Chapter 7

Renewable Energy Solutions for Commercial Ships

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Abstract

Maritime transportation is a keystone of the global economy, facilitating more than 90% of international trade by a fleet of nearly 90,000 vessels. However, the sector's reliance on fossil fuels brings with it significant environmental challenges, including greenhouse gas emissions, air and water pollution, and impacts on marine ecosystems. To address these issues and increase sustainability, there is a growing trend towards integrating renewable energy sources in the maritime sector. In particular, ocean-going vessels contribute more than 3% of global carbon dioxide emissions, while petroleum-based fuels emit significant amounts of nitrogen oxides and sulphur dioxide. In addition, shipping emissions are a major source of ambient air pollution in coastal areas. Projections indicate a potential 50-250% increase in carbon dioxide emissions from international shipping by 2050 if current trends continue. Renewable energy solutions such as wind, solar and nuclear power offer promising alternatives, with advances in technology increasing their efficiency and affordability. However, the transition to marine renewable energy requires overcoming technological barriers, infrastructure limitations and financial challenges. Despite these barriers, adopting renewable energy sources offers an applicable way to reduce the environmental impacts of shipping and ensure a sustainable future for the industry. This study focuses on renewable energy sources used in commercial ships and discusses alternative solutions such as wind, solar and nuclear energy. Furthermore, by highlighting the potential and advantages of renewable energy sources used on commercial ships, this study can be seen as an important step towards reducing environmental impacts and increasing sustainability in the maritime industry.

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1. Introduction

Shipping plays a crucial role in the global economy, since more than 90% of global trade is transported via oceans by around 90,000 vessels (Kodak, 2022; Pandya, Herbert-Burns, & Kobayashi, 2011). The shipping industry not only plays a significant role in global trade but is also a major contributor to environmental challenges. The use of fossil fuels in ships causes greenhouse gas emissions, pollution of the air and water, and other negative impacts on marine ecosystems. There is a growing trend in the marine industry to employ more renewable energy sources to solve these problems and improve sustainability (Huang et al., 2021).

The increase in transport activity is a natural consequence of the trend toward global integration. Transportation and manufacturing processes are accelerating because of factors including globalization, increased needs and technological developments. Increased usage of machines and vehicles causes environmental damage, especially when fossil fuels are used (Millet, Fidan, & Öz, 2023; OECD (Organisation for Economic Co-operation and Development), 2010; Raza & Ather, 2014). Based on information from the International Maritime Organization (IMO), ocean-going ships are responsible for over 3% of the world's carbon dioxide (CO_2) emissions. 15% of global emissions of nitrogen oxide (NOx) and 6% of emissions of sulfur dioxide (SO_2) are caused by the use of petroleum-based fuels in marine vessels. (Samosir, Markert, & Busse, 2017). Furthermore, in coastal parts of Europe, shipping emissions account for 1-7% of ambient air PM (per million)10 levels, 1%–14% of PM2.5, and at least 11% of PM1. (Stathopoulou, 2021). According to the projections made by the IMO for the year 2050, carbon dioxide emissions from international shipping could increase by 50% to 250%. The extent of this increase depends on factors such as future economic growth and energy development (IMO, 2015). However, it is possible to minimize the consumption of fossil fuels by using renewable energy sources (Millet et al., 2023).

According to the data in Figure 1, when CO_2 emissions from various means of transport are examined between 2000 and 2020, maritime transport accounts for 10.86% of the CO_2 emissions in the total transport sector. (IEA, 2023). Although the amount of CO_2 emissions for maritime transport is lower compared to other sectors such as road transport, it represents a significant share. However, the continued growth in goods transported by sea could lead to a 50% increase in global greenhouse gas emissions if no precautions are taken by 2050. Therefore, if precautions are not taken to decrease greenhouse gas emissions, a possible large increase in emissions from maritime transport may occur (Comer & Rutherford, 2020; IEA, 2023; Tatar & Özer, 2018; Tay & Konovessis, 2023).

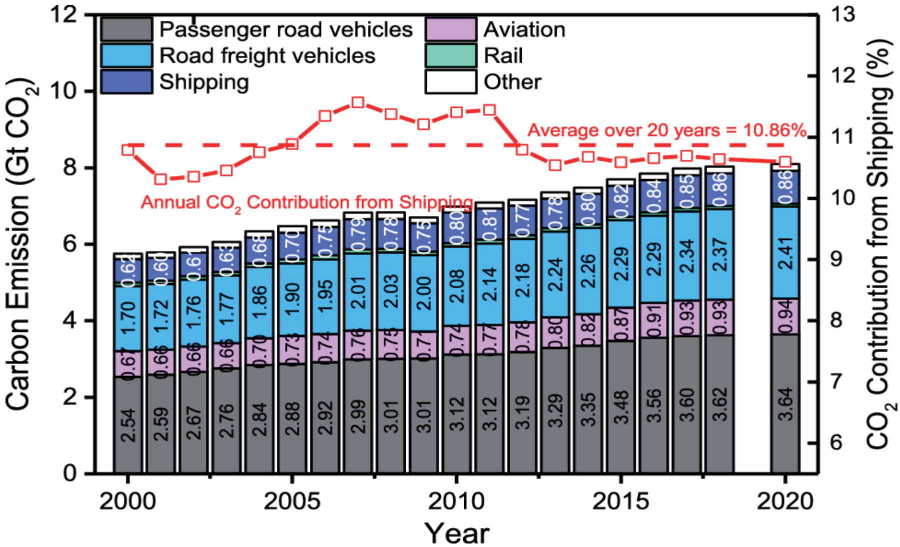

Figure 1. Emissions of carbon from different forms of transportation (IEA, 2023; Tay & Konovessis, 2023)

On a global scale, as of 2019, nuclear energy and other renewable energy sources account for around 19.8% of the world's total energy consumption. Traditional biomass and nuclear energy contribute 8.6% of this scale, while modern renewable energy, which is mostly derived from solar, hydropower, and wind sources, accounts for 11.2% as shown in Figure 2.

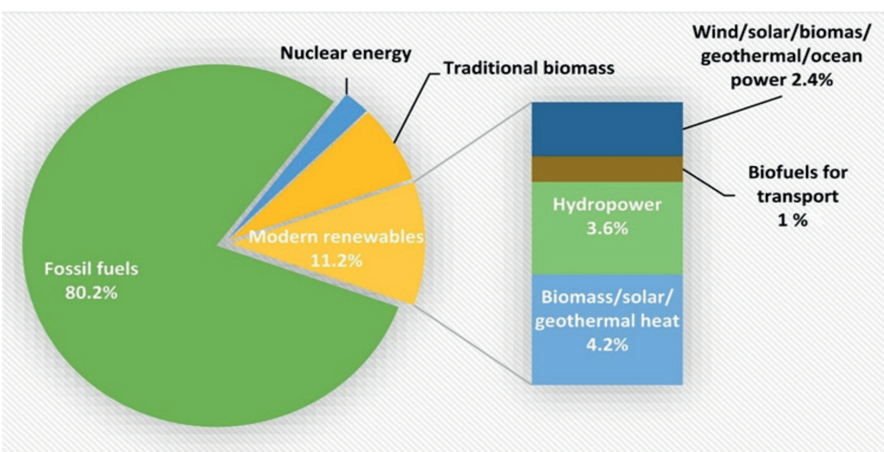

Figure 2. Distribution of energy types in 2019 (Balata, Ahmed, Youssef, & Elgohary, 2023; International Renewable Energy Agency, 2015)

Primary, hybrid, or auxiliary propulsion for onboard and onshore purposes are among the several types of renewable energy solutions for ships that attempt to eliminate the traditional fuel need. Potential renewable energy sources that can be used for vessels include wind energy, solar energy (photovoltaics), biofuels, wave energy, and supercapacitors. (Balata et al., 2023; International Renewable Energy Agency, 2015; Karaca & Dincer, 2023; Margaritou & Tzannatos, 2018)

Considering technological improvements, it is expected that future ships will release fewer pollutants into the environment. However, considering the substantial energy requirements of ships, it is evident that the only way to mitigate the adverse environmental impacts of the shipping industry is through the adoption of hybrid systems employing alternative energy sources. Moreover, research on renewable energy studies for shipboard applications is still in the initial stages and faces significant challenges. (Aijjou, Bahatti, & Raihani, 2019; Margaritou & Tzannatos, 2018)

2. Renewable Energy for Ships

The majority of the energy needs of today are supplied by traditional energy sources such as gas, oil, and coal, all of which have a negative influence on human health and the environment (Kamran & Fazal, 2021). Renewable technologies reduce their negative effects on the environment, generate less secondary waste, and are sustainable because of their capacity (Panwar, Kaushik, & Kothari, 2011).

In many scientific fields, the creation of reliable renewable energy systems remains a primary concern (Chen, Pao, & Yin, 2018; Dincer & Rosen, 2007; Heitz, 2004). This reliability may be achieved by concentrating on selecting an improved technology that is applied properly. Both conventional and renewable energy sources are now used to produce power. Fossil fuels are used to generate conventional electricity, while renewable energy sources, including photovoltaic (PV), wind, and concentrated solar power (CSP), may also provide power. In addition, because nuclear energy is not entirely secure and fossil fuels are running out, renewable energy frequently uses local renewable energy sources and improves local manufacturing capacities. The production of energy by renewable resources is gaining increasing attention worldwide (Kükner & Kaplan, 2017). Based on the REmap 2050 prediction (IRENA, 2019), figure 3 displays the distribution of renewable energy use in terms of total final energy consumption. The marine industry is predicted to employ renewable energy sources at a rate of 2% in the REmap 2050 projections (Gielen et al., 2019).

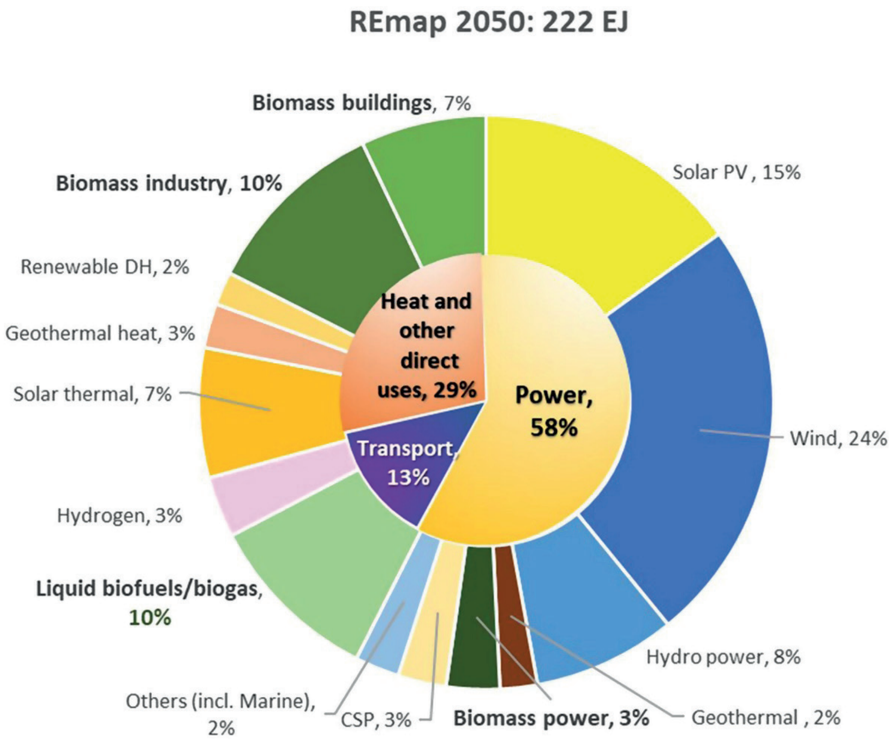

Figure 3. Distribution of the usage of renewable energy according to the final total energy used (Gielen et al., 2019)

Renewable energy propulsion systems, such as wind, solar and nuclear, are frequently employed in ships. These sources of energy are environmentally friendly and generate no carbon emissions. Over time, advancements in the efficiency of these renewable technologies have been notable and substantial cost reductions make them promising and clean alternatives to traditional fossil fuels. Figure 4 shows the main renewable energy types for ships (Yung & Konovessis, 2023).

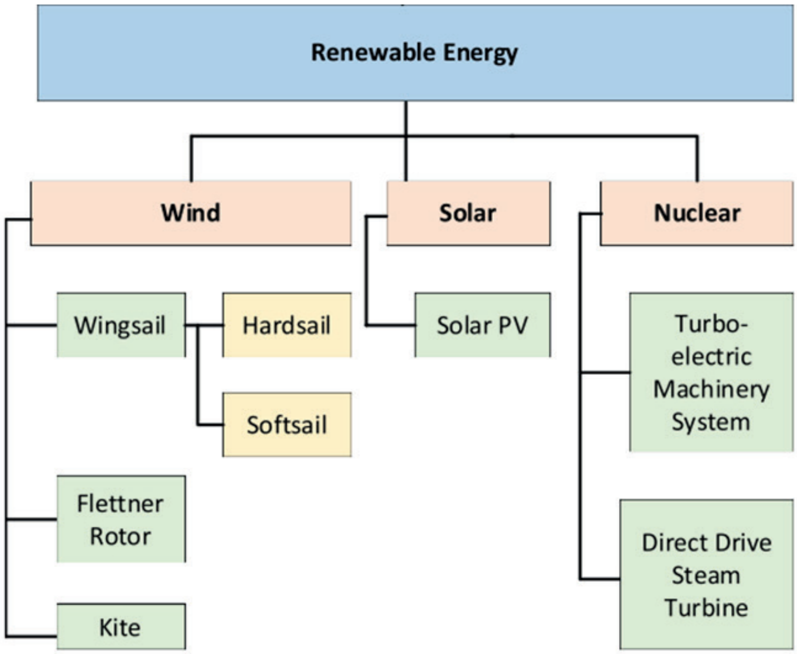

Figure 4. Types of renewable energy for ships (Yung & Konovessis, 2023)

2.1. Wind Energy

The shipping industry, which is one of the biggest and fastest-growing industries in the world, mostly uses fossil fuels as its main energy source. Waves at sea have a permanent presence, which presents an unrealized potential as a sustainable energy source given the inherent character of this sector. Wave energy is easily accessible, although it has not been used significantly in the maritime industry. Wave energy can be a reliable and sustainable alternative to fossil fuels in the maritime sector if used effectively (Balata et al., 2023).

2.1.1. WingSail

Sails for motor vessels can generally be categorized as soft, hybrid and hard sails (rigid sail). Table 1 provides a brief description of sail types and examples (Atkinson, Nguyen, & Binns, 2018)

Table 1. Sail types for motor vessels (Atkinson et al., 2018)

Sail Type	Description	Examples
Soft Sail	A sail made from a lightweight material that deforms, sags and flexes due to the wind forces acting upon it.	Square rigged sail. Sails used on most recreational yachts. All sails used on commercial shipping during the 1800s
Rigid Sail	A sail that is made from a material which does not deform, sag or flex significantly due to the wind forces acting upon it.	Japan Marine Machinery Development Association (JAMDA) sail, Walker WingSail
Hybrid Sail	A sail that includes characteristics of both a soft sail and a rigid sail.	National Maritime Research Institute (NMRI) hybrid sail, DynaRig

Figure 5 from B9 Shipping provides an example of a soft sail ship. This organization is developing an innovative idea to build the first cargo sailing ships that run without using fossil fuels. Their strategy uses an off-the-shelf Rolls-Royce engine running on liquid biomethane made from municipal waste in conjunction with a Dyna-rig sail propulsion system (Lowry, 2017). This innovative design aims to replace traditional bunker fuel with sustainable alternatives for a more environmentally friendly maritime industry (B9 Shipping, 2012).

Figure 5. Soft sail ship (B9 Shipping, 2012)

Figure 6 shows a ship that uses a hard sail system. The primary energy source for this ship is wind, but its wing sails exhibit more similarities to airplane wings than conventional sails. Consequently, aerodynamics plays a crucial role in conceptualizing and developing this innovative design. The wing configuration comprises a main sail and a flap, strategically optimizing aerodynamic forces for enhanced efficiency and performance (Oceanbird, 2022) .

Figure 6. Rigid sail from Oceanbird (Oceanbird, 2022)

In recent decades, hybrid sail concepts have emerged that integrate, design features from both soft and rigid sails. The National Maritime Research Institute (NMRI) hybrid sail, in particular, demonstrated superior performance in lift and drag compared with traditional soft and rigid sails, as indicated by wind tunnel experiments and calculations (Fujiwara, T., Hirata, K., Ueno, M., & Nimura, 2003). This suggests that hybrid sails represent a promising advancement in sail technology, combining the advantages of both soft and rigid designs for improved efficiency (Atkinson et al., 2018).

2.1.2. Flettner Rotor

Anton Flettner invented and demonstrated the Flettner rotor in the 1920s, using the Magnus effect for propulsion as an effective means of reducing fuel consumption and enhancing ship stability in commercial ocean shipping. Despite the effectiveness of the first prototypes, the concept did not receive significant attention at that time, probably because of the lower cost of fossil fuels and the emergence of diesel ship propulsion engineering. However, in the last decade, significant progress has been made, as leading marine designers and researchers have actively studied the modern application of Flettner technology to achieve significant results (Nuttall & Kaitu'u, 2016).

Studies in the literature (Barreiro, Zaragoza, & Diaz-Casas, 2022; Searcy, 2017; F Tillig, Ringsberg, Mao, & Ramne, 2016; Fabian Tillig & Ringsberg, 2019; Fabian Tillig, Ringsberg, Mao, & Ramne, 2018) suggest that Flettner rotors offer significant potential savings and economic appropriateness when installation and maintenance expenses are considered. Fuel savings of as much as 40% are possible, depending on the distance, type of ship and number of rotors involved. Flettner rotors are a major and promising solution for lowering transport emissions because of their ease of use and large savings. (Fabian Tillig & Ringsberg, 2020).

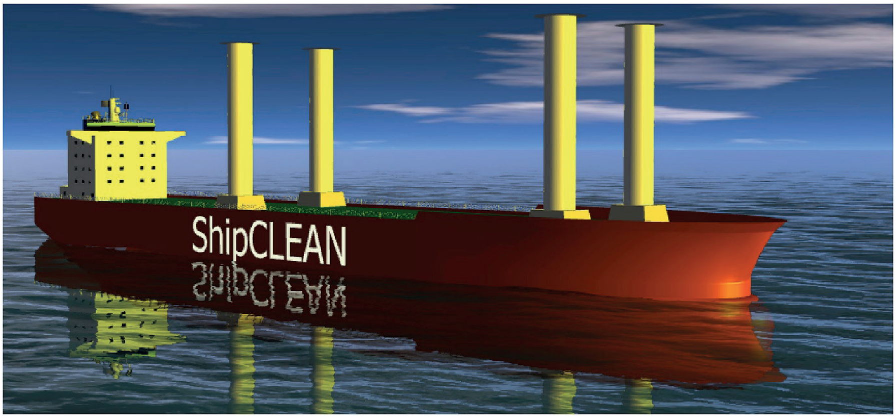

Figure 7. Fletter Rotor system for a ship (Fabian Tillig & Ringsberg, 2020)

2.1.3. Kite

The cleanest and cheapest energy source is offshore wind power. Based on this, a technique was developed that uses wind energy, has a tow kite and attempts to save fuel and cost while lowering pollutants. The ship is propelled by wind power through the automated giant kite system depicted in Figure 8. The system was designed by Skysails GmbH, which was established in 2001. The technology is mostly used on contemporary fishing boats and cargo ships. Research into its suitability for yachts is still ongoing. The sail area, which was initially 6–10 m^2, has grown to 320 m^2, which can now support 2 MW of main engine propulsion power. In the event of favourable wind conditions, the primary engine is supported by the towing kite propulsion system. The towing kite with rope, the control system for automated operation and the release and retrieval system are the three primary parts of the wind propulsion system (Kükner & Kaplan, 2017).

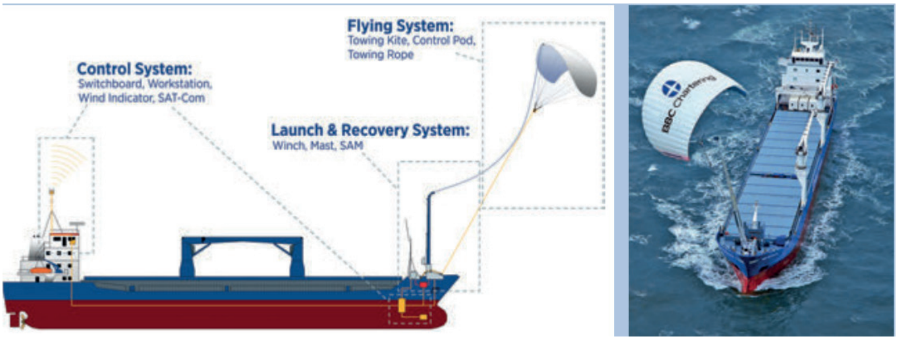

Figure 8. Kite assisted sail (EDT Offshore, 2020)

2.2. Solar Energy

Solar energy is a renewable energy source that might be extremely important in supplying the growing need for energy while preserving the finite supply of fossil fuels. To increase ship efficiency, the use of clean, renewable energy sources, such as solar energy, is suggested. Ships can profit from solar energy because, particularly in tropical areas, most of their top decks are always exposed to the sun (Aijjou et al., 2019).

Shipboard solar photovoltaic technology has progressed and current popular subjects include efficient operation strategies and techniques. This is one of the simplest renewable energy sources to use while on board and will be an essential method to improve a ship's energy structures (Huang et al., 2021).

PV panels are used to generate electricity from solar energy and wind turbines are used to generate electricity from wind energy. Currently, renewable energy sources are reported to be used on ships involved in commercial activities, even though they are still found on ships with low power requirements. Figure 9 shows how solar energy is used on ships (Yiğit, 2018).

Figure 9. Solar energy powered ship "SolarSailor"

2.3. Nuclear Energy

Studies on nuclear sea propulsion began in the 1940s, and the first test reactor in the United States became operational in 1953. The commissioning of the USS Nautilus in 1955 marked the return of nuclear-powered submarines to warships capable of fast cruising for weeks underwater and these developments led to the development of a new generation of nuclear power units such as PWR (pressurized water reactor)-powered submarines and aircraft carriers (Hore-Lacy, 2007).

Particularly for ships that must remain at sea for extended periods without refuelling and for strong submarine propulsion, nuclear power is ideal. According to information provided by (Hore-Lacy, 2007), more than 150 ships are working with more than 220 small nuclear reactors, and a total of more than 12,000 reactor years of naval operations have accumulated; they are mostly used in various applications, from submarines to icebreakers.

A few studies have been conducted on nuclear systems alone or on fossil fuel renewable hybrids and there is a lack of research on nuclear renewable hybrid energy systems for oceangoing marine vessels (Gabbar, Adham, & Abdussami, 2021). According to a study by (Wen et al., 2017), energy storage systems, solar PV, wind energy, hybrid systems with diesel engines and other renewable energy sources might all have a positive economic impact when integrated into maritime vessels.

Figure 10. Nuclear-powered icebreaker Yamal (Wikipedia, 2015)

3. Conclusion

A significant portion of international trade is operated by the shipping sector. However, environmental problems caused by fossil fuels used in this sector pose a significant threat to global environmental health, especially with effects such as greenhouse gas emissions, air and water pollution. In particular, the fact that it corresponds to 3% of the carbon dioxide emissions released by ships into the atmosphere stands out as a problem that needs to be reduced. In this context, the maritime transport sector is showing a trend toward renewable energy sources to increase environmental sustainability and minimize negative impacts. Renewable energy sources such as wind, solar and nuclear energy offer potential solutions to meet the energy needs of ships. Using these technologies, it may be possible to reduce the environmental impact of ships, control emissions and minimize future negative impacts. However, for this transition to be successfully realized, overcoming technological and infrastructural difficulties, financial support and a transformation across the sector are required.

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