [55]. The technology has since seen uptake in military vessels and commercial ferries, as well as in racing boats. More recently, personal watercraft, inflatable, sailboat and motorboat models incorporating foiling systems have started to emerge, although the use of foiling technology within the recreational craft sector is still limited.

5.2.2.2 Barriers and enablers to uptake

Some key challenges with foiling systems, particularly early versions of the technology have prevented large uptake within the recreational craft. These barriers include:

- Increase in boat draft produced by traditional v-shaped fixed foils, making berthing challenging, particularly in marinas with low water depths
- High cost of manufacturing of foils, adding significant costs to the final vessel
- Risk of foil damage, given exposure to high loads as well as potential impact with other objects
- Challenges related to powering vessels via conventional shaft drives once the hull is out of the water
- Lost efficiencies of foils when operating in rough sea conditions where wave height is higher than the foil's height

Most of these barriers have already been overcome by new foiling technologies. For instance, modern foiling systems are retractable, which removes the challenges of berthing and reduces risk of damage. Additionally, foils are now also being applied to adjust the performance of a vessel without lifting the hull out of the water, hence mitigating the challenge of powering the vessel while on the foils. The use of computer-controlled active systems now enables the continuous adjustment of individual foils based on vessel speed and sea conditions.

Nevertheless, some barriers to uptake of foiling systems remain. The technology is expensive and adds a degree of complexity to operating a vessel, which is seen as a barrier for uptake among customers looking for keeping navigation simple. Full foiling systems also add a degree of dynamicity to navigation and stakeholders have highlighted that coastal cruising sailors looking for a more relaxing experience are less likely to adopt full foiling systems, although they may look towards semi-foiling systems as a potential option.

Case study

BAR Technologies

BAR Technologies are a UK company formed in 2016, delivering innovative research and development and engineering marine solutions. Working in partnership with Princess they have developed a dynamic foiling system with the effect of bringing significant hydrodynamic efficiency gains by reducing drag by up to 30%. Their patented FOSS (Foil Optimisation and Stability System) solution does not lift the hull out of the water, rather it adjusts the heel angle and attitude of the boat.

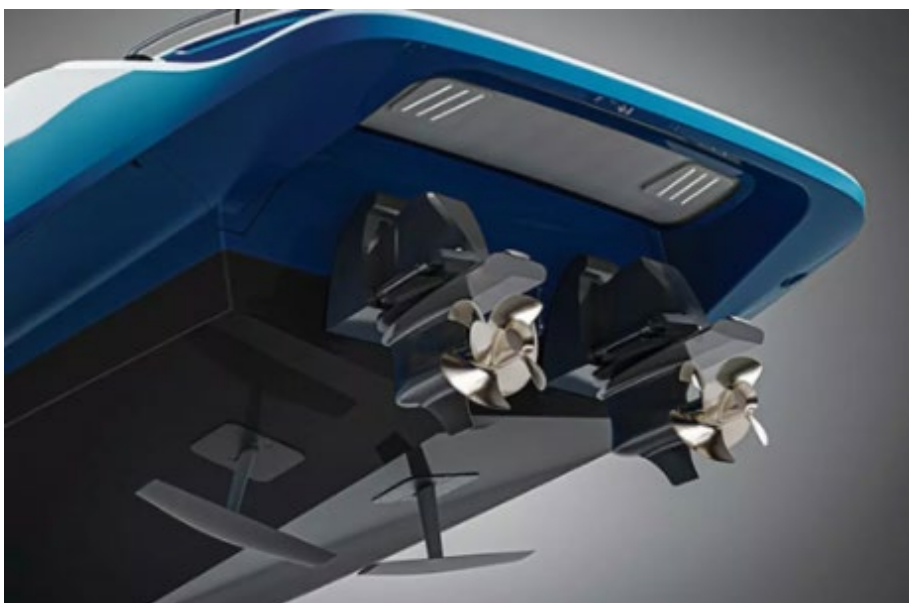


Figure 7: Foil system. Credit - Princess Yachts

Uptake of foiling systems seems most likely to happen on vessels that can operate in water conditions that allow for maximisation of efficiency savings and that cater to customers willing to operate such systems. Application on power boats could aid the deployment of net zero emissions propulsion systems by lengthening range, hence facilitating the transition to fully electric craft. However, incentives for uptake are expected to be required to drive customer demand. For boats targeting the luxury market segments that may be less price sensitive, uptake could be incentivised by setting efficiency or emission reduction targets. For other market segments, price incentives may be needed to mitigate the additional cost required to add foiling technology to a vessel. In the short term, there may be opportunities to offer foils as a luxury addition which may aid the technology trickle down to the wider market.

5.3 Alternative energy sources

5.3.1 Marine solar power systems

5.3.1.1 Technology overview

Solar panels can be installed on recreational craft to generate electricity that is then used to charge batteries to power boat appliances or to support propulsion (in case of an electric or hybrid powered boat). These marine PV systems have the benefit of reducing operational carbon emissions, mitigating cost of fuel, as well as avoiding noise produced by diesel generators. According to the Renewable Energy Hub [56], there are several types of solar panels for boats available in the market, including:

- **Glass fronted:** These are the most popular type of marine solar panel systems, offering the highest power at lower cost compared to other options. There are two types of glass fronted panels:
 - **Polycrystalline panels:** made from small silicon pieces fused together. These panels are the cheapest option on the market, however they have a lower energy efficiency and conversion rating and their performance worsens in hot weather
 - **Monocrystalline panels:** made from large, individual pieces of silicon, these panels tend to have a better efficiency and conversion rating and higher effectiveness in hot weather compared to polycrystalline panels and come at a higher price
- **Polycarbonate:** Panels typically made from polycrystalline technology. They are the most expensive option for marine PV systems. They are more flexible than glass-fronted panels and can be installed as fixed panels via a silicon adhesive. Another key advantage of polycarbonate panels is that they can be walked on. They are thought to be a particularly attractive option for yachts.
- **Fully flexible:** panels capable of adapting to all surface shapes thanks to their flexibility. These panels are based on amorphous technology, which implies lower efficiency compared to other marine solar PVs. They are more robust compared to other marine panels, however, their fixed location implies their angle cannot be adjusted to maximise efficiency

See the Renewable Energy Hub's guidance on [Solar Panels for Boats](#). Costs of PV systems will vary depending on the number of panels required, as well as on the type of panels being fitted. Industry sources suggest that costs of installing a 200 watt system will start from around £600, while a 400 watt system will start from around £1,000, see the Eco Experts guidance on [Comparison of Marine Solar Panels](#) [57].

5.3.1.2 Barriers and enablers to uptake

Initial barriers to uptake included panels not being robust enough to withstand marine conditions, the technology has improved quickly and is now considered mature, with boat solar panels being considered to be a reliable, as well as relatively affordable option for recreational craft.

Given the role of solar panels as electricity generators to charge batteries for the use of electricity of auxiliary power, or in support of main propulsion, their uptake will be linked to improvements in storage

technologies. In this regard, current battery capacity and power to weight ratio is the main issue that needs solving to electrify faster/larger boats. However, for smaller craft or boats operating at lower speeds, solar panel systems are already a viable option and the industry has seen consumer demand increasing in recent years, see the Soundings Online direction on [boat owners turning to solar](#) [58].

Incentivising PV system integration into vessel designs would certainly support the uptake of these technologies on newbuilds. Continued efforts to support improvements in battery storage systems will also benefit the applicability and uptake of solar PV systems.

5.3.2 Marine wind generators

5.3.2.1 Technology overview

Marine wind generators convert wind energy into a rotational motion, which turns an alternator to produce electricity. Electricity is then stored in batteries used to power onboard appliances or support the charging of the propulsion system of an installed electric motor, see the Better Boat guidance on the [best marine wind generators](#) [59]. These systems are applicable for cruising boats, both motorboats and sailboats. The upsides of using wind generators compared to marine solar panels include the potential to generate power for 24 hours, contingent on wind availability (compared to 5-7 hours for solar panels) and higher space efficiency. Downsides include:

- **Noise and vibrations produced by airflow over the blades:** this was an important issue in the past, however more recent technology developments, including the use of CAD blade designs have considerably reduced noise levels
- **Poor performance in low wind conditions:** As the relationship between wind and contained energy is cubic, power output decreases exponentially as wind levels drop. Usually, most marine wind generators provide limited power below eight knots. Also, some wind generators need to be shut down manually in high wind conditions, although there are self-regulating models available in the market
- **Risks of damage high wind conditions:** Turbines operating in storm conditions with winds of around Force eight and above risks leading to serious blade damage, cable burning and battery impairment. To mitigate these risks, some models include a thermal cut-out that disconnects the generator from the battery in case of overheating. Other models rely on feathering blades that can regulate turning speeds in high wind conditions by altering the pitch of the blades (e.g. Superwind generators), see the Sailing Today [test results of different wind generators](#) [60]

The choice of a specific marine wind generator model will depend on several factors. An essential consideration will be related to the boat's power requirements for on-board appliances at anchor and during cruising. Solar panels have become the most popular option for trickle-battery charging in port, although there are small wind turbines available (e.g. Rutland 504 12V system) that can be used for the same purpose. Hence, wind generators being installed today are usually more powerful systems.

The expected average speed the boat will cruise at, as well as the wind conditions typically encountered en route will be another important factor to determine the most appropriate wind generator model. The build

quality of the model will also determine the level of maintenance requirements that can be expected, see the Sail Magazine guidance on [wind generators in the boating industry](#) [61].

5.3.2.2 Barriers and enablers to uptake

As for solar panels, improvements of onboard electricity storage technologies are expected to benefit uptake of wind generators, particularly on larger boats. Wind generators may also benefit from awareness raising in terms of the improvements of the technology that have mitigated some of the risks/downsides that characterised earlier models, including for examples improvements in noise and vibration levels.

5.3.3 Hydro-generators

5.3.3.1 Technology overview

Hydro-generators are a technology that has seen increasing uptake in cruising sailboats, particularly among long distance sailors. A hydro-generator has a reverse propeller, called impeller, that rotates by being dragged by the water behind the boat while the boat is sailing. The rotation applies to an alternator, thereby producing AC power which is then converted to DC for charging onboard batteries for propulsion and/or use of onboard appliances. Hydro-generators can either be implemented as a standalone technology or in combination with a boat's auxiliary propeller for power generation as part of an electric or hybrid engine system. While early versions of standalone hydro-generators had impellers towed behind the boat through a long line, modern impellers are attached to a submersible leg, similarly to an outboard motor, or fastened under the hull, avoiding risk of loss of the impeller due to breaking of the long line or tangling issues, see the Sailing Today [test guidance on hydro-generators](#) [62].

The impeller is usually pitched for boat speeds of five to 30 knots, although specific speed ranges will vary between models. While solar panels and wind generators actual outputs are largely dependent on favourable weather conditions, hydro-generators are able to supply constant power at a given speed (although, of course, they operate only during navigation). While most manufacturers offer units able to provide up to 500-600W at the top end of their speed, checking outputs at actual targeted cruising speeds is important to determine the amount of power generation that can be expected to be achieved during regular cruising conditions (see table below for indicative output values at low speed levels). Additional drag produced by the impeller is considered to be negligible, with producers claims varying from 0.4 knot to 0.1 knot of drag equivalent, see the Sail Magazine guidance on [hydro-generators in the boating industry](#) [63].

Table 5: Examples of hydro-generators outputs per specified speed

Model (type)	Company	Power output at specified speed
ServoProp (integrated with electric motor)	Oceanvolt	1kW at 6-8 knots ⁴
Cruising 300 (standalone)	Watt&sea	100W at 5 knots ⁵
Cruising 600 (standalone)	Watt&sea	120W at 5 knots ⁶
H240 (standalone)	Save Marine	Up to 100W at 5 knots ⁷
Ampair UW 100™	Ampair	100W at 8 knots ⁸
Hydro Charger Standard (standalone)	Swi-Tec	~100W at 5 knots ⁹

5.3.3.2 Barriers and enablers to uptake

As for solar panels and wind generators, hydro-generators would benefit from further improvements in onboard electricity storage systems. However, as this technology is applicable to cruising sailboats, it is likely that these boats will face less challenges than motorboats for electrification.

5.4 Drive train hybridisation/electrification

5.4.1 Technology overview

Fully electric boats are propelled by electricity stored either in a battery or produced from hydrogen through the use of a fuel cell and connected to an electric engine. The powertrain can include either one or two motors and can be integrated with solar/wind power systems to increase range. Electric boats can be equipped with either a propeller or a waterjet. Key benefits of running on an electric motor beyond reduced operational emissions include reduced noise, reduced maintenance requirements, and higher motor efficiency for propulsion compared to conventional ICE motors.

⁴ Hydro-generator, [Oceanvolt](#)

⁵ <https://www.wattandsea.com/en/products/cruising-hydrogenerators/hydro-cruising-300>

⁶ <https://www.wattandsea.com/en/products/cruising-hydrogenerators/hydro-cruising-600>

⁷ <https://www.save-marine.com/en/hydro-generator-save-marine-h240>

⁸ UW100 Seismic - AMPAIR - PDF Catalogs | Documentation | Boating Brochures (nauticexpo.com)

⁹ <https://hydro-charger.com/hydro-charger-standard-for-transom/>

Hybrid engines combine electric propulsion with either an ICE motor or generator. There are three main types of hybrid propulsion systems, see Electric Vehicle Research guidance on [Hybrid Propulsion](#) [64]:

- **Serial hybrid:** an ICE is connected to a generator that powers an electric motor that is connected to the propeller shaft. The ICE is not connected to the driveshaft
- **Parallel hybrid:** both an electric motor and an ICE motor are connected to the same shaft, with the electric motor functioning as a generator while the ICE is running
- **Diesel-electric hybrid:** a large diesel motor is connected to one shaft and a small electric motor is connected to the other shaft. An alternator connected to the diesel motor recharges the propulsion batteries and the electric motor is used to support the diesel engine

Key benefits of using a hybrid system, particularly a parallel hybrid, is the potential to run on the ICE when the motor is within the optimal range and switch to electric propulsion at lower ranges. When running on the electric motor, hybrids benefit from low noise levels, as well as from electric motors being able to provide full torque instantly, thereby enhancing manoeuvrability and power spikes. Another advantage of operating hybrid systems is that the required maintenance of the engine, as well as related costs, are greatly reduced as the ICE is operated less compared to conventional propulsion systems.

Electric boat engines have been available since the 19th century, with the first recorded launch of an electric boat traced back to 1838, see Electric Boat Association [History of Electric Boats](#) [65]. They grew in popularity between the 1880s and 1920s, until uptake dropped off in favour of petrol and diesel engines, see [market barriers towards electric boats](#) [66]. Electric boat market shares are currently limited across countries, but expected to grow significantly in the coming years.

A 2017 IDTechEx report suggests that hybrid and electric boats for the consumer sector will be worth around \$20 billion globally in 2027, see the IDTechEx report on [Electric Boats and Ships 2017-2027](#) [67]. Recreational vessels are a key sector driving the uptake in hybrid and fully electric vessels, with both inboard and outboard electric motors now available. The market is characterised by high fragmentation, with European manufacturers including Greenline Yachts (UK) and leading electric drive company Torqeedo (Germany) among important stakeholders. Until recently, retrofits had represented the main focus for deployment of electric motors. However, boatbuilders are increasingly looking into offering newbuilds directly equipped with electric motors. Hybrid systems using conventional fuels to power ICEs are only considered to be a short-medium term transition technology as emissions from ICEs will need to be abated for the sector to achieve net zero emissions by 2050. However, hybrid drivetrains using alternative fuels to run ICEs or fuel cells can be a long term zero carbon solution, particularly for craft types that will remain challenging to electrify even with improvements in battery systems.

Battery electric vessels supplemented by hydrogen fuel cell technology are a nascent alternative to pure electric boats. Within this system, the fuel cell can act as a substitute of the ICE engine to extend the range available to boats running solely on batteries, while the electric motor can address power spikes (as fuel cells have a lower reactivity). An example of a recreational craft fuel cell technology is Toyota's REH2, which has been tested in real sea conditions on the Energy Observer for more than 7,000 nautical miles. In late 2020, the Energy Observer Developments announced that the REH2 would be deployed on the Hynova 40, a 12m motorboat that can be used either as a day boat or superyacht tender – the first recreational boat to be fitted with fuel cell technology. Field demonstration tests on the Hynova 40 prototype commenced in October 2020, see Toyota's [Motor Europe's fuel cell module](#) [68].

Case study

Torqueedo



Torqueedo was founded in 2005 in Germany and is now the world market leader for electric boats. As a producer of electric inboard, outboard and hybrid engines, Torqueedo has a range of electric inboard motors; both high-RPM version powering planing boats and a low-RPM version for large yachts and other displacement vessels such as ferries. Its hybrid drive system allows cruising for up to 50 nautical miles and it has pioneered the use of electric.

Figure 8: Torqueedo inboard electric set up.

Credit – Torqueedo

Greenline

Greenline is a Slovenian company which built the world's first hybrid yacht in 2008 and has since followed with eight more models. Each includes solar panels for charging, providing 9kW charge per day. It has the ability to charge at port, and an electric motor that can also top up the batteries. There is now two types of yacht, H-drive hybrid engines and E-drive electric engines. Greenline yachts uses Torqueedo electric motors in its vessels.

Greenline is working with Canal Boats Telemark (Norway) and the Norwegian government, using its E-drive electric boats to provide the first fully electric boat rental. Along the Telemark Canal there is already a strong network of charging points.

Various technology adoption barriers remain for transitioning to fully electric drivetrains or hybrid systems using alternative fuels within ICEs or fuel cells, mainly related to limitations on power to weight ratios of current battery technologies, further commercialisation of hydrogen fuel cells and improvements in reliability of electric motors, supply of alternative fuels, as well as the need for safety regulations if higher voltage systems are to be deployed (see next section). Current technology barriers make it particularly challenging to electrify high power or larger boats requiring longer ranges, which may need to opt for conventional hybrid systems in the short-term and then either switch to fully electric propulsion or to running on hybrid systems using alternative fuels. However, small recreational boats operating at cruising speeds and requiring shorter ranges are expected to be able to transition to fully electric power in the short-term.

5.4.2 Barriers and enablers to uptake

When considering electric and hybrid-electric engines to power recreational vessels, there are many promising aspects to the technology as highlighted in Section 5.4.1. Despite this, there are still a variety of technological and commercial barriers to be overcome to support widescale use in recreational vessels.

One key challenge related to electric motors is ensuring an efficient power-to-weight ratio. Compared to conventional petrol or diesel, batteries have a lower energy density and interviewed stakeholders have suggested that in some instances this can be as much as a factor of ten. This barrier is not a burden for slow-moving vessels such as those that sit on canals, but it is particularly relevant for high performance vessels or vessels requiring long ranges. This is expected to make adoption of fully electric drive train challenging for planing motorboats, large boats in particular, as well as high performance sailboats where weight is a critical factor.

Extensive research has been conducted to increase the energy density of batteries in recent years, which has almost tripled since 2010 and improvements are expected to continue, see BloombergNEF: [Lithium-Ion Battery Cell Densities have almost tripled since 2010](#) [69]. In the meantime, hybrid systems have the potential to be more easily adopted on vessels where full electrification is not technically feasible yet and would enable these vessels to run on their electric motor for short distances at low speeds, while using the conventional motor for covering the longer distances or operating at high speeds. However, it should be taken into account that while hybrid systems are more fuel efficient compared to conventional ICEs at low speeds, ICEs consume less fuel than hybrids generally at higher speeds.

An additional issue related to limited power outputs achievable today by electric motors is that batteries used on both fully electric and hybrid systems currently run on low voltages, usually below 48V. This results in a lower power output, which translates into a less efficient power-to-weight ratio compared to higher voltage batteries. Increased battery voltages would enable better power outputs and hence potentially facilitate electrification of some vessels, as well as enhancing performance of ICE engines on high performance vessels allowing potentially for a smaller ICE to be deployed on hybrid systems. However, electric engine manufacturers recognise that an increase in voltage generates various safety issues for vessel users who have little knowledge of batteries and electrical components. The risk of shock or injury greatly increases with voltage in addition to possible higher fire risks. Deploying higher voltage batteries would require new safety regulations and would also benefit from training being provided to boat users, as well as to operations, maintenance, repair and emergency response service providers. One way to address training requirements could be through the roll-out of a certification programmes targeted to specific

stakeholders and focused on requirements for safe handling of higher voltage batteries on vessels. The effectiveness of similar programmes has been demonstrated in sectors such as the Navy, where personnel are specifically trained on safe handling of battery and electrical infrastructure on boats and vessels.

Reliability of electric motors has been flagged by interviewed stakeholders as an aspect that needs to be improved if fully electric boats are to be adopted more widely. Particularly for sea-going vessels, engine reliability is a key requirement as engine failures could lead to safety risks. This technology barrier will be relevant both for motorboats as well as sailboats using limited engine power, as sailors will be relying on engines particularly in emergency situations when dependable systems are crucial. Further R&D work will be required to improve performance of electric motors to overcome this barrier.

On top of these key technical barriers to electric drives, stakeholders have highlighted that currently, there is an important discrepancy between what customers require in terms of power and range compared to what is realistically achievable for onboard battery systems, even when considering future technological improvements. It will be critical that industry stakeholders engage with customers to manage and/or change expectations on the operational performance of electric craft to support uptake of electric drives once key technology improvements are achieved. There is an expectation that younger generations will support driving demand for alternative propulsion systems including electric drive, due to their average interest in environmental credentials of recreational craft.

Infrastructure upgrades for charging will be required and it is important that this challenge is addressed soon. Although electrical infrastructure is already installed at marinas to power lights and electronics on vessels, as well as to support hotel loads, specific charging points and higher voltage will likely be required. Initiatives to implement battery charging infrastructure at marinas have been limited to date in Europe, despite its feasibility. Governments, marinas, and distribution network owners must address the infrastructure gap to accommodate for higher rated cables and sufficient charging infrastructure, particularly for inland waterways and between islands where multi-day trips are common. Overnight mooring and limited battery use on water allows for trickle-charging of batteries. Some degree of demand side response could be implemented by distribution system operators in the future to support 'peak-shaving' by using spare battery capacity during peak-times to feed electricity back into the grid, alleviating demand from conventional generation, presenting opportunities for research on this topic. Being able to leave vessels connected to charging points would also prevent batteries from self-discharging when not in use.

The use of hydrogen fuel cells on electric boats is an emerging technology and commercialisation barriers still remain. The use of onboard hydrogen will require more complex fuel storage systems based on pressurised tanks, as well as the development of hydrogen refuelling infrastructure. Barriers and enablers to hydrogen uptake as a fuel are further explored in section 5.5.1. Given the current technological maturity of marine fuel cells, as well as the significant hydrogen infrastructure requirements, they are expected to only be a potential longer-term solution for recreational craft.

Currently, for the cost of a whole battery-operated system - including DC converter, inverter, and electric motor - the total cost can be as much as four to five times that of a conventional power train. This large initial capital investment can make battery technology less appealing to consumers. Extensive developments have been made in reducing the cost of lithium-ion batteries and some reports suggest that the price per kWh has reduced to rates below \$100/kWh, see the Bloomberg NEF article: [Battery pack prices](#)

[70]. Continued battery cost reductions would help greatly improve the financial case for adoption of electric motors on recreational craft as well as awareness of the potential lower operating costs associated with batteries.

For craft types where full electrification is unlikely to be feasible even in the long-term, a transition from conventional hybrid systems to hybrids based on a combination of an electric motor and either an ICE or a fuel cell powered by alternative fuels will be necessary. Key barriers and enablers for the uptake of alternative fuels are discussed in more detail in section 5.5. For some vessel types, particularly motorboats with long range and high-power requirements, the shift to zero emission propulsion technologies in general is expected to be challenging if current operational requirements are to be maintained (e.g. long range and high power), even with further technology improvements. These vessel types may need to be regulated to limit operational performance and to allow deployment of decarbonisation technologies. If necessary, these regulation could be accompanied or substituted by a shift in demand towards easier to decarbonise craft types.

Although electric/hybrid drive trains are able to reduce operational emissions of vessels, it will be important to take an LCA approach when assessing the overall emissions of electric systems across all lifecycle stages, to avoid increasing emissions upstream or downstream. EOL processes will also be particularly important in regards to batteries, where appropriate disposal strategies will need to be developed to avoid environmental impacts.

5.5 Alternative fuels

There are a range of potential alternative fuels with lower or net zero emissions that can substitute diesel or petrol within marine engines, including lower carbon conventional fuels, synthetic fuels and biofuels. However, given the specific design characteristics (e.g. space availability, weight limitations), usage profiles and safety requirements of recreational craft, as well as the refuelling infrastructure available at marinas, not all alternative fuel options available for commercial vessels are applicable to the recreational craft sector.

This section provides an overview of the main alternative fuel options that could be realistically taken up by the sector in the shorter to longer term, depending on the level of complexity they drive in terms of both onboard and infrastructure requirements. Some alternative fuels, also known as drop-in fuels, like some biofuels, can be directly blended in with diesel or petrol in conventional ICE engines, making these fuels good candidates for reducing emissions of existing vessels in the short/medium term. The share of drop-in fuels can be increased within conventional ICE engines, although it sometimes requires some engine modifications. Other alternative fuels presented in this section are assumed to be used without blending with conventional fuels, as is the case for hydrogen.

5.5.1 Hydrogen

5.5.1.1 Technology overview

Hydrogen internal combustion engines use the conventional principles of internal combustion, and specifically, they are a modified version of an internal combustion engine with hydrogen as the fuel. During the combustion of hydrogen with oxygen, the resulting by-product is water. The hydrogen internal combustion engine is simple to develop as it is an adapted equivalent to the conventional internal combustion engine. The adaptations required are primarily focused around reinforcement of internal components. Dual fuel hydrogen combustion engines are already commercially available for commercial vessels, including for example BeHydro's medium speed engine launched in late 2020, see the ABC-engines news article on [BeHydro hydrogen dual-fuel engine](#) [71].

Recent developments have occurred in the transportation of hydrogen fuel to allow for a consistent supply chain of liquefied hydrogen to locations worldwide. The Hydrogen Energy Supply-Chain Technology Research Association has developed a strategy to overcome the operational issues which need to be addressed to allow for a suitable transportation vessel for liquefied hydrogen, including the process of storing and unloading hydrogen within the vessel, as well as shipping methods to transport hydrogen worldwide. The association is expected to pilot a project transporting liquefied hydrogen over a distance of 9,000km between Australia and Japan to demonstrate the feasibility of transportation.

Companies are starting to produce hydrogen-powered vessels, with notable examples including Cheetah Marine with a hydrogen internal combustion engine-based catamaran, and Yanmar with the development of a hydrogen fuel cell system for maritime applications which should be demonstrated by early 2021.

5.5.1.2 Barriers and enablers to uptake

Hydrogen is a promising long-term option as both energy storage and propulsion, especially among short sea commercial vessels. Despite the extensive developments in technology, there are various barriers still to be overcome – especially for the use of hydrogen within smaller, recreational vessels. Generally, large tanks and vessels are required to store the large quantity of hydrogen which for small vessels and leisure crafts is not a feasible option; as well as creating power-to-weight issues similar to that of electrical engines. The price of hydrogen compared to a diesel alternative can be as much as ten times, which is seen as unattractive to vessel owners. In terms of capital cost, hydrogen tank costs are also a key barrier which is currently being developed by industry.

In addition, installing hydrogen tanks to refuel is currently difficult for marinas, and other available low carbon options present a much more feasible and cost-effective solution. These tanks generally require very cold temperatures and/or high pressures to store, and may require a lot of energy and upkeep to ensure consistent storage. This can be seen as a downside within the recreational vessel industry as these boats are not used as consistently as in the commercial industry. This means that hydrogen can be considered a very inefficient method for storing energy for recreational vessels. In addition, when placed in boats, there may be further implications if fuel is left for longer periods of time. There is also necessary infrastructure

to be implemented in terms of transport of hydrogen for refuelling - such as ensuring fuelling stations are close to remote marinas to allow for on-the-water fuelling.

Safety is an important consideration and hydrogen can be a potentially explosive and dangerous substance to fuel vessels. Unlike commercial vessels, recreational boats are predominantly owned by private individuals who currently do not require any specific training or certification to go offshore. Providing certification on the use of hydrogen as a fuel may be necessary, although this is unlikely to be easy to implement.

5.5.2 Biofuels

5.5.2.1 Technology overview

Biofuel is produced through biomass production and can produce both liquid and gases. Conventionally, the most common types of biofuels are in the form of bioethanol, biobutanol, and biodiesel.

Biodiesel is a renewable, clean alternative to diesel. The oil is produced from seeds and waste oil, or fats, which means it can be produced from food waste, and the combustion of biodiesel produces much cleaner emissions when compared to its conventional alternative. In some instances, to improve fuel efficiency, biodiesel is mixed with regular diesel. Despite this, there is still a noticeable decrease in emissions. Some engines already have the capability to allow for biodiesel to be used, however, more frequent maintenance and care is required to ensure that internal components do not degrade due to its chemical properties. For engines which are not currently biodiesel compliant, minor changes would be required to the engine to allow for its use. Biofuel itself has a short storage life, so it is recommended that the fuel is purchased only before use and not stored for long periods of time – this is a factor which should be considered when looking at changing to biodiesel. As the engine does not require many modifications, it is relatively easy for existing boats to switch to the use of biodiesel.

Extensive research has been undertaken on biobutanol fuel blends for internal combustion engines, an extremely capable biofuel which can reduce CO₂ and VOC emissions. Biobutanol contains nearly 90% of the energy density of regular diesel and is able to be used within an existing recreational craft without any adaptations required to the engine. As such, all existing combustion engines in recreational vessels are capable of using biobutanol.

By increasing the percentage of biofuel in the engine, further reductions in CO₂ can be found. Biobutanol blends of 16.1 vol % can reduce the emissions by up to 70% relative to diesel, according to the US Environmental Protection Agency. This does not require changes to the engine or fuel system. Biobutanol is a drop-in fuel and higher quantities of biobutanol, beyond 24 vol % would need to be further investigated for engine compatibility as many marine engines are not capable of adjusting their air/fuel ratio.

Ethanol fuels can cause issues to the boat and fuel system primarily related to the usage profiles of recreational boats, especially with ethanol fuel mixtures containing more than 10% ethanol by volume. Most boats, particularly in northern climates, are stored for long periods of time. Ethanol fuels, together with water, lead to phase separation which is highly corrosive to fuel system components. Many engines have found large amounts of damage due to ethanol fuels. Biobutanol conversely behaves a lot more like diesel which does not corrode or damage the engine.

Case study

Cheetah Marine

Cheetah Marine started in 1991 building catamaran vessels on the Isle of Wight. In 2016, it modified a Honda outboard engine into a hydrogen internal combustion engine which works in the same way as a traditional petrol engine except with hydrogen as a fuel.

The craft was tested over a 100km distance around the Isle of Wight. The trip was planned to last 12 hours but due to the high performance of the hydrogen engine, it was completed in eight with a large amount of hydrogen still remaining by the end.



Figure 9: Cheetah Marine hydrogen powered craft. Credit - Cheetah Marine

5.5.2.2 Barriers and enablers to uptake

Biodiesel is a promising fuel which can greatly reduce carbon emissions from recreational vessels. Its supply can be generated from conventional feedstock and offers an easy to use alternative to conventional diesel, although there are important considerations on the sustainability of biomass feedstocks. In remote areas where adequate infrastructure is not in place for more advanced fuel alternatives, biodiesel could provide an adequate solution. Despite this, there are some barriers which are holding biodiesels from becoming a more widespread fuel source.

The main barrier for the use of biodiesel comes in the form of cost. The same engine can be used for biodiesel as conventional diesel, however, various adjustments need to be made to accommodate for the new composition of fuel. Rubber inside the engine needs to be replaced along with some components within

the fuel control unit. Conversion kits already exist in the automotive industry to allow the use of biodiesel and has varying costs depending on size, with an average of between £1,000 and £3,000.

Given the long lifetimes of recreational boats (50-80 years), retrofits will be a key part of the decarbonisation strategy. Because of the current costs related to adopting net zero emission technologies, the industry will need to gradually transition to decarbonisation. This solution is seen as attractive to current vessel owners as the majority of infrastructure is already present in the vessel, with the only requirement being to adapt the engine technology to accommodate for the new chemical properties of biodiesel.

Engine conversion also comes as one of the greatest advantages of biodiesel as it offers a low cost alternative to completely replacing an engine with other solutions. Increasing the uptake in biodiesel conversion is seen as the most cost-effective way in reducing carbon emissions for recreational vessels, and this is seen as an attractive measure for existing vessels.

Additionally, the cost of biodiesel compared to regular diesel is higher and mechanisms should be put in place to ensure that consumers are seeing value for money, as in its current state biodiesel only offers a low carbon alternative with no price incentives to justify mass uptake. Closing of this price gap will be important as it is expected that without any incentive mechanisms the sector is likely to find ways to continue using conventional fuels as long as their supply continues, even if supply is primarily directed to other industries outside recreational craft.

In general, a key consideration to take into account when assessing the potential uptake of biofuels in the recreational craft sector is the future availability of sustainable biomass feedstocks compared to potential demand for biofuels from other sectors within and beyond transportation. Within the transport sector, for instance, aviation is expected to take up a significant share of biofuel demand, given the challenges the sector faces in taking up other alternative propulsion options as well as higher expected willingness to pay for fuels compared to the maritime sector.

5.6 Summary of decarbonisation technologies

As summarised above, there are a range of technologies that can be deployed on recreational craft to support reductions in operational emissions. However, these technologies vary in regards to their current maturity level, emission reduction potential and applicability to specific boat types. Table 6 aims to provide a high level overview of the Technology Readiness Level (TRL) and operational emission reduction potential of each technology covered in the previous subsections within section 5.

Table 6: Decarbonisation technology assessment by technology matureness and operational emission reduction potential

Measure category	Technology	TRL ¹⁰	Operational emissions reduction potential
Technical design and performance	Hull design optimisation	8-9	Low
Technical design and performance	Foiling technology	9	Low
Alternative energy sources	Hydro-generators	9	Low
Alternative energy sources	Solar PV systems	9	Low
Alternative energy sources	Marine wind generators	9	Low
Drive train hybridisation/electrification	Electric motors	9 – for current low voltage systems	High
Drive train hybridisation/electrification	Conventional hybrid-electric motors	9 – for current low voltage systems	Medium
Alternative fuel use	Hydrogen (ICE)	8-9 ¹¹	High
Alternative fuel use	Hydrogen (FC)	6-7	High
Alternative fuel use	Biofuels	9	High ¹²

¹⁰ Technology Readiness Levels based on Horizon 2020's definition outlined in following source: Horizon 2020: Working programme 2014–2015, General Annexes–G. Technology readiness levels (TRL). Available from: https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

¹¹ While hydrogen ICE engines have been developed and tested within the recreational craft sector (e.g. on Cheetah Marine's 9.95m catamaran), this technology has been assumed to still be needing to achieve full commercialisation, by achieving cost reductions.

¹² Biofuel emission reductions can only be fully captured when considering lifecycle (or well-to-wake) emissions, as the CO₂ emitted during combustion is balanced with CO₂ absorbed during the growth of the biomass feedstock. Biofuel lifecycle emissions will vary widely depending on the biomass feedstocks being used in the fuel production process; for instance, energy crops may have higher upstream emissions compared to biomass waste

Given the diversity of boat types and operational profiles within the recreational craft industry, there is no universal solution that can be taken up across the fleet for decarbonisation. There continues to be high uncertainty in regards to which technologies will see the highest uptake within specific subsectors of the recreational craft market, as this will be driven by several factors, including further R&D efforts, infrastructure development and future standards/regulations. Keeping in mind the sector's complex structure and high uncertainty regarding future developments, Table 7 aims to provide a simplified overview of the potential short, medium and long-term applicability of decarbonisation technologies across the main boat categories within the recreational craft sector.

The timeframe potentials for each technology represented in the table columns has been assessed separately to the other technologies, although some technologies such as alternative fuel blends and hybrid propulsion based on conventional fuels could act as bridging technologies for longer term solutions like 100% alternative fuels, hybrids using a combination of electric motors and ICE or fuel cells running on alternative fuels and pure electric propulsion.






The table covers only measures that can reduce main propulsion emissions. As alternative energy sources are expected to mainly be applied to reduce auxiliary power emissions, these have been omitted from the table. Additionally, as hull design optimisation and hydrofoils applied on sailboats are assumed to mainly be targeted at enhancing sailing performance, rather than emission reductions from engine propulsion, this has been flagged as part of the table. Within the "100% alternative fuels" column, both hydrogen and biofuel options have been assumed to be longer term solutions, while biofuel blends may be achievable in the shorter to medium term. Achieving 100% biofuel blends is expected to take longer, due to the need to determine biofuel supply availability for the recreational craft sector.

streams/residues, due to potential land use changes required to cultivate the crops. The "High" operational emission reduction potential included in the table reflects potential emission reductions taking into account a well-to-wake approach and assuming sustainable biomass feedstocks are used for biofuel production.

Table 7: Key emission reduction technologies applicability by vessel type and decarbonisation potential within a short – long term timeframe

Sub category	Engine type	Hull Design Optimisation	Hydrofoils	Alternative Fuel Blends ¹	100% Alternative Fuels ²	Hybrid Propulsion ³	Pure Electric Propulsion ⁴
Small planing motorboats	Outboard	●	●	◐	○	—	◐
Small planing motorboats	Sterndrive	●	●	◐	○	◐	○
Small planing motorboats	Inboard	●	●	◐	○	◐	○
Small displacement motorboats	Outboard	●	—	◐	○	—	◐
Small displacement motorboats	Inboard	●	—	◐	○	◐	◐
Large planing motorboats	Sterndrive	●	●	◐	○	◐	—
Large planing motorboats	Inboard	●	●	◐	○	◐	—
Large displacement motorboats	Inboard	●	—	◐	○	◐	○
Small sailboats	Outboard	▲	▲	◐	○	—	◐
Small sailboats	Inboard	▲	▲	◐	○	◐	◐
Large sailboats	Inboard	▲	▲	◐	○	◐	○
Smaller dinghies	Outboard	●	—	◐	○	—	◐
Larger/ higher power RIBs	Outboard	●	●	◐	○	—	◐
PWCs	Inboard	●	●	◐	○	—	◐

Symbol key:

-  = short-term solution (2021-2025) that requires limited R&D
-  = medium-term solution (2026-2035) that requires further R&D
-  = long-term solution (2036-2050) that requires substantial R&D
-  = solution may not be applicable or difficult to implement in the foreseeable future and may require more research
-  = solution applied to enhance boat performance rather than emission reductions

Notes:

1. Including biofuels or other drop-in low or net-zero emission fuels
2. Including hydrogen, biofuels or other net-zero emission fuels
3. Includes hybrid systems using conventional fuels to power ICEs, which could transition to alternative fuels as these become available in the longer term
4. Including electric-drives powered by either batteries or a combination of batteries and fuel cells

6. Supply chain assessment

A decarbonised recreational vessel market is unlikely to observe a significant change to the current supply chain. However, there will be opportunities to develop capabilities and in assessing both the current and future potential supply chain, it is possible to draw out key conclusions and highlight synergies with other industries which will help countries meet 2050 targets.

The following section examines key market segments and should not be used as a definitive conclusion to the evolution of the supply chain. Policy, technology improvements and changing consumer demand, will play a role in the relative uptake within countries and different technologies.

6.1 Summary assessment of the recreational vessel supply chain

6.1.1 Boat manufacturing

Requirements

Common materials used in the industry (see section 5.1) are extremely difficult to recycle and have high associated emissions. The boatbuilding and equipment manufacturing industry has an opportunity to investigate reduction of emissions by utilising bio-based materials or those easier to recycle. National and European recycling programmes could exist, and upskilling of the workforce is required to handle new types of materials.

Hull design optimisation is an increasing area of research and there are opportunities to put greater emphasis on this aspect in naval architecture courses. The transition to using electric motors is not expected to cause significant disruption at a manufacturing level although some training will be required, most probably from the supplier of the engine. The installation of a battery system would include additional weight on the vessel and additional space for the system, which would need to be accounted for in the design.

The use of hydrogen is thought to be particularly important for the inboard motor yachts, as this will not degrade the current standard of travel. Marine specific hydrogen cells are already in development, so once these become readily available, manufacturers will have to install them along with hydrogen tanks, which will require additional space and therefore, possible redesign of the vessel, though this is comparable with a battery system.

The following table is for short-medium term potential, for further information per boat type, please see Table 7 above.

Table 8.1: Current capacity of the boatbuilding industry based on the [Pleasure Boat 2018 Internal Resource Guide](#) ¹³

	Motorboats Inboard	Motorboats Outboard	Sailboats	Inflatables
UK	H	M	H	M
France	M	H	H	H
Netherlands	H	H	H	H
Greece	L	M	-	L
Malta	-	-	-	-
Cyprus	-	-	-	-
	Motorboats Inboard	Motorboats Outboard	Sailboats	Inflatables
UK	M	M	M	M
France	M	M	M	M
Netherlands	M	M	M	M
Greece	M	M	L	M
Malta	-	-	-	-
Cyprus	-	-	-	-
	Motorboats Inboard	Motorboats Outboard	Sailboats	Inflatables
UK	L	L	L	L
France	L	L	L	L
Netherlands	L	L	L	L
Greece	L	L	L	L
Malta	-	-	-	-
Cyprus	-	-	-	-

Synergies with other industries

The recreational craft industry is relying on transferrable knowledge from other industries, particularly HGVs, before battery systems become standard in the industry. The use of lower carbon materials needs to be

¹³ Note this is not exclusive to the low emission technology industries and reflects the current recreational boat supply chain.

developed with consideration for EOL. Other industries including the wind industry are facing similar challenges and learnings may be applied between sectors.

Key conclusions

The boatbuilding industry can adapt relatively easily to the use of new technologies as they become available and demand increases, provided there are strong links with suppliers of technologies. There are unlikely to be significant challenges with adapting design, although mechanisms to incentivise the use and scale-up of innovative materials are important to consider.

Countries that have a strong EV industry are likely to quickly transfer to using electric motors and this will not cause significant problems for boatbuilding and as such, are listed to medium with potential to move to high, likely depending on regulation. Greece is listed as low for sailboat EV boatbuilding as they do not currently have an industry.

Building hydrogen specific boats is anticipated to be low in the short to medium term.

Countries, such as Cyprus, that are recognisably weak in the boat manufacturing supply chain aspect, are instead looking at focusing on other areas such as efficiency solutions, retrofits and education within the sector.

6.1.2 Engine manufacturing

Requirements

Engine manufacturing will likely be provided by electric and hydrogen technology developers and conventional engine manufacturers.

As batteries can be made independently without the specific requirement of a drive train, it has been suggested that battery OEMs and engine manufacturers will not be the same. Where alternative energy sources are utilised, synergies will exist between OEMs and engine manufacturers.

Alternative fuel production such as hydrogen and biofuels for marine purposes are still developing and as such, the supply chain globally is still in its infancy. These fuel types are assessed on each country's ability to produce fuel, independent of applications to recreational vessels. As some alternative fuels can be used in conventional internal combustion engines, there are minimal adjustments required.

At the level of engine manufacturing for recreational vessel applications, construction will be relatively simple and will not require much development as the area of interest for OEMs is to improve efficiency and power density of energy storage infrastructure; as well as scale production of batteries. Further research is also required to ensure safe integration of hybrid and electric drives into vessels.

Assessment has been split into four main categories: where specific technologies are detailed within Section 5.

It should be noted that many manufacturers in Europe have decided to import batteries but maintain boatbuilding in Europe.

Table 8.2 Current capacity for engine manufacturing

	Alternative Energy Technology	Drive Train	Alternative Fuel Production	Policy and Development
UK	M	H	L/M	H
France	M	H	M	H
Netherlands	M	M	M	M
Greece	L	L	L	L

Potential

The future capacity of these technologies will be driven by policy and development which can make it difficult to estimate future potential levels. Furthermore, with increased globalisation, there is a likelihood that manufacturing of alternative fuel technologies may occur in countries outside of Europe.

As mentioned above, engine manufacturers throughout Europe are already importing battery technology from non-EU countries which contributes to the supply chain capacity of each country in the future. Despite this, the “Policy and Development” factor highlights the potential for increasing in R&D within specific countries, which can further contribute to their global offering and shows a desire to innovate.

Synergies with other industries

The use of batteries has synergies primarily with the electric vehicle industry. Extensive research has been conducted in developing battery technology for use in electric vehicles to match the requirements of local regulation, especially in the UK. Major manufacturers from the automotive industry have already pledged to go fully electric by 2030 which may assist in the technology transfer.

The use of hydrogen fuel has synergies with shipping as well as commercial road vehicles. Biofuels are in relative high demand across various industries such as aviation, and technology is likely to further develop in this sector; however, there have been issues identified with availability of fuel.

Key conclusions

Although in Europe, the UK, France, and Netherlands appear to be large players; they do not have a large portion of the global battery market share. As the technology develops and manufacturing improves, it is likely that manufacturing will be based outside of Europe other than small, boutique equipment manufacturers. Considerations, however, should be made for drive train manufacturing and applications to vessels. Many engine manufacturers appear to be opting into importing batteries and applying motor technology in-house.

Hydrogen technology is still in its infancy and hydrogen economy metrics are being used to assess which countries will be key players. As it stands, the UK and France both have a strong infrastructure and a desire to develop hydrogen technology, and as such, focus should be made in improving infrastructure and local trade and partnerships.

Drive train developers have been identified as those who are current players in the vessel industry where the UK and France are regional leaders. They are also regional leaders in policy and funding to encourage further research and development in battery and hydrogen technologies.

6.1.3 Infrastructure

Requirements

Infrastructure upgrades can be complex and need to be planned. Therefore the following tables for potential look at opportunities up to 2050, in recognition of the need for early planning.

For both electric motors and alternative fuels including hydrogen, infrastructure upgrades are vital. Recharging and refuelling points will be required at both marinas along inland waters and larger floating stations for sea crafts. Inland waterways may prove challenging as a robust network will be required before boats can take advantage of current travel patterns.

The Inland Waterways Association has advised the UK government that on inland waters, 430 charging sites should be installed across the 4,700 miles of navigable waterways, to allow charging points to be five hours cruising apart without causing serious congestion. The Inland Waterways Association (IWA) state that charging sites would need to vary from two to 20 sockets depending on the route traffic, see the IWA’s memo on the [Vision for Sustainable Propulsion on the Inland Waterways \[72\]](#). Similar infrastructure will be required across other European networks.

Another infrastructure requirement for using hydrogen would be not only enabling refuelling but emptying of hydrogen at larger marinas. The seasonality of the recreational craft industry means the vessels can be unused for long stretches of time. There are more safety concerns around idling hydrogen, and for vessels that know they are about to enter a static period there should be some way of unloading hydrogen into a larger tank.

Table 8.3: Current Capacity of low emission technology infrastructure

	Electric Charging	Hydrogen Refuelling	Biofuel supply
UK	L	L	L
France	L	L	L/M
Netherlands	L/M	L	L/M
Greece	L	L	L
Malta	L	L	L

Cyprus	L	L	L
--------	---	---	---

Table 8.4: Potential of low emission technology infrastructure

	Electric Charging	Hydrogen Refuelling	Biofuel supply
UK	H	H	L/M
France	H	H	M
Netherlands	H	H	M
Greece	M	H	L/M
Malta	M	M	L
Cyprus	M	M	L

Synergies with other industries

The industry is closely linked to boat manufacturing, as infrastructure investments need to match demand. Government incentives may be required to ensure adequate infrastructure is in place for charging and refuelling points and it is important that the industry discusses decarbonisation holistically.

Hydrogen refuelling is dependent on the national status of hydrogen distribution. If the country has invested in hydrogen distribution infrastructure, with dedicated pipelines (or upgraded gas networks), then refuelling logistics could be easier with lower costs, compared with transported liquid hydrogen. In the future, some larger marinas may choose to invest in on-site electrolysis with renewable energy sources, though this would be a greater infrastructure investment.

Key conclusions

The decarbonisation of the recreational craft sector addresses not only the vessels but the wider infrastructure. This includes ports, harbours and marinas which will need upgrades to support electric charging and storage of alternative fuels. Marinas are often a mix of public and privately owned, and although the fragmentation can prove challenging, there are opportunities for businesses to invest to support the decarbonisation of the sector and benefit from green growth. Infrastructure upgrades and ensuring facilities, including servicing, are fit to cater to new vessels will be crucial to supporting the uptake of hybrid and alternative fuels in recreational vessels.

Currently, the Netherlands, UK and France all have some form of electrification for recreational vessels, mainly on inland waterways within the tourism sector (tourist cruises along rivers/canals). The Netherlands are aiming to phase out all emission vessels within Amsterdam by 2025, which is promising for the country but currently means some boat owners will move their vessels outside of the city, so national regulations are also required to prevent this.

Infrastructure for alternative fuels may be more challenging although opportunities exist for countries who set clear pathways to decarbonisation. For example, stakeholders have highlighted that by 2030, Greece is expected to be a major contributor to the green hydrogen economy and as such, hydrogen transport logistics are expected to be more straightforward through integration with the wider energy system.

6.1.4 Operations and service provision

Requirements

Eliminating fossil fuels from vessel engines will likely reduce the maintenance and service requirements on boats. However, local O&M providers will require training to ensure they have the capability to resolve hydrogen or electrical related faults. This may be easier in countries that also manufacture large proportions of components or engines. Services will follow this type of technology and they need to be supported to encourage technology uptake, which may need longer term planning. Potential is closely aligned with current country technology market segments.

With electric boats, generally lower voltage batteries are used for safety reasons but these are less efficient. Upskilling service and maintenance workers, as well as end users in safe handling courses could allow more efficient higher voltage batteries to be used in some vessel designs, with buyers requiring a certificate before purchase. There are also safety concerns around using hydrogen. All stages of the supply chain, including operations and service provision staff, will require training on the safe handling of hydrogen.

Older vessels can be retrofitted to transition to lower emission technology. When retrofitting older engines to be compatible with biodiesel, rubber seals will need to be replaced to avoid degradation on engines manufactured before 1990, as synthetic seals have been used since then. O&M providers will need to be aware of this to avoid problems.

Table 8.5: Current capacity of low emission technologies for operation and services

	Motorboats Inboard	Motorboats Outboard	Sailboats	Inflatables
UK	M	M	L	L
France	M	M	M	L
Netherlands	M	M	L	L
Greece	L	L	L	L
Malta	L	L	L	L
Cyprus	L	L	L	L

Table 8.6: Potential of low emission technologies for operation and services

	Motorboats Inboard	Motorboats Outboard	Sailboats	Inflatables
UK	H	H	H	H
France	H	H	H	H
Netherlands	H	H	H	H
Greece	M	H	M	H
Malta	M	H	H	M
Cyprus	M	H	M	M

Synergies with other industries

This market segment is closely linked with boat manufacturing since O&M is dependent on the type of boats and engines in the boat park. There may be some trickle-down from commercial shipping and automotive industries who will be using low emission technologies albeit at a different scale and usage pattern.

Key conclusions

The provision of operations and service will need to react and adapt quickly to the rest of the market, though they will be unlikely to drive demand. This segment is a large employer and it will be important that upskilling happens across the network to ensure boats can continue to travel between countries and continue to procure adequate services.

For instance, although hydrogen is uncommon as a fuel type within the sector currently, national hydrogen capacity installation plans are proving that there is a lot of knowledge within the hydrogen economy sector. The UK government has invested significant funds to the development of green hydrogen by 2030. Similarly, various European countries have collaborated with a hydrogen plan for the next decade. It is clear that although hydrogen is not commonly used within the sector, there is plentiful industry knowledge that can be transferred and leveraged for upskilling operations and service provision workforce, as well as the wider supply chain.

While the recreational craft sector will likely react to regulation and technology change, countries who develop a reputation for good operations and servicing for new vessel types will likely attract owners and businesses.

7. Recommendations to enable decarbonisation

The decarbonisation of recreational vessels is complex with many organisations involved across the supply chain. Section 6 overviewed the supply chain needs and the potential opportunities for focus countries. The following section provides a summary of recommendations from the supply chain, outlining potential implementation mechanisms for key organisations. Information has been gathered from primary and secondary research and the information is intended as a platform for discussion.

7.1 Lifecycle assessment (LCA)

A lifecycle assessment (LCA) is a critical approach used to determine the overall GHG emissions produced by a particular product/service throughout its lifecycle. Measuring a product's footprint is the first essential step to understanding the relative impact that each lifecycle phase has on the product's total emissions, as well as to assess and compare potential solutions that can be implemented to reduce the product's carbon footprint.

The maritime sector has mainly focused on environmental impacts produced by vessels during their operations, with the recreational craft sector focusing particularly on addressing air pollutants rather than GHG emissions so far. The international maritime sector has set GHG emission reduction targets, however these are also currently focused on operational emissions only, although discussions on how to incorporate full LCA of alternative fuels is on the IMO's agenda. As the recreational craft sector ramps up efforts to meet overarching national and regional decarbonisation goals, it is critical that the industry adopts an LCA approach to evaluate the most suitable options for decarbonising specific vessel types, which allow for emission reductions during operations, as well as within upstream and downstream activities. The LCA approach will also provide key information to determine when and which retrofits represent the optimal option to decarbonise existing boats, as well as when avoiding retrofits or scrapping boats earlier would lead to lower overall emissions.

7.1.1 Policy makers

Policy makers will play a critical role in shaping the industry's decarbonisation pathway. Ensuring that new policies and regulations are introduced to drive emissions reduction within the sector, and considering potential impacts on the full lifecycle emissions of a boat will be essential to ensuring that reductions in operational emissions do not translate into either upstream or downstream emission increases.

For instance, one of the key measures to provide a clear timeline for the industry to shift towards net zero emission technologies is to set a date for the sector to achieve full decarbonisation. This target should cover the reduction of lifecycle emissions of boats rather than solely operational emissions. Similarly, the effect of implementing any bans on conventional technologies should be assessed in regards to potential

impacts on emissions derived from retrofits or disposal of boats. A sectoral decarbonisation target should be selected to align with broader climate targets and incentives can assist to optimise realistic decarbonisation pathways. Additionally, national recreational craft decarbonisation targets should broadly align across Europe in order to avoid boats being transferred and used in countries with less stringent emission reduction requirements, as well as to facilitate cross-border navigation.

New regulations requiring LCA assessments for either watercraft or specific technologies/ fuels to be used on watercrafts, could be implemented to drive the adoption of LCA assessments within the industry. This would support the development of a better understanding of the industry's current emissions impact, as well as enhanced transparency to enable consumers to make better informed choices. Introducing, for instance, requirements for conducting and disclosing LCA data for boatbuilders could accelerate the shift towards a more holistic way of approaching boat design and manufacturing oriented towards reducing emissions as well as promoting a circular model within the industry.

Developing similar requirements or certification schemes for alternative fuels, including hydrogen, would facilitate the identification of net zero/green fuels that have been produced from renewable resources, as well as having lower/net zero operational emissions. This, in turn, would support the development of a market for green fuels, thereby supporting fuel producers in shifting to increasing existing capacities in green fuel production.

Additionally, to promote uptake of technologies that can support the decarbonisation of vessels, policy makers could consider developing incentive mechanisms to promote increased integration of these technologies in new boat designs.

Both secondary research and discussions with stakeholders throughout the project have highlighted the lack of sectoral data in regards to the accurate number of vessels per vessel type, their operational profiles, annual distance travelled and fuel consumption. Addressing this data gap will be critical to calculate the baseline emissions of the industry (whether at an operational or LCA level), determine the annual rate of decarbonisation that needs to be achieved to deliver net zero emissions by 2050 and to monitor annual changes in emissions to track progress against the 2050 target. Gaining a better understanding of the UK's and European boat park's key characteristics will enable a more informed assessment of current operational requirements of specific vessels and facilitate the identification of optimal decarbonisation solutions, as well as of the related infrastructure requirements. This, in turn, would also provide better visibility to policy maker and other industry stakeholders in regards to the potential demand for each alternative decarbonisation technology that could come from the recreational craft sector and related impacts on the supply of such technologies and fuel types. Additionally, sound sectoral fuel consumption/emissions data would also enable more accurate LCA calculations. Hence, policy makers should consider supporting the development of a standardised data collection systems at a UK or European level allowing to quantify or estimate the operational profiles and emissions per vessel type, as well as at an aggregate fleet level.

7.1.2 Boatbuilders

Boatbuilders across the industry are expected to face increased pressure from both regulators and customers in regards to the environmental credentials of boats being designed and manufactured. To demonstrate sectoral leadership, as well as to be prepared to meet tougher regulations, boatbuilders should start measuring the GHG footprint of their products and processes. This will enable companies to gain a better understanding of current emission hotspots within their product's lifecycles, which will provide the foundations to then evaluate and implement solutions to reduce the overall impact of the products. If a sectoral data collection system is implemented at a national or regional level, boatbuilders should make verified LCA data available for inclusion in the system to contribute to increasing sectoral LCA data availability.

7.1.3 Technology providers

As for boatbuilders, technology providers, including providers of composite materials and battery technologies, should also measure the lifecycle emissions of their products and identify solutions to reduce their impact and facilitate a shift towards a more circular model. Technology providers should also leverage LCA assessments of lower carbon technologies as a means to promote such products to their customers.

7.1.4 Certification and Standards bodies

Certification and Standard bodies can play an important role in supporting the development of standardised methodologies for the development of LCA Certification schemes, that can be applied to either boats or technologies/fuels to identify options with the lowest GHG emissions impact. These schemes will be essential to avoid "green washing" within the sector – i.e. to avoid vessels or technologies being inaccurately marketed as lower carbon solutions.

7.1.5 Industry associations

Ensuring that the industry collaborates closely with other sectors to share knowledge around R&D for decarbonisation technologies and encouraging the harmonisation of standards will greatly facilitate the development and uptake of such technologies. Industry associations can play a critical role in facilitating knowledge sharing by providing a platform for industry stakeholders to discuss challenges related to decarbonisation, as well as to represent the industry in discussions with other sectors on the topic and then disseminate findings. These types of activities are already ongoing in a number of industry associations and their continuation, as well as increased engagement across the different net zero emission technology options will be highly valuable to support industry decarbonisation.

7.2 Electrification and alternative fuels

There is no single technology solution for reducing operational emissions from recreational craft and electrification, and alternative fuels must be utilised to best fit vessel type and activity. Policy makers should support technology R&D as a significant proportion of the total emissions are associated with craft operations. Meanwhile, technology providers must have clear targets for developing, commercialising and scaling-up new technology. Section 5 provides further information on the technical solutions and their key

barriers and enablers to uptake. The following subsections summarise recommendations for key industry stakeholders.

7.2.1 Policy makers

To encourage the roll-out of low carbon recreational vessel propulsion technologies, it is likely that taxation or financial incentives will be required. While the European Green Deal has unlocked significant funding for the development and demonstration of low/net zero carbon technologies within the maritime sector, specific incentive systems to support the actual uptake of these technologies are lacking. In particular, the installation of alternative propulsion systems is more expensive than conventional engines, and deploying mechanisms to make the cost of alternative technologies more attractive to consumers is expected to be required to alleviate existing financial barriers.

For electric/hybrid drive systems, the upfront cost of the technology is higher compared to traditional options, however the cost of recharging batteries is lower. Governments could seek to implement similar incentive schemes as those currently deployed in the automotive sector to encourage the uptake of hybrid or fully electric vehicles.

For propulsion technologies involving alternative fuels that are more expensive than conventional diesel/petrol, governments could look into employing initiatives similar to that of 'red diesel' to alleviate taxes on alternative, lower carbon fuels to facilitate uptake. Other biofuels such as biobutanol could also be considered as advanced biofuels, and producers could be given grants to encourage production. Incentives should also be considered at fuel supply location to ensure ease of blending and distribution.

Additionally, the development of new safety regulations and standards will be critical for the uptake of net zero emission propulsion systems. For electric/hybrid drives, the shift to higher voltages will require the development of safety standards to mitigate the increased risks related to higher voltage systems. The use of hydrogen as a fuel for recreational craft will also require the development of new safety standards both for handling of the fuel on land as well as onboard. Harmonisation of such standards, in addition to charging/refuelling infrastructure, across European countries, is critical to facilitate wide uptake of net zero emission technologies. For example, charging plugs for electric/hybrid vessels should be standardised across countries. Governments should collaborate with international standard organisations to promote harmonisation of new standards/regulations across regions.

Policy makers should look to implement platforms for cross-industry knowledge sharing. This is particularly relevant for the development of standards for hybrid/electric vessels and for hydrogen, where knowledge from other sectors including automotive and aerospace are expected to facilitate the development of industry standards.

7.2.2 Boatbuilders

While the transition to hybrid/electric drives or alternative fuels is not expected to cause significant disruptions to boat manufacturing, some degree of workforce upskilling will be required to ensure that alternative propulsion systems can be effectively and safely integrated into craft designs. Boatbuilders with

capacity to invest in R&D could strive to direct investments into workforce training, as well as into the development of craft models that incorporate alternative propulsion systems. Close collaboration with engine OEMs will be essential to ensure that alternative propulsion systems can be effectively integrated into optimised hull designs. These efforts would demonstrate market leadership, allowing boatbuilders to start preparing ahead of time for future more stringent emission regulations, as well as to potentially tap into new customer segments looking for greener recreational craft.

Boat manufacturers can also play an important role in engaging with customers to raise awareness of the benefits of vessels running on alternative propulsions systems, as well as the limitations from a performance angle. This is expected to help re-balance customer expectations between the operational and environmental performance of vessels.

7.2.3 Technology providers

Improvements in battery technologies both in terms of better power-to-weight and cost will be critical to enable further uptake of electric/hybrid propulsion systems, particularly on vessels with higher power/range requirements or that are especially sensitive to weight. Battery technology providers should keep investing in R&D to pursue such improvements, with the support of grant funding where appropriate.

Achieving enhanced reliability of electric motors will also be critical to ensure that performance and safety requirements can be delivered to customers. Electric motor manufacturers should concentrate R&D efforts on achieving such improvements in the short to medium term to enable further uptake of their technologies.

For hydrogen, while ICE engines are expected to require limited modifications, more R&D work is required to determine the optimal storage solutions onboard recreational craft to minimise additional volume requirements as well as to ensure high safety levels. Additionally, while fuel cells are seen as a potential longer term solution within the industry, further R&D efforts to advance the technology, particularly for use in a maritime setting, would be beneficial to provide additional options to support industry decarbonisation.

There is also additional research required to understand how to make the use of hydrogen compatible on recreational craft which have a low usage profile – whether this means the need for emptying storage tanks if the vessel is not going to be used for long periods of time, or if there are any implications on storage and propulsion systems if hydrogen is left onboard for a prolonged period.

7.3 Marinas

Transitioning to low emission vessels will only be possible with a supportive infrastructure. Industry wide adoption will ensure adequate coverage of refuelling stations, to allow vessel owners to travel freely. Biofuels can be seen as a transitioning fuel and can use existing end-use distribution infrastructure. However, with the numerous types of biofuels available, marinas may struggle with capacity of more than one type of biofuel, and may be able to store only one blend of petrol and diesel. Those marinas that have the means to allocate more space to additional tanks will need to accommodate additional costs and logistical challenges for installation and storage.

While electrical infrastructure is in many cases more advanced, there are significant costs associated with installing and upgrading electric charging points. These include electric grid upgrades, design, engineering and installation. It is worth noting that the electric grid upgrades require planning permission, which could introduce delays of 12-18 months, so advanced planning is key for electrical infrastructure upgrades. Ultimately, there are numerous bodies involved in this process that will need to co-ordinate: marina owners, urban planners, electrical architects, grid operators and equipment providers.

Depending on the quantity of charging points installed and the time of day consumers wish to charge their vessel, the marina could also experience difficulties with peak demand electricity costs. Though the price will undoubtedly be transferred to the consumer, the marina could benefit from on-site energy storage to reduce peak load pressures, although this would be another upfront cost.

As the industry starts to adopt the use of hydrogen as a fuel source, infrastructure upgrades are required for hydrogen refuelling stations. Logistically this includes: delivery to the station, storage, compression and dispensing. The exact infrastructure will be dependent on the available forms of hydrogen, assuming that hydrogen will not be generated on site. SME marinas in rural areas and smaller demand may be more suited to gaseous forms of hydrogen, whereas marinas with a higher demand would be more suited to liquid hydrogen or pipeline delivery hydrogen. Where smaller quantities of hydrogen are required the upgrades will be costlier and this must be taken into account with incentives to ensure SME marinas can also provide adequate upgrades. According to Deloitte, Europe is expected to have ~3,700 hydrogen refuelling stations by 2030 to accommodate the expected increase in hydrogen fuelled vehicles, so there is a strong likelihood the wider industry infrastructure will be in place regarding transport of hydrogen, see the Deloitte report on [Fuelling the Future of Mobility, Hydrogen & Fuel cell solutions for transportation](#) [73].

There are opportunities to adopt renewable energy technologies to generate electricity for use at the marina itself or for charging points. The easiest renewable sources to capitalise on are solar power or wind power. Many marinas would benefit from using solar power, especially in sunnier climates of the Mediterranean. The cost of solar has decreased to affordable prices and many countries still have incentives for using solar panels, though this is no longer the case in the UK. Investing in renewable energy technologies to generate electricity means the marinas can use this electricity on site, in the cafés or visitor centres, to reduce the emission of the marina buildings.

7.3.1 Policy makers

SMEs are unlikely to focus on commercial aspects or infrastructure upgrades as they have a smaller cash flow. Adopting infrastructure upgrades to accommodate low emission vessels will be costly and disruptive to the marina, which will discourage many to do so. Policy makers should consider financial incentives for marinas to upgrade infrastructure to support low emission technologies.

There appears to be a stalemate within the industry in that marinas will upgrade infrastructure if there is significant demand for it, while vessel owners will only meet the demand if the infrastructure is in place. Policy makers have an opportunity to be proactive and also raise consumer demand by offering financial incentives such as reduced mooring costs (through the marina) for vessels complying with sustainability criteria.

Additionally, each low emission technology requires infrastructure upgrades: charging points, hydrogen refuelling or extra tanks for different biofuel mixes. There needs to be clear recommendations from local governments to inform marinas which technology they should invest in. This should be closely linked to the boat building industry, so that the infrastructure upgrades can match the demand of vessel type. Further research should be conducted to identify key potential hotspots for uptake of specific decarbonisation technologies and related infrastructure requirements within specific marinas. The availability of detailed sectoral data– including number of vessels per type, operational profiles, fuel consumption etc. – would greatly support these research efforts.

7.3.2 Marina owners and/or operators

Many marinas will have cafes, local restaurants and shops for vessel occupiers (and the local community) to visit and as such are in a good position to educate vessel owners on sustainability. This could simply be with information boards describing low emission technologies, seminars to discuss new technologies or retrofits of existing vessels and information on upcoming infrastructure upgrades through local newsletters, to enable vessel owners to prepare for the future. Private owners operating a chain of marinas should ensure that knowledge sharing on low carbon technologies is being effectively shared across locations. Though the marina workforce may not have the expertise to provide these services, they could be used as a hub from larger national bodies. Marinas also have the opportunity to promote low emission technologies through small equipment sales such as selling biogas canisters that could be used for cooking on larger vessels.

Large private marinas that have the capacity to make infrastructure upgrades should start considering investing in recharging infrastructure for hybrid/electric vessels to demonstrate sectoral leadership and incentivise investments from other marinas to start creating a recharging network.

There is increasing concern over pollution in mooring areas and operators could consider implementing low emission zones within marinas, where vessels would be required to run either on an electric motor or on low carbon alternative fuels. This could drive local emission reductions while also attracting customers preferring to berth at marinas with better emission control standards. Alternatively, marinas could implement incentive schemes to reward vessels emitting less emissions by offering a reduction on mooring fees or better berthing locations. Such an incentive scheme would need to be based on a system for scoring a vessel's emissions, which could also promote additional transparency in the sector. Both of these potential solutions are expected to be most effective if operated across a network of marinas.

7.4 End-of-life

The majority of boats at the end-of-life are landfilled, sunk or abandoned. Fibre Reinforced Plastic (FRP) is a major component of many recreational boats and while this is highly durable many vessels are now starting to reach their end-of-life, and there are inadequate facilities and networks for dismantling and recycling. Dismantling costs are estimated at between €800- €15,000 for boats depending on their size (7m-15m) which is a significant outlay for a product with no further use, see the [European Boating Agency's position statement on end-of-life boats](#) [26].

In recent years, Europe has made advancements in waste management, however, there are still significant opportunities to develop more sustainable practices in the design, manufacture and end-of-life of recreational vessels. Disposal of boats at scrapping facilities is still relatively low and there is now greater complexity in recognition of the need to increase reuse and recyclability. Therefore, the industry must find ways to deal with FRP waste, reuse of recyclable material, create financial incentives for the disposal and recycling of boats, and improve the legal framework on ownership of the problem.

There are signs of progress at a national level with France leading the way with the French Energy Transition Act, which promotes the principle of extended producer responsibility. Since 2019, anybody introducing recreational boats to the domestic market on a professional basis must pay part of the costs or directly provide facilities to deal with the end-of-life boat.

To adequately address end-of-life, agents from across the supply chain need to be involved in developing better practices.

7.4.1 Policy makers

It is important to implement European wide EOL legislation. There are lessons to be learnt from national strategies currently in place and European governments and EU bodies should listen to industry groups calling for more action. Clear targets must be implemented in regards to the disposal of the current fleet and recycling should be optimised. This requires investment in facilities and consideration of mechanisms to implement or improve vessel registration. Fiscal incentives such as a one-off payment or reduction in recycling costs could be considered to encourage disposal at appropriate sites.

For new build boats, policies could be put in place to reward design and construction of vessels that promote easy separation of components and/or alternatives to FRP (e.g. natural fibres). In addition, certification or sustainability accreditation could be developed as industry best practice.

Specific tax for end-of-life could be applied to all boat sales (including second hand) to assist marinas/ports/harbours in addressing abandoned boats, and to fund dismantling throughout the boat's life rather than it being paid for by the last owner. Further work is needed to fully develop a financial model for extended producer responsibility which accounts for current practice of limited vessel registration.

7.4.2 Boatbuilders

Should look to design boats with components that can be separated, and use of alternative materials, particularly in regard to toxic resins and FRP. While it may not be possible to use bio composites for the hull or whole boat, in the short-term, these could be used for boat moulds and accessories, e.g. hatches. Boatbuilders should also look to become accredited as a more sustainable supplier if a certification is introduced.

There are potential opportunities to develop partnerships with recyclers and dismantlers. This would help address the issue of EOL responsibility in a sector with a strong second hand market as well as an ageing fleet.

7.4.3 Services including O&M and scrapping

The growth of this sector will likely be caused by policy development introducing legislation and greater regulation. The service sector should look to work with the wider industry, including boatbuilders. There are opportunities to develop alternative models of operation such as services for the pick-up and transport of vessels, to dismantling facilities which could be packaged as a service relating to new build boats.

7.5 Nautical tourism

In recent years there has been growing awareness of the importance of clean growth and the role tourism has to play in developing more sustainable practices. The Covid-19 pandemic has promoted the opportunities for outdoor and nature based activities, and nautical tourism is well placed to support economic recovery.

Countries and businesses may be able to capitalise on market opportunities arising from a growth in the recreational craft sector and a move to low emission vessels. There is a shift to greater societal interest in environmental issues and businesses may be able to create new opportunities catering to a demand for more sustainable practices. While there are few companies currently operating, stakeholders have highlighted a number of electric only boat businesses catering to growing demand.

Due to expensive maintenance and initial investment, trends have shown a movement away from ownership towards recreational and tourism activities and alternative models of ownership (e.g. co-ownership platforms and boat clubs). Furthermore, digitisation will aid connectivity between boats and marinas facilitating charter usage.

7.5.1 Policy makers

There are opportunities to build on the growth in interest for outdoor activities and boat ownership as a result of the pandemic. As part of European and EU recovery efforts, sustainable nautical tourism should be encouraged and policy makers must consider how to drive consumer demand towards decarbonisation activities.

Developing standards and awards for service providers and marinas operating more sustainably, such as extension to the criteria for Blue Flag marinas and/or tourism boats would help to promote lower emission vessels. This could be particularly attractive to help decarbonise the charter sector whereby businesses could receive grants to upgrade their practices. Consideration should be given to an LCA approach whereby bridging technologies and retrofitting may be more appropriate to avoid early boat disposal.

Marinas are an important part of the tourism business and the development and extension of low emission areas of operation may support the development of this sector. In addition, supporting and working with

tourism providers to provide adequate infrastructure upgrades such as electric charge points will likely develop consumer demand.

7.5.2 Tourism providers

There is a small but growing opportunity to develop more sustainable tourism offerings through the use of low emission vessels, including electric, sailboats and recyclable materials. Consumer demand for these types of offerings is growing, and other parts of the tourism sector have capitalised on providing more sustainable holiday alternatives.

There are also opportunities for charter companies to operate innovative business models such as boat sharing platforms and digitisation of the infrastructure network.

7.6 Roadmap

Figure 10 presents a summary roadmap for achieving the decarbonisation of the overall recreational craft sector. The roadmap highlights the anticipated timeframes for the key decarbonisation technology categories highlighted in section 5.6, and how they can achieve wide sectoral uptake (within the most appropriate vessel types), and the required enablers to support the development and uptake of these technologies.

Within the first section of the diagram covering decarbonisation technologies, white to light shades of green from the left-hand side indicate timeframes within which efforts should be directed towards R&D to achieve technology improvements and cost reductions, while darker shades of green highlight targeted timings for technology scale up and commercial roll-out. As discussed, some of these technologies, particularly alternative fuel blends and conventional hybrid propulsion, are expected to act as bridging technologies for hard to decarbonise vessel types, up until net zero emission technologies before alternatives are available. The light green/white shades of the bars to the right-hand side represent phase out of bridging technologies. Similarly, within the enablers section of the roadmap, darker yellow shading of the bars indicates timeframes within which key enablers should be discussed, developed and implemented.

Technology pathways and sector wide decarbonisation are greatly dependent on policy action. It is important to note that Figure 10 is illustrative with the purpose to define possible scenarios and likely timeframes for technologies as a whole rather than first movers.

		2021-2025 Short term	2026-2035 Medium term	2036-2050 Long term
Technical design and performance	Hull design optimisation	Short to medium term research, cost reduction and scale-up for the implementation for relevant vessel types		
	Hydrofoils	Short to medium term research, cost reduction and scale-up for the implementation for relevant vessel types		
Alternative fuels	Alternative fuel blends ¹	Short to medium term research, cost reduction and scale-up for the implementation for relevant vessel types		
	100% alternative fuels ²	Medium to long term research, cost reduction and scale up for the implementation for relevant engine types		
Drive train electrification	Conventional hybrid propulsion ³	Short to medium term research, cost reduction and scale-up for the implementation for relevant vessel types		
	Pure electric / zero emission hybrids ⁴	Long term research, cost reduction and scale up for the implementation for relevant vessel and engine types		
Enablers	Key enabler timeframes	Defined emissions targets		
		EOL regulation		
		Awareness raising		
Data Collection Systems & Life Cycle Assessment				
R&D investment				
Scale-up support				
		Infrastructure upgrades		
	UK maritime targets		Zero emission capable vessels	UK as a recognised world leader in zero emission vessels
	EU policies and targets	RCD III consultation outcomes		90% emission reductions in shipping sector

Figure 10: Recreational Marine Craft Sector Decarbonisation Roadmap

Note: The roadmap diagram provides a simplified summary for the sector as a whole to show when technologies will likely become more prevalent and timeframes within which enablers should be implemented, as well as highlighting key industry policies/targets at an UK and EU level

1: Including biofuels or other drop-in low or net zero emission fuels

2: Including hydrogen, biofuels or other net zero emission fuels

3: Includes hybrid systems using conventional fuels to power ICEs, which could transition to alternative fuels as these become available in the longer term

4. Including electric-drives powered by either batteries or zero emission hybrids using a combination of electric motors and either ICEs or fuel cells powered by alternative fuels, as well as required infrastructure upgrades

8. Summary of findings

The recreational marine craft sector is diverse with significant opportunities to implement innovative technology and adapt to more stringent regulation. There is no single decarbonisation solution that can be applied across all boat types and further work is needed to overcome technology, policy, financial and behavioural barriers across a range of decarbonisation options to enable the achievement of a net zero emissions fleet by 2050. Countries must provide clear targets and mechanisms to support a relatively small industry with many SMEs who contribute positively to the economy. It is evident that we need co-ordinated European policies to ensure the problem is not relocated, and this will allow the continent to champion itself as a global leader in marine sustainability. A more detailed summary of policy, regulatory, technology, and R&D findings is presented in the following subsections.

8.1 Technology and R&D

While there is no single technology that is expected to decarbonise the recreational craft sector, some technologies have emerged as promising options, particularly for specific boat types. Design and technical efficiency measures aimed at reducing fuel consumption are key solutions that can be implemented in the short-term across most vessel types to start curbing emissions. However, ensuring that the gap between expected performance predicted based on design improvements and actual operations emissions is minimised through standardised validation systems. In the short to medium term, electrification is seen as a key technology with high potential for uptake on smaller craft, particularly among motorboats with displacement hulls and sailboats. Planing motorboats and larger craft in general will be harder to electrify and will likely need to turn to alternative fuels as decarbonisation solutions in the long-term.

Further R&D efforts are required to support technology innovation and cost reductions that can enable the wide uptake of both fully electric propulsion systems and alternative fuels, as well as to develop more sustainable hull materials. The creation of R&D hubs focused on improving specific decarbonisation technologies is expected to help accelerate innovation within the sector and pool resources for SMEs to help achieve economies of scale which may otherwise be challenging to obtain in a highly fragmented sector. There is potential to expand existing maritime R&D centres to cover challenges specific to the recreational craft sector. This would allow the industry to leverage and enhance existing frameworks rather than starting work from scratch. An example of a UK-based maritime R&D centre that stakeholders have suggested could be considered for this scope is the MarRI-UK Research and Innovation centre.

The development of cross-sectoral knowledge sharing platforms, particularly from the automotive, commercial shipping and wind industries, will also be key to support technology R&D, as well as the development of technology standards. As recreational craft engines are mainly marinised automotive engines, close co-operation with the automotive sector is expected to be highly beneficial. For technologies in earlier stages of development, including for example fuel cells, greater collaboration between academia and industry should be pursued.

In the short-term, there will be a role for bridging technologies that can reduce emissions before net zero technologies and their related supporting infrastructure become widely available and fully commercialised. Hybrid electric drives using conventional fuels to run ICEs are expected to act as a bridging technology for vessels types that are currently harder to electrify. For some of these harder to decarbonise vessels, including large displacement motorboats and sailboats, electrification is expected to become feasible in the long-term based on further technology improvements. For other vessels, including large planing motorboats, hybrids with a combination of electric motors and ICEs or fuel cells running on alternative fuels are expected to be a more practical long-term solution. Alternatively, vessels like large planing boats could use alternative fuel blends as a bridging technology and transition to using 100% alternative fuels within ICEs in the long-term. For such vessels, blending conventional fuels with alternative drop in fuels, including biofuels, will enable short-term emission reductions.

Most propulsion decarbonisation technologies, with the exception of drop-in fuels, will come with more complex handling requirements, as well as higher associated safety risks, compared to conventional propulsion technologies. This may impact existing industry dynamics, particularly regarding the relationship between owners and their boats. More specifically, current owners are not required to hold qualifications related to handling/maintenance of propulsion equipment. However, such courses would need to be rolled out to ensure that boat users can operate boats running either on high voltage battery systems, or alternative fuels like hydrogen, in a safe manner. Additionally, training on how to handle alternative propulsion technologies safely and effectively will need to be rolled out also for staff working within the operations, maintenance, repairs and emergency response service industry. For parts of the market, higher emphasis on the use of drop-in fuels in blends of up to 100% should be considered as a potentially more viable option.

8.2 Policy and Regulation

The recreational craft sector has to date mainly faced regulations aimed at limiting air pollution emissions. While concrete decarbonisation targets have been set for commercial shipping internationally and within some regions/countries, there are a lack of clear emission reduction objectives specific to the recreational sector both at a UK and at an EU level. Such a target should align with overarching national and regional climate targets, and should be agreed across European countries to support harmonisation within the sector. A sectoral decarbonisation target should preferably account for lifecycle emissions to incentivise the abatement of a boat's upstream and downstream emissions, along with operational emissions. The revision of the RCD is expected to introduce regulations on the sector's operational emissions. The level of ambition of emission reduction requirements is yet to be seen, however, these will provide a starting point for driving action among industry stakeholders.

In order to effectively measure a baseline for the industry's emissions, and hence determine the annual emission reductions that need to be achieved as well as monitor progress, there is the need to implement a data collection system, similarly to what has been implemented at both an IMO and EU level for commercial shipping. Such a system should allow to quantify or estimate critical factors that determine a vessel's performance and usage characteristics as well as emission profile. These factors would allow

determination of the decarbonisation technologies that best fit each vessel type and to determine regional infrastructure requirements to support the uptake of such technologies.

Promoting harmonised standards across Europe related to the uptake of decarbonisation solutions will be essential to provide confidence to owners that they can navigate between countries and find similar safety standards and technology/infrastructure specifications (e.g. same electric charging plug design). Harmonisation and integration of standards and regulations that have or are being developed in other industries for the same or similar low/net zero carbon technologies, particularly within the road transport sector, is also expected to further support/accelerate uptake of such solutions within the recreational craft sector.

New regulations aimed at accelerating the recreational craft sector's decarbonisation will need to be accompanied by support mechanisms to overcome existing technical, financial and market barriers to uptake of decarbonisation solutions. In particular, financial incentives and support schemes have been highlighted as beneficial instruments to stimulate innovation and integration of solutions for designing and manufacturing of boats with lower lifecycle emissions. Such incentives could also promote a sectoral shift towards a more circular model by supporting the use of more sustainable materials that are easier to recycle/dispose of once the boat reaches its end-of-life. Government support schemes and R&D funding should be designed to be easily accessible to SMEs and particularly to small companies that have limited resources to dedicate to meeting complex grant funding requirements. Additionally, the creation of schemes/rating systems to facilitate the identification of greener/more sustainable vessels is also anticipated to be an important enabler to support the creation of a market for lower emission products to stimulate consumer demand.

Mechanisms for promoting more sustainable ownership models, particularly within the charter sector, should also be explored as a means to supporting sectoral emission reductions. It may be beneficial to implement policies supporting low emission zones in coastal areas, and financial instruments are expected to be required to support marinas in making the required infrastructure upgrades to accommodate recharging or alternative fuels refuelling infrastructure.

9. References

- [1] European Commission, "Recreational craft sector," [Online]. Available: https://ec.europa.eu/growth/sectors/maritime/recreational-crafts_en.
- [2] Arizton, "Recreational Boat Market - Global Outlook and Forecast 2020-2025," 2020.
- [3] European Commission, "2020 Blue Economy Report: Blue sectors contribute to the recovery and pave way for EU Green Deal," 2020.
- [4] ICOMIA, "2019 ICOMIA Recreational Boating Industry Statistics Book," 2019.
- [5] European Commission, "Impact of Business Development Improvements around Nautical Tourism," 2016.
- [6] E. Majamäki, "Tracking environmental pressures from recreational boating," *Aalto University, School of Engineering*, 2019.
- [7] SHM Group, "How to choose the best inflatable boat? A Buyer's guide," September 2019. [Online]. Available: <https://www.shmgroup.com/blog/how-to-choose-the-best-inflatable-boat-a-buyers-guide/>. [Accessed January 2021].
- [8] British Marine, "Personal Watercraft," On the Water, [Online]. Available: https://britishmarine.co.uk/OTW-Home/Which-Activity/~link.aspx?_id=F7335A7D0A6144AFA8AF3A276EAEED55&_z=z. [Accessed January 2021].
- [9] ECSIP Consortium, "Study on the competitiveness of the recreational boating sector," 2015.
- [10] J. a. T.Lukovic, "The Phenomenon of the Marina Development to Support the European Model of Economic Development," *TransNav*, vol. 7, no. 3, 2013.

- [11] European Tourism Alliance, “Call for Action: Accelerate Social and Economic Recovery by Investing in Sustainable Tourism Development,” 2020.
- [12] British Marine, “UK boatbuilding sector enjoys rising exports amid challenging conditions for the industry,” September 2019. [Online]. Available: <https://britishmarine.co.uk/News/2019/September/UK-boatbuilding-sector-enjoys-rising-exports-amid-challenging-conditions-for-the-industry#:~:text=New%20figures%20released%20today%20at,totalling%20%C2%A3777m%20in%20t%20turnover..> [Accessed February 2021].
- [13] British Marine, “Key Performance Indicators and Industry Trends Research,” [Online]. Available: <https://britishmarine.co.uk/Services/Growth/Statistics-and-Market-Research/KPIs-and-Industry-Trends>. [Accessed March 2021].
- [14] BoatIndustry.com, “2019 figures for the French Boating Industry,” September 2020. [Online]. Available: <https://www.boatindustry.com/news/34542/2019-figures-for-the-french-boating-industry>. [Accessed January 2021].
- [15] OECD, “Peer review of the Dutch shipbuilding industry,” 2020.
- [16] TornosNews, “Survey: Greek yachting charter market soars in 2014-2018,” November 2019. [Online]. Available: <https://www.tornosnews.gr/en/tourism-businesses/yachting/37455-survey-greek-yachting-charter-market-soars-in-2014-2018.html>. [Accessed March 2021].
- [17] Technavio, “Boat and Yacht Transportation Market by Product and Geography - Forecast and Analysis 2020-2024,” 2020.
- [18] Grand View Research, “Leisure Boat Market Size, Share & Trends Analysis Report By Type (New Leisure Boat, Used Leisure Boat, Monitoring Equipment), By Region (North America, Europe, Asia Pacific, South America, Middle East & Africa), And Segment Forecasts, 2021 - 2028,” 2021.
- [19] Markets and Markets, “Recreational Boats Market by Boat Type (Outboard boats, Inboard boats/stern type, Sail boats/Yachts, Personal Watercraft, Inflatable), Power source, Activity Type (Watersports+Cruising, Fishing), Distribution Channel, and Region - Global Forecast to 2027,” 2020.

- [20] Global Market Insights, "Recreational Boating Market Size By Product, By Engine, Industry Analysis Report, Regional Outlook, Growth Potential, Competitive Market Share & Forecast, 2020-2025," 2019.
- [21] Verified Market Research, "Global Boat Market Size and Forecast," 2020.
- [22] IFBSO, "All forthcoming shows ordered by date," [Online]. Available: <https://ifbso.com/shows/all-shows>. [Accessed March 2021].
- [23] T. a. R.Dunn, "Boating- and Shipping-Related Environmental Impacts and Example Management Measures: A Review," *Marine Science and Engineering*, vol. 8, no. 11, 2020.
- [24] C. Depree, "Potential impacts of emissions from outboard motors on the aquatic environment: a literature review," *West Coast Regional Council*, 2007.
- [25] BEIS, "Greenhouse gas reporting: conversion factors 2020," July 2020. [Online]. Available: <https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020>. [Accessed January 2021].
- [26] European Boating Agency, "EBA Position Statement: End of Life Boats," October 2015. [Online]. Available: <http://eba.eu.com/site-documents/eba-position-statements/eba-position-elb.pdf>.
- [27] European Commission, "Large scale demonstration of new circular economy value-chains based on the reuse of end-of-life fibre reinforced composites," 2021.
- [28] IMO, "Reducing greenhouse gas emissions from ships," [Online]. Available: <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx>. [Accessed January 2021].
- [29] IMO, "Draft amendments to the MARPOL convention would require ships to combine a technical and an operational approach to reduce their carbon intensity.," [Online]. Available: <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx>. [Accessed March 2021].
- [30] European Commission, "Communication COM/2020/301: A hydrogen strategy for a climate-neutral Europe," July 2020. [Online]. Available:

https://knowledge4policy.ec.europa.eu/publication/communication-com2020301-hydrogen-strategy-climate-neutral-europe_en#:~:text=Communication%20COM/2020/301:%20A%20hydrogen%20strategy%20for%20a%20climate-neutral,industry,%20transport,%20power%20generation%20

- [31] European Commission, “Europe's moment: Repair and prepare for the next generation,” May 2020. [Online]. Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940.
- [32] RYA, “Recreational Craft Directive (RCD),” [Online]. Available: <https://www.rya.org.uk/knowledge-advice/legal/buying-a-boat/Pages/recreational-craft-directive.aspx>. [Accessed March 2021].
- [33] European Parliament, “Directive 2013/53/EU of the European Parliament of the Council of 20 November 2013 on recreational craft and personal watercraft and repealing Directive 94/25/EC,” December 2020. [Online]. Available: <https://www.legislation.gov.uk/eudr/2013/53/contents>.
- [34] European Boating Industry, “UPDATE ON REVIEW OF THE RECREATIONAL CRAFT DIRECTIVE,” 2021. [Online]. Available: <https://www.europeanboatingindustry.eu/newsroom/newsletter/item/421-update-on-review-of-the-recreational-craft-directive>.
- [35] European Commission, “Targeted Consultation on the Recreational Craft Directive,” January 2021. [Online]. Available: https://ec.europa.eu/growth/content/targeted-consultation-recreational-craft-directive_en.
- [36] Vehicle Certification Agency, “Non-Road Mobile Machinery (NRMM),” January 2021. [Online]. Available: <https://www.vehicle-certification-agency.gov.uk/vehicle-type-approval/non-road-mobile-machinery-nrmm/>.
- [37] British Marine, “Important update on marinised engines,” March 2018. [Online]. Available: <https://www.britishmarine.co.uk/News/2018/March/Important-update-on-marinised-engines>. [Accessed January 2021].
- [38] Transport & Environment, “REDII National Implementation,” January 2020. [Online]. Available: https://www.transportenvironment.org/sites/te/files/publications/2020_01_REDII_general_implementation_briefing.docx_.pdf.
- [39] Department for Transport, “Maritime 2050 Navigating the Future,” 2019.

- [40] Department for Transport, "Clean Maritime Plan," 2019.
- [41] Climate Change Committee, "The Sixth Carbon Budget: The UK's path to Net Zero," 2020.
- [42] BEIS and Prime Minister's Office, "The Ten Point Plan for a Green Industrial Revolution," 2020.
- [43] HM Revenue & Customs and HM Treasury, "Carbon Emissions Tax Consultation," 2020.
- [44] BEIS, "Participating in the UK ETS," 2021.
- [45] Norwegian Government, "The Government's action plan for green shipping," 2019.
- [46] Inland Waterways International, "Amsterdam 2013-2025," [Online]. Available: <https://inlandwaterwaysinternational.org/amsterdam-2013-2025-electrification-of-all-canal-traffic/>. [Accessed January 2021].
- [47] IAmsterdam, "Boating," [Online]. Available: <https://www.iamsterdam.com/en/plan-your-trip/getting-around/boating#:~:text=As%20of%201%20January%202017,there's%20no%20need%20to%20worry.> [Accessed January 2021].
- [48] Safety4Sea, "Amsterdam canal boats go electric ahead of 2025 diesel ban," March 2020. [Online]. Available: https://safety4sea.com/amsterdam-canal-boats-go-electric-ahead-of-2025-diesel-ban/?__cf_chl_jschl_tk__=3b8886553fba9d6646d6e87d9f5ac5223754c3bc-1620980415-0-AUBpZII_u_pD-4WbCvQgOI6LRGGIhrrwPn_R4L4nKGcIn4a_XC-tN_WLVyeWkqx2Awzev4o0ZliUGOcLsLGTmM2fHkmS5mKUm.
- [49] British Marine, "National Environmental Roadmap Part 1," 2020.
- [50] Greenboats, "Material & Technology," [Online]. Available: <https://green-boats.de/materials/>. [Accessed March 2021].
- [51] Yachting World, "The future of yachting: Smart technology for your next yacht," May 2020. [Online]. Available: <https://www.yachtingworld.com/features/future-yachting-smart-technology-126136>.

- [52] Ultimate Boat Company, "Multihull Sailing Yacht," [Online]. Available: <https://ultimate-boats.com/boats/multihull/>. [Accessed March 2021].
- [53] D. Yu and L. Wang, "Hull Form Optimization with Principal Component," October 2018. [Online]. Available: <https://arxiv.org/pdf/1810.11701.pdf>.
- [54] Z. Li and C. Weimin, "Key Technology of Artificial Intelligence in Hull Form Intelligent Optimization," in *International Conference on Mathematics and Artificial Intelligence*, Chengdu, 2020.
- [55] Ancasta, "Development of Foiling – 100 Years in the Making," [Online]. Available: <https://ancasta.com/features-and-articles/the-development-of-foiling-sailboats/>. [Accessed March 2021].
- [56] Renewable Energy Hub, "Solar Panels for Boats," 2020. [Online]. Available: <https://www.renewableenergyhub.co.uk/main/solar-panels/solar-panels-for-boats/>. [Accessed February 2021].
- [57] J. Whiting, "Marine Solar Panels: Compare Solar Panels for Boats," The Eco Experts, May 2020. [Online]. Available: <https://www.theecoexperts.co.uk/solar-panels/marine>. [Accessed February 2021].
- [58] K. Kaven, "Going Solar is an Evolving Option for Boat Owners," Soundings Online, March 2018. [Online]. Available: <https://www.soundingsonline.com/features/solar-powered-boats>.
- [59] Better Boat, "Blowin' in the Wind: The Best Marine Wind Generators," [Online]. Available: <https://betterboat.com/boating/best-marine-wind-generators/>. [Accessed March 2021].
- [60] Sailing Today, "Nine wind generators on test," Gear on Test, [Online]. Available: <https://www.sailingtoday.co.uk/gear/gear-on-test/nine-wind-generators-on-test/>. [Accessed February 2021].
- [61] G. Snook, "Know How: Wind Generators," Sail Magazine, November 2017. [Online]. Available: <https://www.sailmagazine.com/diy/know-how-wind-generators>.

- [62] D. Kent, "Hydrogenerators – on test," *Sailing Today*, [Online]. Available: <https://www.sailingtoday.co.uk/gear/gear-on-test/hydrogenerators/>.
- [63] S. Fortescue, "Know how: Hydro-generators," *Sailing Magazine*, November 2017. [Online]. Available: <https://www.sailmagazine.com/diy/know-how-hydro-generators>.
- [64] Electric Vehicles Research, "Hybrid Propulsion," March 2012. [Online]. Available: <https://www.electricvehiclesresearch.com/articles/4231/hybrid-propulsion>. [Accessed March 2021].
- [65] Electric Boat Association, "History," [Online]. Available: <https://www.electricboatassociation.org/history/>. [Accessed March 2021].
- [66] T. Tveitdal, "Market Barriers Towards Electric Boats," *Norwegian University of Science and Technology*, no. https://www.ntnu.edu/documents/139799/1279149990/33+Article+Final_trulstv_fors%C3%B8k_2017-12-07-17-25-18_TPD4505+Truls+Tveitdal.pdf/4523bd20-1024-4179-8dde-878d847a7e29, 2017.
- [67] IDTechEx, "Electric Boats and Ships 2017-2027: Technologies, Markets, Forecasts, Key Players and Opportunities," 2017.
- [68] Toyota Europe Newsroom, "Toyota Motor Europe's fuel cell module brings hydrogen to the wider maritime industry," February 2021. [Online]. Available: <https://newsroom.toyota.eu/toyota-motor-europes-fuel-cell-module-brings-hydrogen-to-the-wider-maritime-industry/>. [Accessed October 2020].
- [69] Bloomberg NEF, "Lithium-Ion Battery Cell Densities Have Almost Tripled Since 2010," February 2020. [Online]. Available: <https://cleantechnica.com/2020/02/19/bloombergnef-lithium-ion-battery-cell-densities-have-almost-tripled-since-2010/>. [Accessed February 2021].
- [70] Bloomberg NEF, "Battery Pack Prices Cited Below \$100/kWh for the First Time in 2020, While Market Average Sits at \$137/kWh," December 2020. [Online]. Available: <https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/>. [Accessed February 2021].

[71] ABC-Engines, "BeHydro hydrogen dual-fuel engine launched in Ghent," September 2020. [Online]. Available: <https://www.abc-engines.com/en/news/behydro-hydrogen-dual-fuel-engine-launched-in-ghent>. [Accessed February 2021].

[72] Inland Waterways Association, "IWA Vision for Sustainable Propulsion," 2020.

[73] Deloitte, "Fuelling the Future of Mobility: Hydrogen and fuel cell solutions for transportation," 2020.



www.carbontrust.com

+44 (0) 20 7170 7000

While reasonable steps have been taken to ensure that the information contained within this publication is correct, the authors, the Carbon Trust, its agents, contractors and sub-contractors give no warranty and make no representation as to its accuracy and accept no liability for any errors or omissions. Any trademarks, service marks or logos used in this publication, and copyright in it, are the property of the Carbon Trust. Nothing in this publication shall be construed as granting any licence or right to use or reproduce any of the trademarks, service marks, logos, copyright, or any proprietary information in any way without the Carbon Trust's prior written permission. The Carbon Trust enforces infringements of its intellectual property rights to the full extent permitted by law.

The Carbon Trust is a company limited by guarantee and registered in England and Wales under Company number 4190230 with its Registered Office at: 4th Floor, Dorset House, 27-45 Stamford Street, London SE1 9NT.

© The Carbon Trust 2021. All rights reserved.

Published in the UK: 2021