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# Circular economy approach in the maritime industry: Barriers and the path to sustainability

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**Abstract**

The maritime industry lags behind other transportation sectors in the circular economy (CE) approaches and sustainability. Circularity is not well-established in the maritime, and there is a need to "close the loop" to minimise waste and increase the revenue stream. Although recycling contributes significantly to reducing the demand for raw materials, a significant number of parts and equipment from ships are currently underutilized. Therefore, this study aims to; i) identify the barriers to the successful implementation of CE principles in the maritime, ii) reveal the potential benefits of circular applications (6R), iii) briefly present remanufacturing environments in the aviation and automotive industries, and then iv) investigate the current situation and future potential in the maritime through industry investigation, stakeholder interviews and a structured questionnaire.



*Keywords:* Circular economy; remanufacturing; maritime industry; sustainability; ship recycling

## 1. Background

The share of the maritime industry in total world trade is massive. Around 90% of the goods are carried by marine vessels globally (Stopford, 2009). Like all transportation industries, the maritime industry is facing sustainability-related questions and concerns. Following the public and policymakers' pressure, the maritime industry is changing and has pledged to lower its global greenhouse gas emissions by 50% by 2050 (International Maritime Organization, 2018). It is a unique industry that consists of various stakeholders that design, build, operate and scrap the vessels or supply service, governance or equipment to these stakeholders (Milios et al., 2019).

The potential of ship recycling in material recovery is vast, considering that 95–98% of ship materials by weight are recycled (McKenna et al., 2012, Gunbeyaz, 2019).

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However, this number twists the situation and puts the industry in place rather than its actual condition, as most of a ship's weight consists of metals. Moreover, the overall perception of the maritime sector in terms of circular economy is recycling, and the other aspects are mostly overlooked. In fact, recycling is the lowest hierarchy of end of life in a circular economy (MacArthur, 2013, Gilbert et al., 2017).

## 2. Circular Economy Approach

One of the most comprehensive definitions of circular economy (CE) in the literature is "*an economic system in which resource input and waste, emission, and energy leakages are minimised by cycling, extending, intensifying, and dematerialising material and energy loops. This can be achieved through digitalisation, servitisation, sharing solutions, durable product design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling*" (Geissdoerfer et al., 2020). The Circular economy concept emerged as a response to the linear economy (Pearce and Turner, 1990), in which goods are produced from raw materials, sold to end-users, and sent to waste once the economic life ends (Jawahir and Bradley, 2016). On the other hand, the circular economy approach focuses on reusing existing materials rather than using raw materials (Kok et al., 2013), reduces waste, and monitors the consumption of resources with the closed-loop approach (Govindan and Hasanagic, 2018). In the realisation of CE, reduce, reuse, recycle, recover, redesign and remanufacture principles (RRR or 6R) are dominant (Gong et al., 2020).

The circular economy approach focuses on improving the utilisation of the resources and increased value retention and extraction through reuse, repair, remanufacture and recycling (Milios et al., 2019, Tukker, 2015). Resources recovered or retained through these activities minimise raw material, labour, energy and capital, but it also minimises the environmental impact caused, such as CO2 emissions, during the manufacturing operations. In addition to resource preservation and environmental protection, the circular economy is also expected to create economic benefits of 1000 billion US annually. The manufacturing industry would benefit from up to €600 billion (Kalmykova et al., 2018, Grafström and Aasma, 2021).

While the 6R principles have become more prevalent in other transportation industries, such as automotive and aviation, the marine industry presents a mixed overview (Gunbeyaz, 2019, McKenna et al., 2012). Ship recycling is a common practice in the maritime industry (Kurt et al., 2017, Gunbeyaz et al., 2020); however, implementing other CE principles -such as reuse and remanufacturing- is far behind. Low utilisation of reuse and remanufacturing might result from various barriers, including a lack of understanding in the industry. Therefore, after pointing out the benefits of CE, this study aims to define the barriers to successful implementation on the path of sustainability. Figure 1 illustrates the stakeholders and CE principles in the maritime industry.

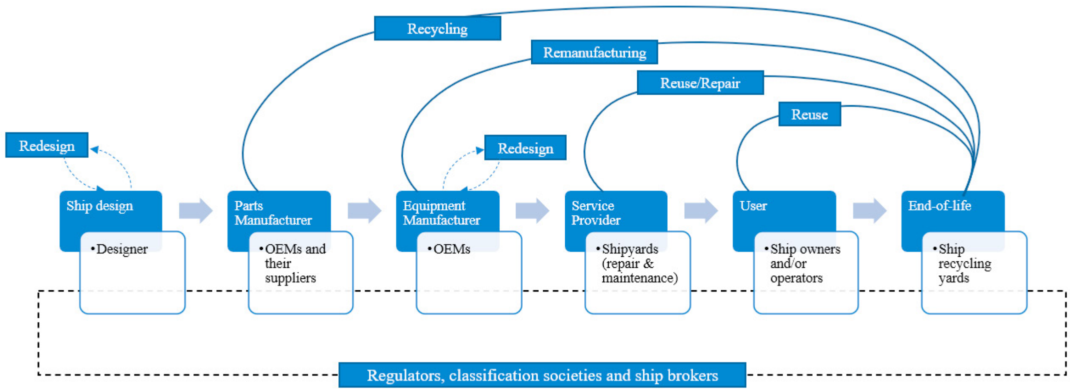


Fig. 1. Maritime stakeholders and CE practices, modified from Milios et al. (2019).

## 3. Benefits of Circular Economy

The circular economy concept offers a lot through 6R, which covers a product's lifecycle entirely - from the design stage to the end-of-life phase. Firstly, CE promotes closed-loop recycling systems where the material goes back to the original same product system (Karvonen et al., 2015). For example, remanufacturing requires a reverse logistics structure to complete the material cycle. Therefore, Jansson (2016) describes remanufacturing as a system that consists of external and internal processes, as shown in Figure 2. The former corresponds to the acquisition of the core components and sales distribution of the reman products (Karvonen et al., 2015), while the latter corresponds to the operation of remanufacturing itself. In this notation, the reverse supply chain part covers the flow of goods from customers and forms the "restorative closed-loop supply chain.

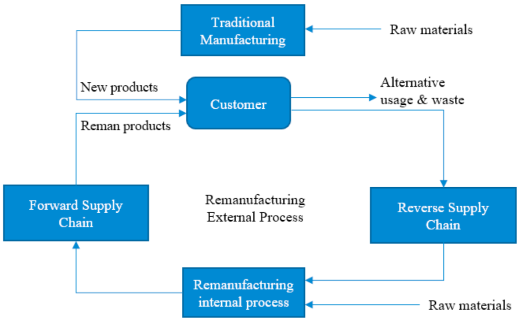


Fig. 2. Forward and reverse supply chains in remanufacturing, modified from Jansson (2016).

Remanufacturing is part of end-of-life strategies and is often referred to as the ultimate form of recycling. While in recycling, large amounts of energy and labour are lost (MacArthur, 2013), remanufacturing saves materials and energy and produces less waste (Karvonen et al., 2015). A recent study by Afrinaldi et al. (2017) demonstrated these benefits through a cylinder block of a diesel engine, confirming an 88-99% reduction in energy consumption, use of material and emissions while saving 39% of costs compared to the production of a new cylinder block. Umeda et al. (2012) suggest that high-performance products (e.g., Caterpillar's engines) can be remanufactured for six or even seven cycles, saving enormous energy and material. Therefore, it can be said that remanufacturing is one of the critical aspects of the circular economy as it provides an opportunity to enhance sustainability for all stakeholders.

There are three dimensions of sustainability. They are commonly referred to as economy, environment and social aspects (Koehler, 2021). And the circular economy approaches, such as remanufacturing, support all these dimensions, leading to a win-win-win scenario where customers need to pay less for the remanufactured products; OEMs or remanufacturing companies earn more; and the need for raw material and energy consumption is minimised (Jansson, 2016). Table 1 below summarises the main benefits derived from circular economy practices.

Table 1. Benefits of CE principles, modified from Jansson (2016).

| Sustainability dimensions | | Benefits | |
|---|---|---|---|
| Economy (customers) | Same original performance and reliability at costs typically only 50-80% of a new | Better availability, more options at repair and overhaul times | |
| Economy (business) | Remanufacturing is based on an exchange system where customers return cores in exchange for our remanufactured products. | Remanufacturing is an additional option to support customers and help lower owning and operating costs. | Profit margins are often bigger for remanufactured products than for new products |
| Environment | Reduce waste and minimise the need for raw material to produce new parts | Keeping non-renewable resources in circulation for multiple lifetimes | Reduces energy consumption and greenhouse gas emissions, and Material and energy savings are up to 90%. |
| Society | Creates many job positions requiring skilled personnel. | | |

Implementing the reuse and remanufacturing can postpone the recycling stage by extending the lifetime of marine equipment or asset, which will help towards energy saving, resource efficiency, and cost and emission reduction. The circular economy principles, especially reuse and remanufacturing, can postpone the recycling stage and reduce the "new-build" need, eventually reducing the gas emissions of production and end-of-life stages. Moreover, this extended life cycle will increase the product's value as well (Stahel, 2013). For shipyards, reuse and remanufactured items are excellent options as they might shorten the lead time of the equipment and the vessel's construction. Moreover, since RRR options will cost much less than newly manufactured alternatives, the yards have a clear economic benefit.

In terms of the shipowners or the final customer, as in other industries, the benefit is the cost reduction for the equipment purchase and extended life cycle. In addition, remanufacturing can save up to 5% to 52% of CO2 while consuming 29-98% less material and 21-55% less energy within the automotive industry (Koehler, 2021) which can be achieved within the maritime industry as well. Considering the size of the elements, it is safe to say that maritime industry benefits would be on a much larger scale.

### *3.1. The situation in other transport industries*

The overall design life of an aircraft is 20 to 30 years (DAC, 2019), followed by storing and/or dismantling recycling stages. However, the overall service lives of aircraft are in decline, as currently, 15 years or newer planes are being scrapped (Keivanpour et al., 2013, Jensen and Remmen, 2017). In the next 20 years, 8,500 to 12,500 planes are expected to reach their end of life (Jensen and Remmen, 2017, Van Heerden and Curran, DAC, 2019). Therefore, many aviation companies have launched programmes to overcome this upcoming challenge. Aircraft Fleet Recycling Association (AFRA) "promotes environmental best practices, regulatory excellence, and sustainable developments in aircraft disassembly, salvaging, and recycling aircraft parts and materials". Since its launch in 2005 by BOEING and ten founding partners, AFRA has dismantled more than 9,000 aircraft while reaching over 40 members, including OEMs, aircraft dissemblers, logistics, insurers, appraisers, recyclers, and technology developers (DAC, 2019, AFRA, 2022). In addition to AFRA, there are other initiatives, such as the PAMELA project (Process for Advanced Management of End-of-Life of Aircraft), the first initiative by Airbus in 2005.

The relationship in overall remanufacturing systems mentioned above can be seen in the aircraft remanufacturing processes, where the manufacturers are heavily involved. It is common to see parts, including engines, avionics, landing gear, and cabin interiors, undergo remanufacture at least once (Wahab et al., 2018). According to Jensen and Remmen (2017), the main challenge of the aircraft industry is the lack of directives, the complexity of the design and the complexity of the stakeholder relationship, which is again similar to the issues of the maritime industry.

Like the aviation industry, the automobile industry is in much better shape than the maritime industry in terms of circularity. Automobile parts remanufacturing is the largest industry globally (Wahab et al., 2018). The average lifetime of vehicles is 10-12 years in the EU, which is very low compared to other transport industries. 6.1 million passenger cars, vans and other light goods vehicles were scrapped in the EU in 2019, totalling 6.9 million tonnes; 95.1 % of the parts and materials were reused and recovered, while 89.6 % were reused and recycled (EUROSTAT, 2021).

Automotive remanufacturing is mainly represented by Automotive Parts Remanufacturing Association (APRA), established in 1941 and reached 1000 members globally in 2016 (APRA). Remanufactured automotive parts include engine blocks, transmissions, alternators, starters, compressors etc. APRA implements remanufacturing as an integral part of the circular economy and represents the industry's interests, including free trade, an independent aftermarket and legal certainty. APRA suggests that remanufacturing should be actively promoted by the relevant stakeholders (politicians, lawmakers and companies). EU's Directive on End-of-Life Vehicles (Directive, 2000) has pushed the manufacturers to green their processes and supply chains and forces suppliers to reuse, recycle, and adopt other forms of recovery for end-of-life vehicles and their components (Masoumi et al., 2019). Authorities and the public have an industry-shaping power in terms of regulations, limitations, rules in general, and purchasing preferences, unlike the maritime industry. In Automobile Industry, remanufacturing has been shown to lower energy consumption by as much as 80% compared to making new parts. The process requires 88% less water and releases about 90% fewer chemicals. This approach can reduce waste dumped by 70% (Rommel, 2018).

Overall, both aviation and automotive industries were able to form global associations to create awareness, share best practices and ultimately increase RRR rates on the path to sustainability. These examples clearly show the importance of cooperation and joint efforts amongst stakeholders worldwide to achieve a more sustainable industry.

## 4. Current situation and RRR potentials in the maritime industry

A maritime circularity-focused questionnaire was designed and carried out within the scope of this study to identify current and potential RRR rates and barriers to the successful implementation of circular economy principles. The target group consisted of shipowner/operator companies, building and repair shipyards, professionals, original equipment manufacturers (OEMs), ship recyclers, classification societies, and local or international authorities. In order to discover the viewpoints of all corresponding parties, the questionnaire is tailored according to the background of the participants. For instance, while an OEM participant would encounter (re)manufacturing capability-focused questions, a shipowner is questioned about their perception of remanufactured components.

While this paper does not cover the entire survey, it does include some of the key questions and responses. Participant distribution according to their organisations is shown in Figure 3a. The experience level of the participants in the maritime industry is relatively high. Only 15% have three years or less experience, while 59% have more than seven years in the sector.

According to an introduction question, 25% of the participants stated that they had never heard of the circular economy concept before this study. The rest, 75% of the participants, affirmed that they had heard it before. Then, they were asked to rate their knowledge of circular economy practices (RRR) in general and in the maritime industry – on average, the participants identified themselves at a medium knowledge level (2.96/5). Only 45% are confident that they have adequate background to successfully implement circular economy applications into the business.

Further in the questionnaire, the reuse-remanufacturing-repurposing-recycling (RRR) potential of engines and hydraulic components onboard vessels is examined. According to participants from various maritime industry stakeholders, these components have significant RRR potential. Thirty-six participants rated main and auxiliary engines with medium, high, or very high potential, while 35 rated hydraulic components the same out of 47 respondents, as shown in Figure 3b.

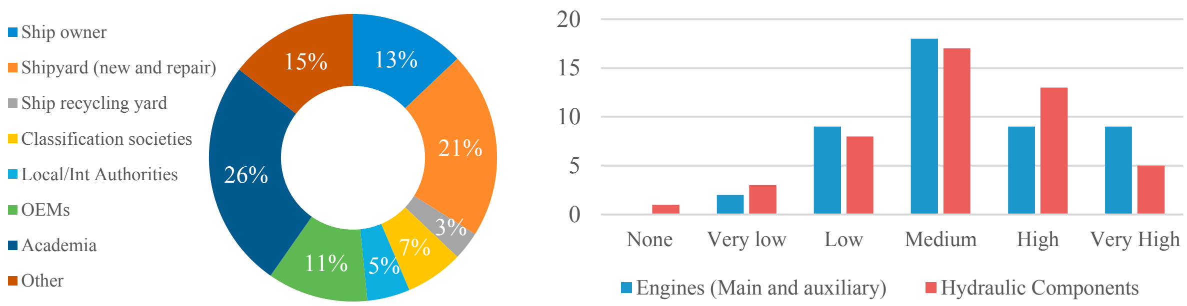


Fig. 3. (a) Percentage-wise distribution of participants 'organisations; (b) RRR potential of engines and hydraulic equipment.

Shipowners/operators, building and repair shipyards, experts from academia, designers and engineering consultants are asked for their opinions on remanufactured components to discover whether they would prefer them. According to their response, only less than a fifth of respondents strictly refused remanufactured options. At the same time, 41.5% stated that it would depend on incentives; another 41.5% found reman components favourable and affirmed they might prefer them. These results reveal a positive perception of remanufactured products at present. And a substantial portion of the industry tends to join that when convenient motivation is provided. In the next step, the respondents' preference for remanufactured products, provided they have the same reliability and quality as newly manufactured components, is further questioned. In this case, 89.5% of the decision-makers strongly expressed that they consider remanufactured products preferable.

Since remanufacturing is strongly associated with the reverse supply chain, checking used or second-hand market conditions is essential. To that end, ship recyclers, OEMs, academia, designers and engineering consultants are asked about the current demand for used components onboard vessels. According to the results, the complete engine is the most in-demand product, scoring high demand overall. Following that, cylinder heads, hydraulic pump & motors, turbochargers, and engine blocks all score medium to high demand. Both high RRR potential declared and considerable demand for used products by the stakeholders indicate that the industry has an appetite for further advancements. If classification societies, regulators and authorities provide the necessary incentives and support, the industry might move towards CE principles such as remanufacturing.

## 5. Barriers in the maritime industry to the circular economy

### *5.1. Low awareness, limited knowledge level and lack of technical expertise*

The overall maritime industry is unfamiliar with the circular economy concept, as the questionnaire shows that 25% of the participants have not heard of the circular economy before. Moreover, the participants' self-assessment shows that those who heard about the circular economy have medium knowledge on average.

Low awareness of the shipyards and recycling facilities directly affects the end-of-life practices of vessels as it is reflected in dismantling methods and reverse supply chain. Currently, yards (both repair and recycle) are not aware of the potential of the items they are dismantling. Milios et al. (2019) suggest that although the system for scrapping the components is well structured, the take-back approach for 6R is non-existent. Our questionnaire shows that it is not non-existent but limited to local capacities (e.g. the used part sales in the Aliaga region through local online platforms). Also, since the current approach does not pay attention to the quality, the equipment left for repair and reuse in the shipyards does not meet technical standards as in remanufacturing by OEMs.

There is a need to improve the ship repair and recycling facility workers' skills for removing components from end-of-life ships without damaging the core products. More than half of the relevant participants (56%) raised this technical expertise gap in the survey. The quality of the items dismantled from vessels is difficult to ensure, which can increase the remanufacturing costs and the difficulty of the processes.

Moreover, to establish reuse or remanufacture applications, a sufficient volume of cores must be collected in good condition (Matsumoto and Umeda, 2011). That is directly affected by the technical capacity and capabilities of recycling yards. Furthermore, since the maritime industry lags behind in practice, maritime OEM manufacturers' remanufacture and rebuild capacities are lacking (apart from the well-known engine remanufacturers, which serve other industries as well), especially compared to other sectors such as automotive. Therefore, there are challenges related to the processes, and the know-how gap might increase the cost and lead times (Milios et al., 2019).

### *5.2. Regulation and certification related barriers (Classification societies, Flag authorities etc.)*

The most critical barrier to the implementation is found in the regulations. The maritime industry is heavily regulated with rules, regulations, and legislation to avoid environmental damage and human health. Ships have to be registered to a Classification society, which regulates the vessel on behalf of the flag state and ensures that vessels' structures and the yard that builds (repairs or refits) the vessel comply with those rules. This is a critical part of the maritime circular economy approach as it directly affects the fate of equipment. As part of their responsibilities, class societies check the certification of every item onboard a vessel, including new, used or remanufactured items. Currently, classification societies do not favour remanufactured items in retrofitting ships and prefer new components (Milios et al., 2019).

In the case of new items, the certification procedure is a standard and straightforward process, it is done by the relevant stakeholders, and generally, there are no issues here. On the other hand, the problem starts when reusing or using remanufactured equipment. This will need to be re-certified by both the classification society and the OEMs before it can be put on board the vessels, which creates a conflict of interest for the original equipment manufacturer and third-party remanufacturer. Classification societies are also reluctant to re-certify used or remanufactured products since there is a lack of knowledge.

Furthermore, since the control over certification belongs to the OEM, OEMs may not decide in favour of the third-party remanufactured parts in the maritime industry. The re-certification costs, requirements and standards are kept high as a deterrent in addition to the actual legal requirements. However, the survey results show that OEMs do not object to third party companies stepping in as long as OEMs provide original spare parts and have the right to inspect and authenticate the finished products.

### *5.3. Long lifecycle of maritime vessels*

One of the unique aspects of the maritime industry is that the average lifespan of the vessels is longer compared to other transport modes, with an average economic life of 30 years (Hiremath et al., 2014). The maritime industry regulations occasionally change to address the world's developments, requirements, or trends. Therefore, a good design ten years ago or a product in line with the previous regulations becomes obsolete following a requirement change. Thus, used products or remanufactured products may not satisfy current regulations. The most obvious example of this problem is the remanufactured engines which are expected to be in the same condition when they were manufactured as brand new products, but remanufactured or reused engines may not satisfy the current regulations in terms of exhaust emissions as a result of the IMO MARPOL (Annex VI) requirements.

Apart from that, due to the long lifecycle, at the end-of-life stage, ship owners end up with outdated components that are no longer suitable for use within the maritime industry. Or, even if it is suitable, the equipment might not be economical to use compared to newer alternatives in terms of operating costs. Design for Remanufacturing (DfRem) can be a crucial element to challenge that; however, currently, there is only limited interest within the maritime industry.

### *5.4. Geographic barriers to reverse supply chain and asset tracking issues*

Today, Asian shipbuilding yards dominate the new-built market, while the scrapping market is dominated by other countries, namely Bangladesh, India, China, Pakistan and Turkey. Therefore, the production and demolition locations are entirely different, which creates the issue of the core collection. There are long distances to cover, and the present reverse supply chain is not developed enough to support 6R principles at this point.

Due to the long lifecycle of vessels, poor standardisation in the industry and a vast range of materials and equipment on board, asset (and onboard equipment) tracking stands as a serious barrier. Milios et al. (2019) state that a shipping company tried to facilitate reuse and recycling effectiveness by mapping the components, but the extensive supply chain made this impossible. Furthermore, this wide supply chain also prohibits effective communication. These two problems cannot be overcome without an industry-wide application and collaboration.

### *5.5. Perception and Industry Acceptance*

Another major challenge in the maritime industry is the perception (or establishing trust in RRR products) of the users (shipowners) or shipyards. Shipowners and shipyards are not in favour of using remanufactured or used items for several reasons. The survey showed that 1/5 of the participants strictly refused the option, while 2/5 asked for incentives. Most shipowners are unaware that remanufactured products come with an extended warranty time. And the survey discovered that 83% of the concerns regarding RRR products are based on reliability and performance concerns, compared to the brand-new options. Hence, the maritime industry's demand for RRR products is still limited. Similar parts are only used in sister vessels as spare parts, and some shipowners buy the same engines from the end-of-life step to dismantle the machine and keep it as a spare part.

## 6. Conclusion

In this paper, main barriers towards circular economy in the maritime industry are discussed and presented. Low awareness, regulation and certification issues, long lifecycles of vessels, long geographic distances between building and recycling yards, technical expertise gaps, perception of remanufactured products amongst shipowners and shipyards, and equipment tracking issues are identified as existing barriers based on stakeholder views. The survey results showed a significant RRR potential in the maritime industry. There is also considerable demand for used products as well, which signals that the industry has an appetite for further advancements regarding CE principles. With proper incentives and support provided by authorities, regulators, and classification societies, industry could progress towards a more circular and sustainable future, as no stakeholder group can achieve circularity on their own.

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