POSSIBILITIES AND LIMITATIONS IN THE APPLICATION OF THE GREEN PLAN FOR SSS SHIPS FROM THE ASPECT OF IMPROVING THE QUALITY OF PROPULSION SYSTEMS

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Abstract. The article studies the ways to achieve complete decarbonization of the SSS fleet in accordance with the IMO Strategy and the Green Plan for Europe 2050. Therefore, experts from the fields of shipping, shipbuilding, mechanical engineering, energy, technology, human resources management, logistics, maritime law, occupational safety and ecology assessed the selected elements of the quality of propulsion systems on ships. During the study, the sizes of these elements for the target year 2050 were numerically estimated. As a result, a matrix of development was created in relation to the current situation by which it is possible to determine their synergistic effect and the individual impact on other elements. The results of the research have shown that there is a real possibility of achieving the set goals if the values of individual quality elements of propulsion systems are improved.

Keywords: quality of propulsion systems, alternative fuels, short seal shipping, growth matrix.

INTRODUCTION

The quality of reliability of ship propulsion maintenance has been brought to an enviable level of safety during the long-term operation of coastal liner ships powered by internal combustion engines. With the advent of new propulsion systems that use alternative fuels, problems can be expected related to the specifics of the areas in which short sea shipping takes place.

The issue of transformation of propulsion systems of SSS fleet ships in terms of decarbonization, i.e. the use of environmentally neutral fuels and thus zero greenhouse gas emissions, is analyzed in this paper exclusively from the point of view of sustainability and reliability without entering the economic and political sphere of decision-making. Namely, the research starts from the preamble of the European Green Plan (EC, 2019) as a given goal, the achievement of which opens space for numerous variations on the topic of selection of propulsion and fuel for which ship owners or ship owners will opt. Coastal liner shipping has the purpose of transversal or long-shore connection of points (ports) on the coast or islands for the transport of passengers, goods and vehicles according to a predetermined sailing schedule (Bukša & Bukša, 2011). It takes place continuously with frequency in the function of transport demand and is interrupted only exceptionally depending on hydrometeorological conditions. Navigation is exposed to maritime risks related to system factors and circumstances (Bukša, 2010).

The genesis of the reliability quality problems of new propulsion systems and alternative fuels stems from ubiquitous efforts to reduce greenhouse gas emissions in maritime transport, which in turn have triggered market competition for dominance in the marine propulsion industry. The evident climate change and the Green European Plan have prompted many manufacturers of environmentally friendly machines, innovators in the supply of environmentally friendly fuels, to offer a range of propulsion systems to the market in the euphoria of general decarbonization, most of which are still in the experimental phase. Ship owners are gradually introducing new technologies on their vessels in accordance with their market, geographical and climatological position. Ship owners from Scandinavian countries and Germany went the furthest in this, using dual fuel, hybrid diesel-battery or LNG-battery and battery ships on shorter lines that are not exposed to wind and sea shocks. Larger ship owners, those with dozens of vessels, are still hesitant to procure new vessels, awaiting relevant research into the functional characteristics of such vessels under various operating loads as well as appropriate logistical support for fuel supply, battery replacement, spare parts delivery, etc. Ship owners' thinking is perfectly acceptable. to manage fuel and lubricant costs and maintain the reliability of the propulsion system. Also, ship owners manage the renewal of the fleet looking for optimal solutions and select the maritime properties of the ship as well as the propulsion machine in accordance with the climatological, meteorological and tide gauge characteristics of the area in which they sail. Optimistic demands for a complete renewal of the fleet of ships in the SSS system by 2050 require the selection of leading technology to adapt the accompanying fuel supply industry or battery charging stations, shipyards, spare parts supply, crew training and customized maritime colleges.

From fuel to ship moving, the overall energy conversion efficiency consists of three parts (Shi et al., 2010): "the engine efficiency, the transmission efficiency and the propulsive efficiency. In off-design conditions, there are three factors, namely the engine speed, the propeller pitch ratio and the rudder activity, and an additional disturbance, ship loading factor that can impact the behavior of ship propulsion system and influence the overall energy conversion efficiency" The basic goal of this research is to improve the quality of propulsion systems in terms of:

- reducing and eliminating GHG emissions;
- noise reduction and elimination in engine rooms and on board;
- reducing and eliminating the release of oily liquids from the ship and
- maintaining the reliability of propulsion systems,

that is, the search for the implementation and manner of using alternative propulsion and fuel on SSS ships, without violating the existing standards of transport service.

Improving the quality of propulsion systems set by IMO strategic documents and the Green Plan exposes SSS ship owners to additional costs of transformation of existing or procurement of new propulsion systems, costs of sustainable development, costs of LCC as well as costs of environmentally neutral fuels.

Conventional life cycle costs (LCC) are based on four categories that are estimated based on the costs of investment, operation, maintenance and disposal at the end of life, while the LCC method in the environment considers the above-mentioned costs and external environmental costs. Given that maritime operations contribute significantly to global warming and environmental pollution, it is necessary to consider the life-cycle costs of vessels from an environmental point of view, which include reducing greenhouse gas emissions and end-of-life environmental management of vessels.

MATERIALS AND METHODS

The Green Plan for Europe as an ecologically neutral continent until 2050 is a challenge that, in addition to benefiting future generations, is associated with additional costs for those existing. The new costs that will result from this relate to the costs of transforming or replacing existing propulsion systems as well as all processes that use fossil fuel energy and which need to be replaced by alternative environmentally neutral fuels. In this context, the position of SSS ship owners facing the challenge of transforming or replacing propulsion systems on their ships in order to meet the given decarbonization conditions should be observed.

The problems observed relate primarily to the time period in which they should adapt their fleet to the Green Plan, given the specifics of maritime transport, in which alternative propulsion and associated fuels should not be a limiting factor in maintaining safe maritime service in liner coastal transport. Namely, the replacement of existing ships at larger ship owners (30 to 50 vessels) requires time and capacity of overhaul and construction shipyards.

Another problem is a stable fuel supply, safe boarding and compliance with safe use regulations. The third challenge are the external factors, i.e. the sea and the wind, whose power and direction affect the additional loads of the propulsion system, which must fulfil the function of propulsion of the ship even in extreme conditions.

The complexity of finding solutions goes beyond the capabilities of SSS ship owners and requires a multidisciplinary approach that should consider the knowledge and experience of experts in shipping, shipbuilding, mechanical engineering, energy, technology, human resources management, logistics, maritime law, occupational safety and ecology. Considering the above, the key elements of the development of propulsion systems for the target times in 2030 and 2050 were identified and a survey of opinions and attitudes of experts in these areas on the projection of those elements of development that participate in improving the quality of propulsion systems on SSS.

The transition period until 2050, for the transition to environmentally neutral propellants, is a necessity arising from insufficiently researched technology of supply of ecologically neutral energy sources and thus the choice of ship propulsion. In addition, it should be considered that between the decision of the ship owner which installation and which energy source to use and the beginning of operation, it is necessary to consider the free capacities of the shipyard, the capacity of making propulsion machines and the fuel supply schedule to each port of Short sea Shipping – SSS (Bukša, 2005).

SSS vessels typically operate in limited geographical areas, on relatively short routes with frequent port calls. Due to their relatively low energy demand, these vessels are often ideal candidates for testing new fuels characterized by high energy or fuel storage costs (Sopta et al., 2020).

The SSS fleet in the EU, with the exception of inland waterway vessels, makes up a respectable number of vessels that should be replaced or refurbished over a thirty-year period in accordance with the requirements of environmental neutrality of energy (NMA, 2017).

Possible scenarios for the transformation of SSS fleet marine propulsion systems have been proposed by Sopta et al. (2020). According to them, three scenarios are possible for propulsion systems powered by environmentally friendly fuels with a set target system— zero emissions by 2050.

Table 1.

Possible scenarios according to default milestone

UP TO 2030.	UP TO 2050.
Development of internal combustion propulsion systems: a. development of dual fuel system— diesel fuel and LNG b. development of LNG-powered systems c. development of hydrogen-powered systems	Hydrogen as a propellant for marine propulsion systems: indirect— use of hydrogen fuel cells to start electric motors and direct— the use of hydrogen as a gas in internal combustion engines.
Development of electric propulsion systems: development of hybrid systems— diesel and electric power development of electrical systems— batteries electrical system development— batteries + hydrogen cells	Fossil fuels are used exclusively to drive the main machine in navigation and manoeuvring. All other energy needed to maintain the ship's systems is obtained from renewable sources on board— photovoltaic cells, wind farms, stored energy in batteries— hybrid propulsion, batteries and onshore power sources.

Source: authors´ adaptation according to Sopta et al. (2020)

The transition further, as stated in the DNV GL – Maritime. (2020), opens the issue of safety of alternative fuels, but also the issue of investing in low-carbon shipping.

a) Safety issues of alternative fuels

Most alternative fuels are gases or liquids with a significantly lower flashpoint than conventional fuel oils and will, unlike conventional fuel oils, create an explosive gas atmosphere in an enclosed space unless properly contained. Some alternative fuels are also toxic to humans in small quantities and in low concentrations, and some are stored at very low temperatures, adding to the challenge of integrating a safe storage and distribution system. On the positive side, many have a substantially higher auto-ignition temperature than fuel oils (DNV-GL, 2020).

Storage of gaseous fuels in liquefied form will require control of temperature and/or pressure in the storage tanks. Due to the high energy content, damage to storage tanks can have potentially catastrophic consequences. The differences in properties and associated hazards for alternative fuels require additional safety barriers to maintain the safety level when compared with conventional oil fuel. Each alternative fuel has its unique properties and associated hazards requiring special consideration (DNV-GL, 2020).

b) Investment issues of low-carbon shipping

Ship owners have conventionally gravitated towards solutions that are cheaper, more reliable, more efficient, and which demand less space onboard. Going forward, owners will still favor such solutions. The challenge is that solutions intended to reduce global maritime GHG emissions are typically more expensive, less mature, less efficient and require more space onboard.

Ship owners making the decision to deploy new, improved technologies and fuels will not risk investing in immature solutions. A number of actions can help to ensure demand for shipping powered by carbon-neutral fuels, thereby reducing market and regulatory risks and accelerating uptake of the fuel (DNV-GL, 2020): International, regional, national and local regulations will be the key drivers to incentivize uptake of new solutions. This covers both technical requirements and pricing mechanisms. Supportive green procurement policies from both public and private cargo-owners, combined with long-term contracts, will enable investments in ships powered by carbon-neutral fuels.

The answers to these questions depend heavily on compliance with the projected GHG emission limits with the SSS, which in turn depend on the development of the technologies needed for new generations of low-carbon ships.

The results of this research are based on face-to-face in-depth interviews conducted with experts in the fields of shipping, shipbuilding, mechanical engineering, energy, technology, human resources management, logistics, maritime law, occupational safety and ecology in the Croatian maritime industry. Purposeful sampling was used for selecting the participants. Basically, interviewees were approached both personally and by formal email where individual interview requests have been sent. Later, snowballing strategy has been applied in order to approach the most fitting personnel for the sake of this research.

The sample consisted of 28 participants and the research was conducted in two stages. In the first stage, participants from the maritime industry were approached. 19 participants were a mix of different professions and working at different levels; three general managers, three human resources managers, two security managers, two front office managers and seven non-supervisory staff. In the second stage, the research extended to key outsider players from both the public and service sector. The variations in participants' profiles enrich the revealed data.

Although all participants are from the Croatian maritime sector, the interview questions have been deliberately formulated for each participant. Understanding the variances among participants in terms of their job description, management level, authority and alternative fuel knowledge entails altered research interviews.

Notwithstanding the revealed data from each participant contributes to fulfilling the research objectives. Ironically the variances among participants' profiles support the understanding of the GHG problem from different perspectives and hence a more integrated approach.

In order to design a model of growth and development of quality improvement elements of propulsion systems, a growth matrix was used which in a specific way takes into account the structural relationship of quality improvement elements, as presented by Stojanović (1990). Their structural relationship is specific due to the fact that the development elements depend on each other and their relevance for the development potential should be monitored simultaneously by taking into consideration direct and indirect growth rates. The growth matrix has been used as a base for mathematical modelling of the development potential by Pupavac and Zelenika (2007) in their research, and over time it has lived up to expectations.

A PROJECTION OF ELEMENT DEVELOPMENT FOR IMPROVING THE QUALITY OF PROPULSION SYSTEMS ACCORDING TO THE GREEN PLAN FOR SHORT SEA SHIPPING

The projection of the development of elements characteristic for the implementation of the Green Plan in the PRS system is based on the selection of key elements of development, their evaluation in the current moment in 2021 and the projection for 2030 as the reference IMO year and the projection for 2050 as the reference year of zero greenhouse gas emissions.

Projection of the development of elements in the model of improving the quality of propulsion systems in the SSS according to the targeted excellence to be achieved.

In devising a projection of model elements, the current condition of the model elements (in 2021) was considered and each element was given a numeric value (on a scale from 1 to 10), i.e. an input estimating its importance for quality greenhouse gas emissions from SSS ships management. The evaluation for 2030 has been made empirically, i.e. by conducting interviews with experts in shipping, shipbuilding, mechanical engineering, energy, technology, human resources management, logistics, maritime law, occupational safety, ecology and controlling.

In order to reach the performance needed for the application of the IMO Strategy, it is estimated that with a systematic application of quality propulsion system improvement it would take a period of at least ten years for the SSS carrier to be ready for a fair market match with direct competitors. Therefore, the estimated element values for the IMO Strategy can be expected in 2030.

However, in order to become a leader in the SSS market, it is necessary to start the process of procuring new ships powered by environmentally neutral fuels to meet the requirements of environmental neutrality by 2050. The experience of the automotive industry, which has carried out business reengineering and is gradually replacing internal combustion engines with electric drives using batteries or hydrogen fuel cells, indicates that a period of 30 years is required to achieve a high degree of excellence in such drives.

Therefore, for the Green Plan scenario, it is possible to forecast the values of the elements only with the condition of a complete transition to electrically powered ships and a change in business philosophy that would take into account the functions of quality and controlling.

That input is crucial in order to be able to determine direct and indirect growth rates of all the management elements in a quality improvement system using a growth matrix.

The first prediction period from 2021 to 2030 (a ten-year period) has been chosen for the following reasons:

— In accordance with the Initial IMO Strategy on reduction of GHG emissions from ships (IMO, 2018) on reduction of CO2 emissions in maritime transport by 40% compared to 2008, it is certain that ship owners are allowed to use alternative fuels on existing propulsion engines in the transition period with certain modifications. This primarily involves the use of natural gas, ammonia and hydrogen and hybrid propulsion machines dual fuel, diesel / batteries, LNG / batteries, diesel / hydrogen cells. The transition period until 2030 is used for the education of seafarers, modifications to propulsion engines, construction of new ships in accordance with technical and technological development, construction of infrastructure for fuel supply.

— The period of 10 years of planning in the maritime and shipbuilding industries is included in the medium-term plans, which are considered principle development plans because they do not contain specific technical characteristics but are adjusted in accordance with the development of ship propulsion technology.

— A period of 30 years (until 2050) is considered long-term planning and usually serves as a starting point for the adoption and determination of medium-term development plans. These plans determine the general orientation of the development of improving the quality of propulsion systems and development guidelines and changes in business.

In order to forecast the values of elements in 2050 as accurately and objectively as possible in relation to 2021, their growth is analysed and compared with the projected values (inputs) of elements in 2030.

CALCULATION OF GROWTH RATES OF DEVELOPMENT ELEMENTS FOR THE PLANNED PERIOD UNTIL 2050

To adequately quantify and examine the growth of development potentials for improving the quality of propulsion machines in the SSS fleet, a growth matrix was used that treats the structural relationships of development elements in a specific way (Stojanović, 1990). It is due to the fact that development elements are interdependent and their role in the growth potential should be monitored simultaneously through direct and indirect growth rates.

After the basic characteristics of a growth matrix have been analyzed and a model has been devised, it is possible to apply shipbuilding company product quality improvement development model element values to the model and create a growth matrix of that model. The effects of a shipbuilding company product quality improvement development model based on a growth matrix are manifold:

— a growth matrix provides an opportunity to cover all internal and external factors influencing the quality of the propulsion systems of the shipping company SSS at the same time;

— the model elements are interdependent and their variations should be observed simultaneously through direct growth rates;

— it is possible to demonstrate the relationship between different elements through appropriate rows and columns showing synergic effects of the model;

— each row or column in the growth matrix shows how one element relates to the others, including parameters that identify direct growth rates, i.e. individual model effects.

The results obtained by designing the model, evaluating its elements and testing can be divided into individual and synergistic effects thanks to the results obtained through direct and indirect growth rates. The model contains the element values used in 2021 and their predicted values for 2030 and 2050.

EVALUATION OF ELEMENTS OF DEVELOPMENT OF IMPROVING THE QUALITY OF PROPULSION SYSTEMS ON SSS SHIPS

The questionnaire asked maritime experts to assess (in the range of 1-10) the current value of each element and knowledge of the general situation in maritime affairs, trends in the search for environmentally neutral ships in the SSS, new construction market, technological advances in ship development, production technology, environmentally neutral fuels and developments in society and the economy, and to project the future value of these elements for the next 10 and 30 years, respectively.

1. Expertise and motivation of human resources in the PRS was assessed with an average grade of 7, with a projection for 2030 of 7 and for 2050 also a grade of 7. This expressed lack of growth can be interpreted by the general situation in liner coastal shipping with pronounced seasonality, the absence of market competition, the ownership structure with a stagnant perspective due to opportunities in society and the education system;
2. Acceptance (understanding) of the necessity of abandoning conventional propulsion machines and transformation to environmentally neutral plants for the purpose of preserving the natural environment and preventing climate change was rated for the time being with a high average score of 8. Experts predicted that awareness of the harmful effects of fossil fuels will grow, for 2030 it was rated with an average grade of 9 and to be fully accepted in 2050 (grade 10);
3. The reliability of alternative drives is an element that evaluates the general applicability of new technological solutions that are currently, with the exception of dual fuel, in the experimental phase. Therefore, the evaluation of this element by connoisseurs is quite reserved. Thus, the reliability of alternative drives for 2021 was rated at four (grade 4) with a development perspective until 2030, which was rated with an average grade of 6, and in the target 2050 with a grade of 8. This skepticism is explained by insufficient information on the use of such drive systems;
4. Availability of motor fuel with less or no greenhouse gas content. The availability of gas as an alternative fuel for ships in the SSS system is practically the same as diesel fuel. The same is the case with electricity for charging rechargeable batteries (if the electricity is produced from renewable sources). However, the availability of ammonia, hydrogen, and hydrogen cells will not be possible in every port of call for SSS ships for the foreseeable future until cost-effective transport and storage solutions are found. Respondents obviously thought in this direction as well, considering that they assessed the existing availability with an average grade of 7 and the development until 2030 with a grade of 8, and awarded the same grade in 2050;
5. The quality of the maritime transport service in the PRS system is an element that has been assessed almost in unison for the present and the future, with a high average score of 8, considering that the type of ship propulsion cannot significantly affect the transport service.

6. The quality of environmental protection due to the release of GHG from SSSs is recognized as a need and desire due to the obvious climate change and is considered an imperative. In this sense, the respondents also assessed the current situation with a grade of 5 with a progression to 8 for 2030 and to a grade of 10 for the target year 2050;

7. Working and space conditions are elements whose progress is limited by the space of the engine room, the changes of which are possible only with large investments, and accordingly modest growth is foreseen. In 2021, it was evaluated with an average grade of 4, and the same value is forecasted for 2030, but in 2050, in the conditions valid for Scenario III, it will increase to 5, which makes an overall increase of one point.

8. The technological level is an element for which growth is expected within the development of the entire maritime transport sector, that is from 7 in 2021 to 8 in 2030 and 9 in 2050, which would make a total increase of 2 points;

9. The IT level is a necessity that must be achieved in order to achieve a higher quality of service and environmental protection, and from the current 5 in 2021, growth is projected to 8 in 2030 and 10 in 2050, which would make total increment of 5 points;

10. The business policy of the shipping company is an element that is crucial for the development of product quality, because the policy pursued by the management depends on the abyss of transformation into environmentally neutral plants. Experts believe that the current business policy can be evaluated with an average score of 6, which is conditioned by the current economic situation (COVID 19 crisis) and a forecast of 7 for 2030 and 8 for 2050;

11. Fleet integration is a development element specific to multi-vessel ship owners in the PRS service that largely depends on the availability of new technologies. Successive procurement of new vessels can lead to the emergence of different technologies within the fleet of the same ship owner, which will result in increased maintenance costs. Therefore, this element was carefully (with a certain reserve) evaluated, so the evaluations for 2021 are 5, 6 for 2030 as well as for 2050;

12. Ethics and social responsibility are an element that is unavoidable in all proverbial activities and refers to socially acceptable behavior that is often neglected in projecting business costs and thus quality. Experts considered that there was little room for improvement in this element and evaluated 2021 with a score of 6, and 2030 and 2050 with a score of 7;

13. Sustainable development costs are an element that has a significant upward trend but is necessary to maintain the level of transport services in line with the concept of sustainable development. Experts believe that these costs will grow until the cycle of transformation of the propulsion on all vessels is completed. Thus, the score rises from an average of 5 in 2021 to 7 in 2030 and 9 in 2050;

14. The life cycle costs of a ship LCC are the element that accompanies the ship from the shipyard to the cutting or waste disposal in an environmentally friendly manner. The cost of LCC by its definition grows along a normal curve with its peak at the time of full operation of the ship. In the observed case, the costs of LCC will increase with the need to replace the propulsion machines or to leave operation early and send to the cutting site. In that sense, there were also the ratings of this development element, which was rated 5 in 2021, to reach 8 in 2030, and 9 in the 2050 projection;

15. Controlling is an element that controls, measures, regulates and balances the relationship between the costs of plant quality and the consequences for the environment. This element is of great importance for achieving optimal costs for the best quality. Experts have recognized the value of this element and believe that its impact in the future will be crucial to achieve the desired quality of ship propulsion. Thus, the score rises from an average of 5 in 2021 to 7 in 2030 and 9 in 2050.

RESULTS AND DISCUSSION

A scientifically based assumption is that the development potential for improving the quality of propulsion systems on SSS ships consists of n interrelated elements. The value (e.g. as input) of the i-th development element (i = 1, ..., n) in the period t and t-1 will be marked as yit and yi,t-1. The input value growth of the i-th element of product quality improvement development the potential for improving the quality of propulsion systems on SSS ships:

$$\Delta y_{it} = y_{it} - \Delta y_{it-1} \qquad (1)$$

The indirect i-th element growth rate of the product quality improvement development potential for improving the quality of propulsion systems on SSS ships in relation to the j-th is defined as the ratio of the i-th element input growth of the product quality improvement development potential in the shipbuilding industry, Δyit, to the input of the j-element of the product quality improvement development potential for improving the quality of propulsion systems on SSS ships in the t period, namely:

$$r_{ijt} = y_{it} / y_{jt} \; i,j = 1, \ldots, n. \; Y_{jt} \neq 0. \qquad (2)$$

Based on the data from Table 2, it is possible to determine the growth matrix for the model elements of product quality improvement development potential for improving the quality of propulsion systems on SSS ships in relation to the current and future values in the period from 2021 to 2050.

Table 2.

Evaluation of development elements

	EVALUATION OF DEVELOPMENT ELEMENTS	Input Yit			Growth
		2021	2030	2050	Δyi, 2050
1.	HR expertise and motivation	7	7	7	0
2.	Acceptance (understanding) of the necessity of abandoning conventional propulsion machines	8	9	10	2
3.	Reliability of alternative drives	4	6	8	4
4.	Availability of alternative fuels	7	8	8	1
5.	Quality of maritime transport service in the PRS system	8	8	8	0
6.	Quality of environmental protection due to GHG discharge from SSS ships	5	8	10	5
7.	Working and space conditions	4	4	5	1
8.	Technological level	7	8	9	2
9.	IT level	5	8	10	5
10.	Business policy of a shipping company	6	7	8	2
11.	Fleet integration	5	6	6	1
12.	Ethics and social responsibility	6	7	7	1
13.	Sustainable development costs	5	7	9	4
14.	LCC life cycle cost	5	8	9	4
15.	Controlling	5	7	9	4

Source: Calculation based on data survey questionnaire

Growth matrix = growth vector × reciprocal values vector, i.e.:

$$R_{2050} = \Delta y'_{2050} \cdot \frac{1}{y_{2050}} \tag{3}$$

$$R_{2050} = \begin{bmatrix} 0 \\ 2 \\ 4 \\ 1 \\ 0 \\ 5 \\ 1 \\ 2 \\ 5 \\ 2 \\ 1 \\ 1 \\ 4 \\ 4 \\ 4 \end{bmatrix} \cdot \left[\frac{1}{7}, \frac{1}{10}, \frac{1}{8}, \frac{1}{8}, \frac{1}{8}, \frac{1}{10}, \frac{1}{5}, \frac{1}{9}, \frac{1}{10}, \frac{1}{8}, \frac{1}{6}, \frac{1}{7}, \frac{1}{9}, \frac{1}{9}, \frac{1}{9}\right. \tag{4}$$

The product of the external vector Δy’(2050) and 1/y(2050) determines the matrix of the development potential for improving the quality of propulsion systems on SSS ships in relation to the current values:

Table 3.

Matrix of quality development of propulsion systems on SSS ships

$$\begin{bmatrix}
0/7 & 0/10 & 0/8 & 0/8 & 0/8 & 0/10 & 0/5 & 0/9 & 0/10 & 0/8 & 0/6 & 0/7 & 0/9 & 0/9 & 0/9 \\
2/7 & 2/70 & 2/8 & 2/8 & 2/8 & 2/10 & 2/5 & 2/9 & 2/10 & 2/8 & 2/6 & 2/7 & 2/9 & 2/9 & 2/9 \\
4/7 & 4/10 & 4/8 & 4/8 & 4/8 & 4/10 & 4/5 & 4/9 & 4/10 & 4/8 & 4/6 & 4/7 & 4/9 & 4/9 & 4/9 \\
1/7 & 1/10 & 1/8 & 1/8 & 1/8 & 1/10 & 1/5 & 1/9 & 1/10 & 1/8 & 1/6 & 1/7 & 1/9 & 1/9 & 1/9 \\
0/7 & 0/10 & 0/8 & 0/8 & 0/8 & 0/10 & 0/5 & 0/9 & 0/10 & 0/8 & 0/6 & 0/7 & 0/9 & 0/9 & 0/9 \\
5/7 & 5/10 & 5/8 & 5/8 & 5/8 & 5/10 & 5/5 & 5/9 & 5/10 & 5/8 & 5/6 & 5/7 & 5/9 & 5/9 & 5/9 \\
1/7 & 1/10 & 1/8 & 1/8 & 1/8 & 1/10 & 1/5 & 1/9 & 1/10 & 1/8 & 1/6 & 1/7 & 1/9 & 1/9 & 1/9 \\
2/7 & 2/10 & 2/8 & 2/8 & 2/8 & 2/10 & 2/5 & 2/9 & 2/10 & 2/8 & 2/6 & 2/7 & 2/9 & 2/9 & 2/9 \\
5/7 & 5/10 & 5/8 & 5/8 & 5/8 & 5/10 & 5/5 & 5/9 & 5/10 & 5/8 & 5/6 & 5/7 & 5/9 & 5/9 & 5/9 \\
2/7 & 2/10 & 2/8 & 2/8 & 2/8 & 2/10 & 2/5 & 2/9 & 2/10 & 2/8 & 2/6 & 2/7 & 2/9 & 2/9 & 2/9 \\
1/7 & 1/10 & 1/8 & 1/8 & 1/8 & 1/10 & 1/5 & 1/9 & 1/10 & 1/8 & 1/6 & 1/7 & 1/9 & 1/9 & 1/9 \\
1/7 & 1/10 & 1/8 & 1/8 & 1/8 & 1/10 & 1/5 & 1/9 & 1/10 & 1/8 & 1/6 & 1/7 & 1/9 & 1/9 & 1/9 \\
4/7 & 4/10 & 4/8 & 4/8 & 4/8 & 4/10 & 4/5 & 4/9 & 4/10 & 4/8 & 4/6 & 4/7 & 4/9 & 4/9 & 4/9 \\
4/7 & 4/10 & 4/8 & 4/8 & 4/8 & 4/10 & 4/5 & 4/9 & 4/10 & 4/8 & 4/6 & 4/7 & 4/9 & 4/9 & 4/9 \\
4/7 & 4/10 & 4/5 & 4/5 & 4/5 & 4/10 & 4/5 & 4/9 & 4/10 & 4/8 & 4/6 & 4/7 & 4/9 & 4/9 & 4/9
\end{bmatrix}$$

From the upper matrix it can be calculated the growth rates of the development elements of improving quality of propulsion systems on SSS ships, Table 4.

Table 4.

Growth rates of elements of quality improvement products of the shipbuilding industry

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	28,6	20,0	25,0	25,0	25,0	20,0	40,0	22,2	20,0	25,0	33,3	28,6	22,2	22,2	22,2
3	57,1	40,0	50,0	50,0	50,0	40,0	80,0	44,4	40,0	50,0	66,7	57,1	44,4	44,4	44,4
4	14,3	10,0	12,5	12,5	12,5	10,0	20,0	11,1	10,0	12,5	16,7	14,3	11,1	11,1	11,1
5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	71,4	50,0	62,5	62,5	62,5	50,0	100	55,6	50,0	62,5	83,3	71,4	55,6	55,6	55,6
7	14,3	10,0	12,5	12,5	12,5	10,0	20,0	11,1	10,0	12,5	16,7	14,3	11,1	11,1	11,1
8	28,6	20,0	25,0	25,0	25,0	20,0	40,0	22,2	20,0	25,0	33,3	28,6	22,2	22,2	22,2
9	71,4	50,0	62,5	62,5	62,5	50,0	100	55,6	50,0	62,5	83,3	71,4	55,6	55,6	55,6
10	28,6	20,0	25,0	25,0	25,0	20,0	40,0	22,2	20,0	25,0	33,3	28,6	22,2	22,2	22,2
11	14,3	10,0	12,5	12,5	12,5	10,0	20,0	11,1	10,0	12,5	16,7	14,3	11,1	11,1	11,1
12	14,3	10,0	12,5	12,5	12,5	10,0	20,0	11,1	10,0	12,5	16,7	14,3	11,1	11,1	11,1
13	57,1	40,0	50,0	50,0	50,0	40,0	80,0	44,4	40,0	50,0	66,7	57,1	44,4	44,4	44,4
14	57,1	40,0	50,0	50,0	50,0	40,0	80,0	44,4	40,0	50,0	66,7	57,1	44,4	44,4	44,4
15	57,1	40,0	50,0	50,0	50,0	40,0	80,0	44,4	40,0	50,0	66,7	57,1	44,4	44,4	44,4

Source: Calculation based on data survey questionnaire

A projection of direct growth rates of propulsion system quality elements on SSS ships for the period up until 2050

The conducted research and evaluation of the development potential of the quality of propulsion systems on SSS ships gave direct growth rates of individual development elements of quality have been obtained, Fig 1.

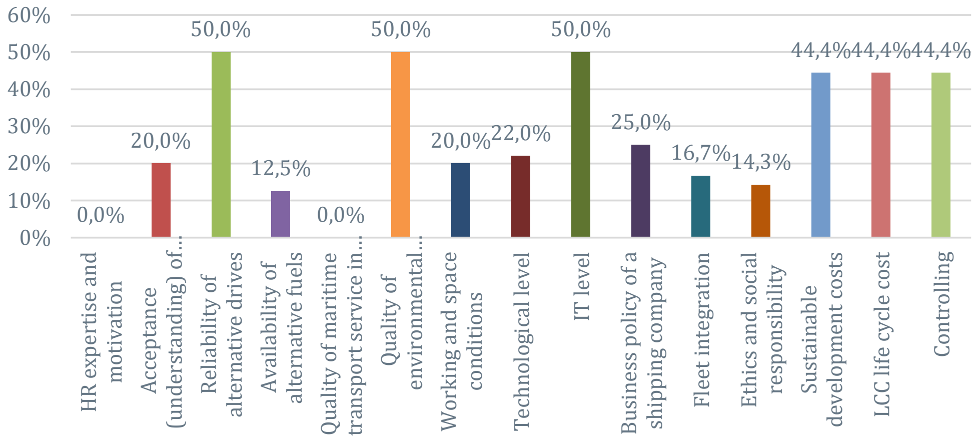

Fig. 1. Direct rates of development of quality elements of propulsion systems on SSS ships
Source: authors´ analysis according to the calculation from table 4

Figure 1 clearly presents the results of the research, i.e. the direct growth rates for each element of the development potential of the quality of propulsion systems on SSS ships.

Direct growth rates show that the greatest impact on the entire PRS system should be the reliability of alternative plants, the quality of environmental protection and the IT level (50%). Sustainable development costs, LCC costs and controlling have a significant impact with 44.4%. The limiting factor for the growth and development of the quality of propulsion systems on SSS ships is in human resources in the SSS and the improvement of the quality of service, the growth of which was not predicted by the surveyed experts.

Based on the data from Table 4, indirect growth rates can be predicted between individual elements of the development potential for improving the quality of propulsion systems on SSS ships. In the continuation of this discussion, only the quality of environmental protection due to the release of GHG from SSS ships and the IT level is compared with other elements of development potential. The comparison of other elements is possible according to the same principle, and is omitted due to rationalization.

A projection of indirect growth rates of quality elements of propulsion systems on SSS ships for the period up to 2050

When only direct growth rates are observed, the growth of one element is expressed independently of the growth of others. However, when defining the indirect growth rates, i.e. the growth of the i-th element in relation to the j-th (i, j = 1, ..., n), it is possible to determine the structure of the growth of the elements and to express all relations through the matrix of growth within the system. By expressing the direct and the indirect growth rates at the same time, it is possible to monitor the changes in the growth intensity of individual elements and their structural relationships.

Improving the quality of environmental protection due to the release of GHG from medium-sized ships is a prerequisite for all activities aimed at achieving the full quality of environmentally friendly propulsion systems, i.e. achieving ecological neutrality of medium-sized ships. Therefore, it is important to see how the development element of "environmental quality" in the foreseeable future is reflected in other development elements, as is possible by analyzing indirect growth rates.

Comparing the importance of environmental quality with other elements (Figure 2) that affect the development potential of the quality of propulsion systems for the period 2021/2050, the growth rate of working and space conditions was noticeable at 100% in relation to the integration of the fleet (83.3%), expertise and motivation of human resources, as well as ethics and social responsibility (71.4% each). Such high rates of working and space conditions indicate the fact that this element of development potential is strongly influenced by the transformations of propulsion systems. Namely, the results suggest that the transition to environmentally neutral propulsion systems will require SSS ship owners to change working and space conditions, expertise and motivation of human resources, changes in ship owners' business policy and changes in attitudes towards ethics and social responsibility.

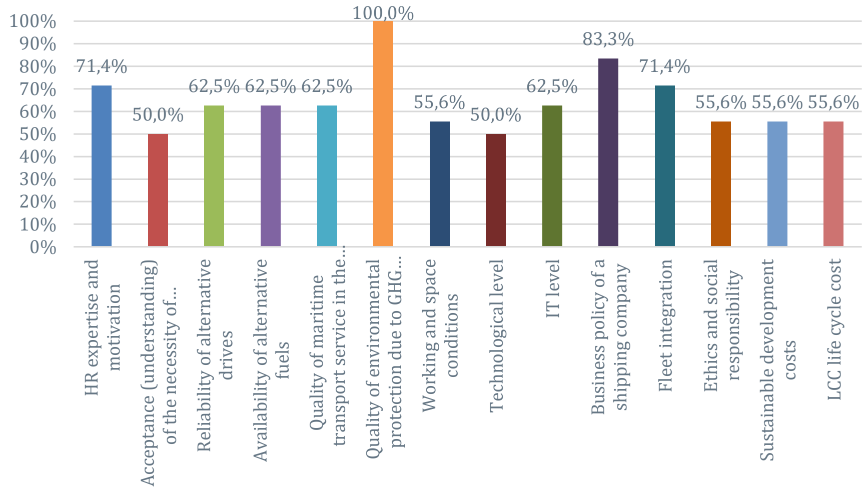

Fig. 2. Indirect growth rates of environmental quality improvement due to GHG discharges from medium-sized ships compared to other development elements Source: authors´ analysis according to the calculation from table 4

Improving the quality of propulsion systems will affect both the increase in maintenance costs and the cost of LCC, but also the importance of controlling in order to sharpen the focus of management on the key factors by which they are monitored. This further leads to the continuous improvement of the technological and IT level, maintaining the reliability of the system and the motivation of human resources.

Other important data arising from the projection of the potential for improving the quality of propulsion systems is obtained when comparing the indirect growth rates of other elements with the element of growth of life cycle costs of ships in the fleet of SSS.

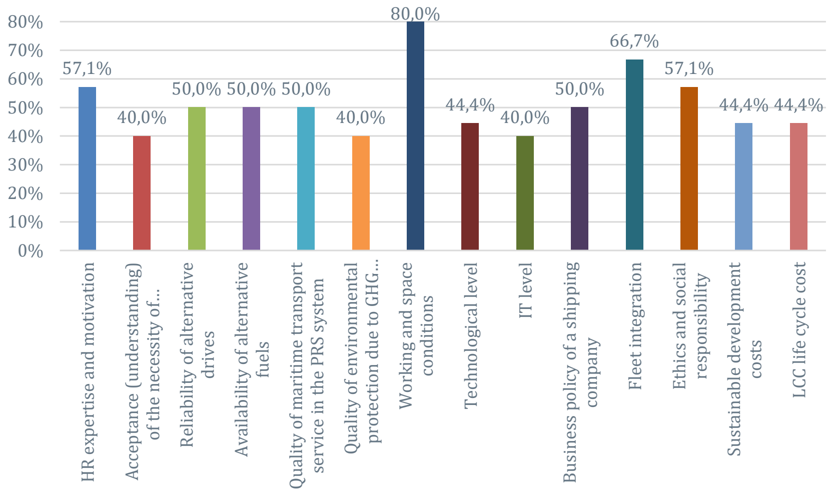

Fig. 3. Indirect growth rates comparing the appearance LCC level with other elements
Source: authors´ analysis according to the calculation from table 4

When comparing the indirect growth rates of other elements with the growth of LCC costs (Figure 3), it is clear that the highest growth rates in relation to the impact of LCC costs will be achieved in labor and space elements (80%), followed by fleet integration (7%), expertise and motivation of human resources and ethics social responsibility with 57.1% each, which means that the growth rates of the importance of these elements contribute most to the growth rates of LCC costs as an element of development potential of ship propulsion systems in SSS.

CONCLUSION

By researching and assessing the development potential of the quality of propulsion systems of SSS ships, direct growth rates of the observed development elements were obtained. Direct growth rates show that the most significant impact on the quality of the overall propulsion system is related to the availability of alternative fuels, the amount of GHG and the IT level. The experts who assessed the development elements clearly identified the elements on which future activities aimed at improving the quality of propulsion systems must be based. Furthermore, the human resources element has been identified as a limiting factor for the development of quality improvement systems, but no progress is expected in this area in the foreseeable future (30 years).

By showing direct and indirect growth rates simultaneously, it is possible to monitor changes in the growth intensity of elements and their structural relationships.

The research was conducted on a limited sample of experts from the fields of shipping, shipbuilding, mechanical engineering, energy, technology, human resources management, logistics, maritime law, occupational safety and ecology using the growth matrix of selected elements. The calculated growth rates show the interdependence of elements that can accelerate but also limit development processes according to the set goals. By calculating indirect rates, it is possible to determine which element has what effect on the overall development or the way in which it correlates to other elements.

This method of research opens up possibilities for combining a number of factors that may at some point become important for the topic of improving the quality of propulsion systems from the point of view of GHG emissions.

For some future research, the issues of safety of alternative fuels and investments in low-carbon shipping are open.

REFERENCES

Bukša, J. (2005). The Meaning of the Short Sea Shipping and the Short Sea Shipping Project Joining Modalities. *Journal of Maritime and Transportation Sciences, 43*(1), 131-140.

Bukša, J. (2010). Management of business-technological risks in coastal liner container shipping, University of Rijeka, 155.

Bukša, J., & Bukša, T. (2011). Quality management in coastal liner container shipping from the aspect of cost management. *Seafaring, Scientific Journal of Maritime Research, 25*(2), 387-403.

DNV GL – Maritime. (2020). Assessment of selected alternative fuels and technologies. Hamburg: DNV GL and the Horizon Graphic. Retrieved from: https://www.dnv.com/maritime/publications/alternative-fuel-assessment-download.html

DNV-GL. (2020). Maritime forecast to 2050. Energy Transition Outlook 2020, DNV, Retrieved from: https://download.dnv.com/eto-2021-download?_ga=2.47613159.1348788878.1663929986-1921737678.1663929986

EC. (2019). Europski Zeleni plan. European Commission. Retrieved from: https://www.consilium.europa.eu/hr/policies/green-deal/

IMO. (2018). Initial IMO strategy on reduction of ghg emissions from ships. International Maritime Organization. Retrieved from: ttps://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Resolution%20MEPC.304%2872%29_E.pdf

NMA (2017). Breaking new ground in hydrogen ferry project. Bergen: Norwegian Mariteme Authority. Retrieved from https://www.sdir.no/en/news/news-from-the-nma/breaking-new-ground-in-hydrogen-ferry-project/

Pupavac, D., & Zelenika, R. (2007). Mathematical modeling of the development potential of logistics operators. Shipping *Scientific Journal of Maritime Research, 21*(1), 23-43.

Shi, W., Grimmelius, H. T., & Stapersma, D. (2010). Analysis of ship propulsion system behaviors and the impact on fuel consumption. *International Shipbuilding Progress, 57*(1), 35-64. doi:DOI: 10.3233/ISP-2010-0062

Sopta, D., Bukša, T., Bukša, J., & Peronja, I. (12 2020). Alternative Fuels and Technologies for Short Sea Shipping. *Journal of Maritime and Transportation Sciences, 59*(1), 61-84. doi:https://doi.org/18048/2020.59.04.

Stojanović, D. (1990). Economic mathematical methods and models, Growth matrix: supplement. Belgrade: Faculty of Economics.