

Article

Eco-Trends in Energy Solutions on Cruise Ships

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Abstract: Today the world's largest cruise ships can take on board more than 6000 passengers and almost 3000 crew members. Managing a significant number of people and all equipment and operations on ships requires the delivery of tens of thousands of kilowatts, which poses a huge challenge for both cruise ship builders and ports supporting these ships as well as for ship owners themselves, as the costs involved represent the largest share in the structure of expenditure in cruise shipping companies. In recent years, various communities and institutions, including the International Maritime Organisation and the European Union, exert pressure on cruise ship owners to use green renewable energy solutions. For these reasons, cruise ship owners are constantly looking for cost-effective and environmentally responsible solutions regarding new energy sources for ships. The aim of this paper is to identify modern solutions applied on cruise ships in the field of energy generation and to indicate benefits for the environment and ship owners in this respect. The following research questions were formulated: (1) What factors force cruise ship owners to introduce modern energy policy solutions? (2) What kind of green energy solutions are currently used on cruise ships? (3) What kind of renewable energy solutions do cruise ship owners use to reduce energy consumption on board cruise ships? The research was conducted by applying a few research methods, i.e., desk research method and exploration method, critical and comparative analysis, and also inductive and deductive reasoning. The results of this research can provide an interesting source of information for cruise ship owners, cruise seaport authorities, and shipyards involved in the construction of new vessels.



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1. Introduction

The contemporary cruise ships use the same amount of energy as small cities on land; therefore, they are often called “floating cities”. As much as 60% of energy is used for the propulsion and 40% for the hotel-related activities and operations aboard the ship [1]. For more than a decade, we can observe a tendency to build larger and larger ships, which results in an increased energy demand. At present, the largest cruise ships of nearly 400 m in length and over 40 m of beam can accommodate almost 6500 passengers and nearly 3000 crew members and on-board personnel. Providing hotel and catering services aboard the ships for such a huge number of passengers and offering access to sport and recreation as well as cultural, entertainment, and other related facilities requires adequate amount of electric energy and effective management of processes related to energy supply and transfer. Large cruise ships generate numerous environmental pollutants from the combustion of fuel used for the ships' propulsion but also from waste generated by consumption on board ships.

Cruise ships release various harmful substances into the atmosphere such as: sulphur oxides (SO_x), nitrogen oxide (NO_x), and carbon dioxide (CO₂) and also phosphorus (P₄), soot, heavy metals, and other particulates. As a result of the alarming news on the pollution of the natural environment caused by cruise ships, the legislative solutions have been initiated and introduced, limiting SO_x emission into the atmosphere since, unfortunately, most cruise ships are still powered by heavy fuel oil (HFO). The European Union initiated

directives for the protection of the seas and oceans and sea port areas such as Directive 2012/33/EU of the European Parliament and of the Council of 21 November 2012 [2] amending Council Directive 1999/32/EC [3] as regards the sulphur content of marine fuels. The United Nations International Maritime Organisation (IMO) has estimated that the maritime shipping industry contributes 2.5% to 3.0% of annual human-produced carbon dioxide (CO₂) emissions [4]. IMO introduced sulphur emission limitations in the open sea at 0.5 percent after 2020 and 0.1 percent [5] (pp. 253–255) in special emission control areas (ECAs), which include the Baltic Sea, the North Sea/English Channel, some waters surrounding the North American coast, and Puerto Rico and the U.S. Virgin Islands [6] (p. 17). Ships operating in these sulphur ECAs have been required to reduce their emissions' sulphur content to 0.1%. In these circumstances, ship owners have three options to choose from i.e., (1) switch to low-sulphur fuel, (2) continue to use heavy fuel oil and install scrubbers, and (3) switch to liquified natural gas to limit the negative impact on the environment and greenhouse effect.

In addition, the control of diesel engine NO_x emissions is based on IMO regulations, i.e., 13.8 and 5.3.2 NO_x Technical Code 2008 (resolution MEPC.177(58) as amended by resolution MEPC.251(66)). Different levels of control are based on the ship construction date and the engine rated speed (Table 1).

Table 1. The NO_x limits according to MARPOL * Annex VI [7].

Tier	Ship Construction Date On or After	Total Weighted Cycle Emission Limit (g/kWh) <i>n</i> = Engine's Rated Speed (rpm)		
		<i>n</i> < 130	<i>n</i> = 130–1999	<i>n</i> ≥ 2000
I	1 January 2000	17.0	$45 \cdot n^{(-0.2)}$, e.g., 720 rpm–12.1	9.8
II	1 January 2011	14.4	$44 \cdot n^{(-0.23)}$, e.g., 720 rpm–9.7	7.7
III	1 January 2016	03.4	$9 \cdot n^{(-0.2)}$, e.g., 720 rpm–2.4	2.0

* MARPOL (International Convention for the Prevention of Pollution from Ships) is the convention containing Annex VI (Prevention of Air Pollution from Ships, which entered into force in May 2005).

In accordance with MARPOL Annex VI Regulation 13, procedures concerning the compliance of a ship engine with the emission standards for NO_x are certified with the Engine International Air Pollution Prevention Certificate (EIAPP) [7].

Cruise ship owners must also respect the IMO 2015 Guidelines for Exhaust Gas Cleaning Systems, which outlines requirements for the testing, certification, and verification of EGCS, including wash water discharge and monitoring criteria. The use of the SO₂ (ppm)/CO₂ (%) ratio method simplifies the monitoring of SO_x emission and facilitates the approval of an EGC unit [8] (Table 2).

Table 2. Fuel oil sulphur limits recorded in regulations 14.1 and 14.4 and corresponding emission values [8].

Fuel Oil Sulphur Content (% m/m)	Ratio Emission SO ₂ (ppm)/CO ₂ (% v/v)
4.50	195.00
3.50	151.70
1.50	65.00
1.00	43.30
0.50	21.70
0.10	4.30

Cruise ship owners look for solutions that would ensure safety of supply and would be ecological [9] (pp. 2417–2431) and economically effective as well as socially responsible [10] (pp. 56–65). The costs of energy represent the highest costs in the structure of cruise line ship owners' budgets and constitute a huge management challenge. The Earth's climate has changed dramatically in recent years, which caused violent unforeseen weather disasters. That is why we have observed the trend to live following the so-called "eco" idea, which

should be understood as living according to nature, without harming the natural environment, in accordance with sustainable development. The term “eco” is an element of words related to environment protection (ecology), with eco-life, eco-food, eco-consumption, eco-leather with eco-tourism, and renewable energy (eco-energy) etc. The word *eco* as you can see is now used in all areas of human life. Eco has become fashionable and is promoted by various social and economic environments. Companies want to be seen as socially and ecologically responsible. The maritime economy is also a part of this trend. It can, therefore, be said that compliance with the principles of respect for the environment is in line with the idea of eco-trends. In the tourist sector it has been prepared a Green Tourism Supply Chain Management (GTSCM), which refers to activities related to the tourism industry and its impact on the environmental deterioration and climate change [11].

Sometimes the word *eco* is equated with the word *green*, especially when it comes to business. In literature, there are terms such as *green energy*, *green economy*, *green industry*, etc., which should be considered as doing business with respect for environmental protection. “*Green energy*” is any energy type that is generated from natural resources, such as solar energy, wind power, geothermal energy, biomass, and hydroelectric power. It often comes from renewable energy sources although there are some differences between renewable and green energy” [12] because not all sources that are used by the renewable energy industry can be considered as *green energy*. *Green energy* means “without any losses for the environment”, but *renewable energy* is a wider term also including those activities that can have an impact upon the environment, for example a hydroelectric dam, which may divert waterways and have an impact upon the local environment [12].

The world’s largest cruise shipping companies are the leaders in the world in introducing eco energy solutions aboard the ships. The latest trends include solutions with the use of renewable sources of energy, i.e., wind—wind power plant, water—water turbines, and sun—photovoltaic panels. All these solutions are already being applied aboard cruise ships. Another important trend involves installing electric engines, which are less harmful to the environment, and LNG 4 engines [3]. The use of modern engines can generate savings in energy consumption by even 25%, which generates measurable benefits for ship owners.

The aim of this paper is to identify modern solutions applied on cruise ships in the field of energy generation and to indicate benefits for the environment and ship owners in this respect. The following research questions were formulated: (1) What factors force cruise ship owners to introduce modern energy policy solutions? (2) What kind of green energy solutions are currently used on cruise ships? (3) What kind of renewable energy solutions do cruise ship owners use to reduce energy consumption on board cruise ships?

2. Materials and Methods

The studies were conducted by using a few research methods, i.e., desk research method and exploration method, critical and comparative analysis, and also induction and deduction reasoning. The analysis involved the internal materials from three largest shipping companies in the world, i.e., (1) Caribbean Corporation & plc (CCL), (2) Royal Caribbean Cruises Ltd. (RCCL), and (3) Norwegian Cruise Line Holdings Ltd. (NCL). The annual reports were analysed as were management reports, press reports, and previous reports on studies and analyses of the cruise ship tourism market.

3. Results

3.1. Energy Solutions Aboard Cruise Ships

At present, around the world we can observe a tendency to build giant cruise ships. All the world’s leading cruise shipping companies, which include Caribbean Corporation & plc (CCL), Royal Caribbean Cruises Ltd. (RCCL), and Norwegian Cruise Line Holdings Ltd. (NCL), already own such cruise ships and have additionally placed orders for more such ships.

Every cruise ship requires enormous amounts of energy. Energy is used to power ship’s engines, entire equipment responsible for cooling the systems, air-conditioning,

water heating (in bathrooms, swimming pools, and in the kitchen), water purification, potable water treatment, power supply for passenger and freight elevators, electronic devices, garden watering systems, room heating, coolers (in food storages, cabins, and kitchens), and also to power lightning in cabins and hotel facilities and public spaces or all units operating aboard the ships (kitchen, warehouse, laundry, spa centres, entertainment, sport and recreation facilities, etc.).

The ships powered in a traditional way use various drive models, including, most frequently, diesel engines, which are powered through diesel fuel ignition. The other very popular drive is a diesel electric engine connected to generators producing electric energy. Ships are also powered by gas turbines, believed to be a more ecological drive system [13].

The largest cruise ships in the world, for example Allure of the Seas and Oasis of the Seas (Table 3) owned by the Royal Caribbean Cruises Ltd. use fuel for the main engine in the amount of 5.2 cubic meters of fuel oil per engine per hour for the 16-cylinder engines and 3.9 cubic meters per engine per hour for the 12-cylinder engines [14].

Table 3. Technical data of the largest cruise ships in the world, owned by the leading cruise shipping companies [14–17].

Name of Ship	CCL		RCCL		NCL	
	Carnival Mardi Gras	Carnival Panorama	Allure of the Seas	Oasis of the Seas	Norwegian Escape	Norwegian Bliss
Capacity	6500	5140	6780	6780	4266	4002
Crew	2000	1450	2200	2000	1733	1700
Gross Tonnage	181,808	133,868	225,282	225,000	165,157	168,028
Length	340.0 m	323.0 m	362.0 m	361.0 m	325.9 m	333.0 m
Beam	42.0 m	48.0 m	60.5 m	47.0 m	46.5 m	41.0 m
Decks	19	15	16	15	20	20
Installed power		MAN Diesel and Turbo 3 × 81.84/60CR + 2 × 14V48/60CR generating sets 61.4 MW (83,700 hp)	3 × Wärtsilä 12 V engines each 13,860 kW 3 × Wärtsilä 16 V engines, each 18,480 kW	3 × Wärtsilä 12 V engines each 13,860 kW 3 × Wärtsilä 16 V engines, each 18,480 kW	2 × MAN 14V48/60CR (2 × 16,800 kW) 3 × MAN 12V48/60CR (3 × 14,400 kW) 1 × Cat 3516C DH (1 × 2500 kW) 2 × ABB Azipod XO units (2 × 20 MW)	2 × MAN B&W 14V48/60CR 3 × MAN B&W 12V48/60CR
Propulsion	Azimuth Electric Propulsion Drive (2 × 37MW)	2 × ABB Azipod (2 × 16.5 MW)	3 × ABB Azipod, all azimuthing (3 × 20 MW)	Asea Brown Boveri Azipod, all azimuthing (3 × 20 MW)	3 × Brunvoll AS FU 115 LTC3000 thrusters (3 × 3.5 MW)	2 × ABB Azipod XO units (2 × 20 MW)

Approximately 97 MW is used by the hotel sector for the purpose of lightning, electronic equipment, elevators for guests or catering services, and also for cleaning the water used by the hotel guests. The propulsion on these ships is provided by three 20 MW Azipods, ABB's brand of electric azimuth thrusters [18]. It should be noted that electric power system Azipod[®] made by ABB installed on ships reduce fuel consumption by as much as 25% [19,20].

In the face of modern-world challenges, deteriorating natural environment, and increasingly stricter regulations on pollution emitted into the environment, the shipping company managers meet new challenges related to looking for pro-ecological operational strategies.

3.2. New Trends in Energy Solutions on Cruise Ships

Nowadays, cruise ship owners are very open to various new solutions that enable harvesting energy from renewable sources. Consequently, the recently ordered cruise ships are equipped with hybrid engines; electric propulsion systems; solutions combining solar panels, wind, and liquid natural gas energy, or photovoltaic panels; or equipment for collecting energy from wind farms located in the ports or wind farms, and also with

engines emitting less SO_x into the natural environment. Such investments are cost intensive but economically efficient in the long term. Moreover, in this way, ship owners care about their appropriate image among clients, posing as the “leaders of ecology”, “pro-ecological cruise lines”, “ecologically responsible cruise lines”, etc.

The companies also look for innovative solutions applied in other sectors. In recent years, it has become popular to install LNG engines or battery technology and also to use fuel cell technology or a wind turbine electric plant, or even several solutions at the same time.

Apart from the solutions related to the replacement of engines and power sources on cruise ships, ship owners, looking for savings regarding energy costs, decide to make investments in the installation of collectors on sunny parts of a ship and to run optical fibres down to cabins from the collectors [21]. At present, on the market, there are various collectors used on ships, e.g., SP4-4, SP4-6, SP4-8, SP4-12, SP4-20, differentiated by parameters such as, width (from 1100 to 1950 mm), height (from 880 to 1180 mm), weight (from 50 to 85 kg), and number of wires (from 4 to 20). For one cabin with a bathroom, it is sufficient to provide only three cables [21–23]. Therefore, such solutions are more frequently used on currently operating vessels.

In order to find energy savings and reduce the related costs, LED luminaires (cost reduction by approximately 15% to 20%) and solar lighting are applied in the cabins. Furthermore, in terms of savings in energy consumption, [21–23] it is also important to select appropriate electric equipment for the cabins, i.e., TV, coffee machine, electric kettle, fridge, and hair dryers for bathrooms. The cruise line managers more frequently choose energy-saving devices, which make it possible to save 20% to 30% of energy. Interesting solutions regarding the efficient power sources for the equipment in cabins are applied for fridges, i.e., instead of absorption cooling, chilling water network chillers are applied to produce the cooling. It allows to save up to 90% of energy consumption [21].

A significant issue to settle involves outdated technologies for the heating and ventilation systems on ships. They became particularly important in 2020 with the outbreak of the COVID-19 pandemic. Therefore, cruise ship owners were somehow forced to invest in this area. On many older vessels, a fan coil is used in the cabins, but for several years, modern vessels introduce technologies, such as the active chilled beam, which eliminate need of a fan in the cabin [21].

The cooling of passenger cabins also consumes large amounts of energy since they heat up from the sun rays. A solution that may help to reduce the amount of energy for cabin cooling with air-conditioning systems may involve using adequate glass in large balcony windows. Unfortunately, such windows are more expensive, heavier, and darker, which significantly reduces the cabin viewing quality, which is a matter of concern to the ship’s passengers. Nevertheless, cruise line managers decide to introduce such solutions to reduce the ship’s operating costs and, thus, the cruises’ ticket prices.

Photovoltaic panels are more frequently used to harvest energy from renewable sources. Unfortunately, photovoltaic panels are not very aesthetic; therefore, ship designers have serious issues with their location in order to not destroy the beauty of the ship. Furthermore, at present, the photovoltaic panels produce only 168 W/m^2 , i.e., not much, if we take into account the ship’s size and the volume of energy consumption generated at least by the hotel section aboard the ship (4 MW) [21]. However, despite the low effectiveness, the cruise line managers decide to introduce such solutions because of their significant marketing leverage.

Moreover, in order to find savings in energy consumption, sensors and other automatic solutions are installed in the cabins, turning the equipment off when the cruise traveller leaves the cabin.

On the market, there are also new solutions that could support the process of harvesting energy for cruise ships, such as vertical wind turbines, which use the so-called Magnus effect, i.e., a spinning ball or cylinder travels through air generating a pressure difference and, thus, a force affecting the object. At the moment, such solutions are not yet

very popular on cruise ships, but everything indicates that on new vessels such solutions will be applied in the near future.

3.3. New Trends in Engine Solutions on Cruise Ships

Liquefied natural gas (LNG) is a non-toxic liquid coming from natural gas cooled to $-162\text{ }^{\circ}\text{C}$ ($-260\text{ }^{\circ}\text{F}$), and it is the cleanest-burning fossil fuel [18]. Since this fuel is much more accessible and much less harmful to health and environment, it is more often used in maritime transport, including the cruise ship tourism sector. Unfortunately, this fuel is more expensive than others, which constitutes a serious issue for many ship owners who are looking for other solutions [24]. The first ship powered by LNG fuel was introduced in 2000. Since then, about 80 such vessels have been launched, and some dozens of new ones have already been ordered [18].

In parallel, intensive works are underway to install electric propulsion systems on ships [20], as auxiliary systems. It involves numerous benefits for the natural environment, i.e., decreased emissions of NO_x , SO_x , and PM and significant reduction of noise and vibration levels [18]. However, regrettably, the present technologies do not yet allow the use of pure electric propulsion on cruise ships, and these solutions are only applied in hybrid ships.

Recently, the fuel cell technology applied on ships is gaining in popularity [20]. The two largest entities on the market, i.e., CCL and RCCL, already use these solutions successfully. The report provided by DNV GL commissioned by the European Maritime Safety Agency (EMSA) indicates that, in the cruise ship tourism sector, the most frequently used solutions include fuel cell technologies such as (1) the alkaline fuel cell (AFC), (2) the proton exchange membrane fuel cell (PEMFC), (3) high-temperature PEMFC (HT-PEMFC), (4) direct methanol fuel cell (DMFC), (5) phosphoric acid fuel cell (PAFC), (6) molten carbonate fuel cell (MCFC), and (7) the solid oxide fuel cell (SOFC) [18].

Unfortunately, the engines cannot be replaced on all ships used by the shipping companies due to construction issues and financial limitations; therefore, ship owners take other actions for reducing sulphur oxide (SO_x) emissions from maritime vessels [18].

A quite popular option, used by all cruise lines in the world, includes the exhaust gas cleaning (EGC) system. The EGC system has become an integral part of reducing emissions emitted by vessels globally.

Due to the fact that, unfortunately, on older vessels, the engines cannot always be replaced, the only solution to adjust to the compulsory legal regulations involves applying gas cleaning systems to reduce sulphur oxide (SO_x) emissions from maritime vessels [18].

Following the introduction of the IMO regulations, all the world's three largest cruise companies decided to use heavy fuel and planned to install scrubbers on the majority of their ships [18].

3.4. Good Practices in Energy Solutions Applied by the World's Cruise Shipping Companies

All of the above-mentioned solutions are being introduced to a greater or lesser extent on various cruise ships owned by the leading cruise shipping companies. The regulations limiting SO_x emissions to the environment, introduced by the IMO, forced cruise line managers not only to invest in the existing fleet of ships but also to look for new solutions. Large shipping companies are looking to the future, ordering new vessels in an effort to ensure low pollution emissions to avoid further investment in the future. At present, the CCL fleet provides 85 vessels powered by heavy fuel oil, which have been installed with scrubbers; 13 powered by low-sulphur fuel; and 2 by LNG. Meanwhile, the RCCL fleet has 13 ships powered by heavy fuel oil, which have also been installed with scrubbers, and 29 powered by low-sulphur fuel. Moreover, the NCL has 11 cruise ships powered with heavy fuel oil and installed with scrubbers and 13 cruise ships powered by low-sulphur fuel. Neither CCL nor RCCL provide LNG-powered vessels in their fleet (Figure 1).

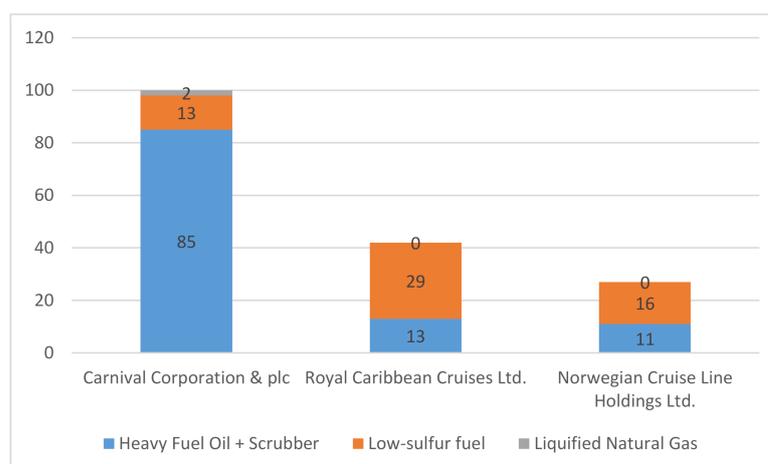


Figure 1. Cruise line fuel choices for cruise ships [13].

Carnival Corporation & plc declares that they follow the International Convention for the Prevention of Pollution from Ships, MARPOL [25]. Moreover, they emphasise that all their ships in the fleet have certificates that confirm they meet the regulations related to the protection of natural environment, i.e., an International Oil Pollution Prevention Certificate, an International Sewage Pollution Prevention Certificate, an International Air Pollution Prevention Certificate, and a Garbage Management Plan [25] (p. 21).

CCL is proud to have achieved the exhaust reductions, i.e., in 2020, they achieved 29.1% reduction relative to 2005. The following are the greening activities used by CCL in relation to harvesting energy [26]:

- provided ships powered by LNG fuel both at sea and in port,
- joined the Getting to Zero Coalition for decarbonisation,
- invested in fuel cell technology, and
- invested in battery technology.

In 2019, CCL signed an agreement with Corvus Energy aimed to install batteries on the CCL ships in 2020 [26]. Moreover, from 2021, they plan to test new solutions, i.e., fuel cells on a large passenger ship (powered by hydrogen derived from methanol). This solution causes reductions in carbon emissions, noise, and vibrations [26] (Table 4).

Table 4. Eco-energy solutions on cruise ships in the world’s largest cruise shipping companies [27–30].

Type of Solution	Carnival Corporation & plc	Royal Caribbean Cruises Ltd.	Norwegian Cruise Line Holdings Ltd.
Next-generation liquefied natural gas (LNG)-powered cruise ships	X	X	
ABB Azipod XO electrical propulsion system			X
Wind turbine electric plant (the Reading Wind Facility in Kansas)		X	
Battery technology	X		
Vertical wind turbines on board (Magnus effect)	X	X	X
Photovoltaic (PV) panels installed	X	X	
Replacement of incandescent bulbs with fluorescent ones		X	X
Lighting by LED luminaires	X	X	X
Collectors on sunny parts of a ship			X
Chilling water network chillers to produce cooling		X	

One of the latest investments of CCL is the purchase of a ship named Mardi Gras, which is the largest Carnival Cruise Line ship ever constructed and the first in North America that is powered by liquefied natural gas (LNG) [29,31]. This type of vessel is included in the next-generation “green cruising” ship design. CCL is introducing Bio-LNG on their ships, i.e., biofuel made by processing organic waste flows. This type of fuel is practically neutral to the natural environment, and engines powered by this type of fuel are quieter and are characterised by lower NO_x emission. Thanks to the cooperation

with Shell, the CCL management hopes that, in the near future, all cruise ships, especially those operating in North America, will be powered by LNG [26]. In 2018, CCL introduced the first cruise ship in the world powered by LNG; another nine have been ordered until 2025 [26]. Moreover, for several years, CCL has been introducing the exhaust gas cleaning technology on more than 70 vessels [18].

The introduction of new solutions on cruise ships is also a major challenge for seaport management whose infrastructure is not adapted to the new developments. For example, the fact that CCL has been introducing new cruise ships powered by LNG resulted in the port of Canaveral in Florida investing in a new LNG bunkering barge, the Q-LNG 4000, aimed to supply the alternative LNG fuel [15].

CCL has also been awarded several times for their activities dedicated to the protection of natural environment, e.g., “Greenest Ship owner of the Year” Neptune Award, Germany’s Blue Angel Award, and *Newsweek*’s 1st Ranking of America’s Most Responsible Companies 2020.

As the main competitor of CCL, Royal Caribbean Cruises Ltd. (RCCL) has introduced similar ecological solutions on their ships. The investments are very capital-intensive, but the long-term benefits will compensate for the expenditure. It should be noted that RCCL owns the largest cruise ships in the world (Table 3), i.e., Oasis of the Seas (361 m, 6780 PAX) and Allure of the Seas (362 m, 6780 PAX). The energy demand on these vessels is huge, and it is certainly related to significant emissions of harmful substances into the environment. As stated above, 4.2 million tons of greenhouse gases emitted into the environment annually comes from the RCCL ships. Consequently, RCCL plans to reduce greenhouse emissions by 35%, according to its 2017 Sustainability Report [28]. To this end, they signed a cooperation agreement and financed the construction of Reading Wind Facility, using 62 wind turbines with up to 230-foot blades, able to produce 760,000 megawatt hours of electric energy annually. Pursuant to the agreement, they will use energy from wind farms up to 2032 [28].

RCCL has also decided to install fuel cell technology on ships “Fuel cells generate energy by exploiting an electrochemical reaction at the interface between the anode or cathode and the electrolyte membrane. They involve no combustion, converting fuel directly to electricity and heat” [27].

In the context of energy saving, RCCL has introduced the following solutions aboard their ships [32]:

- energy management software, an industry first, to achieve top fuel efficiency;
- air lubrication systems to reduce drag and increase fuel efficiency;
- the use of energy-efficient equipment in galleys;
- the replacement of incandescent bulbs with fluorescent ones; and
- LED lighting.

Moreover, RCCL is also planning to use new fuels in their ships, such as liquefied natural gas; the first such vessels will begin operating in 2022 and 2024 [18].

The third important entity on the cruise shipping market, the Norwegian Cruise Line Holdings Ltd. (NCL), also does not lag behind when it comes to solutions for the protection of the natural environment and green energy. They also declare that they respect the provisions of the MARPOL Convention and that all ships in their fleet meet the strict requirements regarding exhaust emissions [33] (pp. 21–45). In fact, NCL is perceived in the world as the forerunner of pro-ecological solutions applied aboard cruise ships. Norwegian Bliss is fitted with the highly efficient ABB Azipod XO electrical propulsion system with an electric-drive motor housed inside a submerged pod [19].

The most important goals defined by NCL regarding actions for the protection of natural environment include [34]:

- fuel and energy efficiency,
- trying to equip cruise ships with cold-ironing capabilities,

- establishing a KPI based on the data collected from ships and identifying areas where improvements in energy savings could be made,
- committing to use of the Shipboard Energy Efficiency Management Plan (SEEMP) and improving voyage planning and other areas where energy savings could be achieved, and
- wasted heat recovery (WHR).

The Exhaust Gas Cleaning System (EGCS) allowing to reduce SO_x emissions even by 99%. From December 2020, the system has been applied on 11 NCL ships, including, e.g., the Norwegian Bliss, Norwegian Encore, Norwegian Epic, and others. NCL has also been investing in preparing ships to be connected to the onshore electrical power grid when the ship is docked. Regrettably, there are still very few ports in the world with infrastructure adapted to such solutions. NCL already has six vessels equipped with this technology. They have also taken action to optimise the energy consumption and to this end, the SEEMP has been developed, identifying issues related to the optimisation of ship propulsion and electrical equipment aboard the ships. NCL is also proud of the program called wasted heat recovery (WHR) for improving water production and saving fuel [34].

3.5. Factors Determining the Introduction of New Energy Solutions Aboard Ships

The observation of measures taken by the leading shipping companies has indicated that, recently, they have invested significant resources in environment protection solutions and in searching for new energy sources for their ships.

The cruise shipping companies are aware of the effects [35] of such significant SO_x emission [36] generated by cruise ships for the natural environment [37] and take strategic actions to reduce the level of exhaust emissions by introducing various ecological solutions in this respect. An average large cruise ship usually use up to 250 tons of fuel per day [38], which is around 80,000 gallons [39]. Unfortunately, the statistics also indicate that cruise ships owned by the leading shipping companies in the world emit huge amounts of harmful substances, e.g., ships in the RCCL fleet emit more than 4.2 million tons of greenhouse gases [40] annually.

The factors forcing ship owners to take action to introduce new energy supply solutions for cruise ships include the following:

- legal factors, i.e., local, national, and international legal restrictions on environmental protection and the reduction of harmful substance emissions into the environment;
- economic factors relating to the search for cheaper energy technologies and the reduction of energy consumption by ship engines and operational activities aboard the ships related to the consumption of energy by cruise travellers;
- social factors, i.e., pressure exerted by coastal communities and various international environmental organisations, the fashionable *eco trend* in the economy, shaping the image of modern cruise lines as socially and environmentally responsible, the desire to stand out from the competition, etc.; and
- organisational and technical factors—it means that, currently, a great number of cruise ships are equipped with old technological solutions that are inefficient and harmful to the environment, therefore cruise ship owners search for eco-solutions to adjust emissions of harmful substances to legal requirements.

On the other hand, taking into account economic factors, it is worth pointing out that cruise ship owners look for more economically effective energy sources for the newly built ships, and they try to reduce energy consumption by older generation ships with the aim of looking for savings. Moreover, they search for new solutions introduced by competitive cruise shipping lines.

Recently, it has also become fashionable to run business according to *eco trend*, that is the reason why cruise ship owners introduce policies of shipping companies aimed towards sustainable development and renewables source of energy and care for developing the ecologically responsible and innovative cruise line image. They also emphasise that

they are socially responsible, and in their actions regarding ecological energy solutions aboard cruise ships, they meet communities' expectations in coastal destinations.

In recent years, port city authorities and local communities have expressed their concerns about air quality and threats to the natural and cultural environment caused by giant cruise ships visiting their cities. Cruise ships moored at the ports keep their engines on, which results in enormous air pollution and thick smog in the port cities. It should also be stressed that almost 20% of greenhouse gases (water vapor, H₂O; carbon dioxide, CO₂; methane, CH₄; nitrous oxide, N₂O; and ozone, O₃) in the world come from transport, including a significant share on the part of maritime transport [37], and this has not only a local but also a global impact on the environment.

Seaport authorities and various organisations in coastal tourist destinations monitor the state of environmental pollution by cruise ships. For example Marseille Provence Cruise Club prepared a report [41] indicating that when a cruise ship is berthed in the port it uses from 0.5 to 2 tonne of desulphated fuel every hour (while an average car uses 7 litres and a truck up to 60 litres), which is the equivalent of several hundred cars or several dozen trucks or buses. "The main engines that provide propulsion are stopped and the only engine kept running is the generator needed to provide electrical power on board a ship; the generator power output and fuel consumption are significantly lower than the main engines (on average 10% of the installed capacity to run their generators)" [41]. Nevertheless, air pollution at seaports is large enough and harmful to the environment and human health, that local communities and territorial authorities are seeking to reduce the number of ships accepted simultaneously in ports, to counteract these phenomena, as has been observed in the case of Venice, Dubrovnik, or Barcelona in recent years.

The statistical data shows that annually, over 50,000 Europeans probably die prematurely as a result of shipping-based pollution. Other data show that a single cruise ship is responsible for emitting as much pollution as 700 trucks or even one million cars [24,42].

The port city authorities also try to limit the number of cruise ships in ports and force cruise ship owners to adjust to the port infrastructure capacity as well as rigorous regulations on exhaust emissions. Larger and larger cruise ships pose significant threat to the port traffic, port quay infrastructure, and the natural environment.

For ship owners, fuel costs constitute the highest costs related to ship operations, and the prices are unstable and very sensitive to various events and fluctuations in the world. Forecasting the economic activities in such uncertain circumstances constitutes a significant challenge for the shipping company managers. Certainly, stringent legal regulations force cruise ship owners to make investments in the existing fleet and look for new, more economically effective, and ecological technological solutions in the newly built cruise ships.

4. Discussion

The above-mentioned analysis proves that on the one hand, the cruise shipping companies outdo one another in introducing new technological solutions regarding harvesting new sources of energy in line with the "green energy" approach [12], but on the other, use the solutions provided by their competitors. At present, the most popular solution involves introducing cruise ships powered by LNG fuel and hybrid solutions combining harvesting energy from solar batteries, wind farms located in seaports, or from fuel cell technology [43].

All newly ordered cruise ships are now equipped with environmentally friendly solutions related to energy harvesting, which gives hope that the amount of pollution emitted into the natural environment will gradually decrease. However, we need to remember that currently in the world there are about 360 giant cruise ships in operation, and they are still powered by heavy fuel oil (HFO) and generate high SO_x emission into the environment [42]. All cruise ship owners declare that they take action to reduce the amount of SO_x emissions in accordance with the IMO recommendations; nevertheless, the problem is still very serious. The Friends of the Earth Organisation is monitoring the

level of pollution emitted by ships into the environment and regularly publishes Cruise Ship Report rankings [44] indicating which cruise lines care about the natural environment. Unfortunately, the results of their analyses are not satisfactory.

The second trend observed in the activities of cruise shipping companies, apart from the introduction of new sources of energy harvesting, involves efforts to reduce the energy consumption on ships by installing energy-efficient equipment and materials aboard the ships, in cabins, bathrooms, and public areas. Automatic solutions and intelligent technologies are introduced into the cabins to make sure the electrical equipment is switched off during the absence of passengers. These processes are supported by various sensors and intelligent electronic solutions. Significant savings are also generated by installing energy-efficient LED luminaires. There also install collectors on sunny parts of the ship and run optical fibres down to cabins from the collectors [21]. The ship owners also make use of photovoltaic panels, sensors, and various other solutions.

The future also belongs to solutions currently used in smaller vessels operating in the canals, rivers, and lakes, namely hybrid solutions that include, e.g., LNG hybrids with batteries or diesel–electric propulsion [18].

5. Conclusions

The data related to the condition of natural environment, water and ocean pollution, and the amount of pollution generated into the environment by cruise ships is alarming. The activity of pro-ecological organisations, seaport management, tourist destinations' local authorities, and coastal city residents means that cruise ship owners have no choice but to take action to protect the natural environment. In addition, the travellers using services offered by cruise lines more and more frequently take into account the opinions on cruise lines, including the one related to their adverse impact on the environment. Nowadays, the consumer movements in the era of IT technologies and social media are increasingly important and have significant impact on consumers' decision-making process considering taking up certain offers.

The conducted analyses have shown that, in the face of numerous strict regulations, competition, and pressure from business environment, cruise line managers are forced to take action on green energy harvesting for cruise ships' propulsion and operational activities. The studies resulted in the following conclusions:

- In order to meet the IMO restrictions on the reduction of SO₂ emissions into the environment, all the leading cruise shipping companies install scrubbers on cruise ships powered by heavy fuel oil to meet the sulphur emission regulations.
- To reduce energy consumption, various energy-efficient materials, accessories, and equipment are installed on cruise ships, such as solar lighting, lighting by LED luminaires, sensors and automatic devices, etc.).
- Cruise line managers should expect further restrictions regarding limiting harmful emissions to the environment. This can cause other unforeseen investments in their fleet of cruise ships; therefore, currently ordered new vessels are equipped with eco-solutions related to energy harvesting for the propulsion of ships and all the ships' operational activities.
- The currently ordered cruise ships are equipped with green technology solutions, mainly LNG fuel supply, battery technology, and fuel cell technology, as well as various combinations of these options.
- The world's largest cruise shipping companies have provided a sustainable development strategy in order to implement multiple energy-saving initiatives and to develop emission abatement solutions to improve the level and quality of emissions from their cruise ships.

The introduction of strict regulations, the involvement of many entities in reducing the energy consumption aboard cruise ships, and the reduction of harmful substances emitted into the environment allow hope that the situation should gradually improve. Nevertheless, it is important to realise that the damage already done to the environment, resulting

from the emissions of pollutants into the seas and oceans as well as the atmosphere, is unfortunately already irreversible.

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