Prioritizing Shipyard Conversion Requirements Regarding Green Ship and Green Shipyard Concept

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Zero waste to zero emission targets set by the International Maritime Organization (IMO) regarding ship emissions until 2070 brought the realization of the green ship and green shipyard concepts to the forefront. Shipyards around the world are predominantly second and third generation. The fourth and fifth generation shipyards do not fully meet the 2070 criteria. Therefore, it is necessary to build green shipyards or convert the existing shipyards to produce green ships. The study aims to determine the shipyards' conversion requirements and to prioritize the conversion needs so that a 32,000 DWT dry bulk carrier can be built and classified as a green ship. Qualitative research methods were used in the study, and the criteria determined in this context are analyzed using Analytical Hierarchy Process (AHP). At the end of the study, suggestions for transformation strategies for green shipyards were developed.

KEY WORDS

~ Green ship
~ Green shipyard
~ Maritime shipping
~ Maritime transportation management engineering
~ Maritime technologies
~ Maritime economy

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1. INTRODUCTION

1.1. Green Ship and Green Shipyard Concepts

The concept of a green ship refers to a vessel designed and operated to minimize its environmental impact. This can include features such as energy-efficient engines and propulsion systems, using renewable energy sources, reducing emissions and waste, etc. A green shipyard, on the other hand, refers to a shipyard that is designed and operated in a way that minimizes its environmental impact. This can include features such as using renewable energy sources, implementing waste reduction, and recycling programs and using sustainable materials in the construction and maintenance of ships. Although technology has developed rapidly since the beginning of the industrial revolution, the adverse effects of industrial products on the environment and human health have been ignored unless they are visible. Today, as the new industrial revolution continues, and the periodic technological leap is on the verge, zero waste and zero emission targets have started to be considered in principle, especially with the leadership of organizations such as the IMO and the regulations they have promulgated. There are positive developments regarding decarbonization and waste management. However, a generally accepted standard definition or standard configuration has yet to be determined for green ships and shipyards worldwide.

1.1.1. Definition of the Problem

To date, there have been lots of academic studies written about the subject of green technologies. However, only a few of them are about green ships and green shipyards. There are commonly second and third generation shipyards in the world. First generation shipyards (1960) are the first shipyard structures in which shipbuilding was carried out in one-piece masonry. Equipment and steel construction areas or buildings within the shipyard area are far from each other and there is no communication and information exchange between them. In second generation shipyards (1960-1970), units (e.g., booster unit) and blocks (steel construction) started to be used as a production method in shipbuilding, especially with the developments in assembly management and adaptation of welding technology by following other sectors. In third generation shipyards (1970-1980), mechanization gained importance in the erection of blocks (steel construction). The first applications of production lines (panel lines) started. The production speed of assembly processes increased. In fourth generation shipyards (1980-1990), steel assembly was fully automated and many production lines (panel lines) established. In many applications, these were combined under one roof and gained a factory appearance. CAD (computer-aided design), CAM (computer-aided manufacturing), CAL (computer-aided lofting), CAE (computer-aided engineering), CIM (computer-integrated manufacturing), applications and special operating systems and information technology applications have been seen effectively. The last, fifth generation shipyards (1990 and later) are aimed to have a product-based production structure. Main goal is to ensure the integrity of the hull and equipment for the entire ship. In addition, it prioritizes the use of automation and robots and provides full integration of all systems. The investments in transforming these shipyards into fourth- and fifth-generation ones are gaining momentum. For this reason, clean ships/ shipyards in emission and waste management and smart ships/ shipyards in digitalization and automation have started to be used in terms of terminology (Smart Green Shipping, 2023). The main question is when green ships and green shipyards will be cost-effective and feasible. Considering the IMO's 2070 objectives, new technologies should be industrialized gradually. It is not possible to renew the conservative-infrastructure shipyards and sub-industry all at once, and the fact that the commercial lifespan of the conventional vessels currently in service has not yet been completed necessitates their sustainment for a while if they fulfill the IMO criteria. Therefore, it is focused on the question of how the prioritization should be in the conversion of the third-generation shipyards into green ones that can produce green vessels within the scope of the study. Within the scope of the IMO's GHG strategy, the aim is to reduce the total annual GHG values by 50% and CO_2 emissions by 85% by 2050. However, The Paris Agreement includes a goal to reach global net-zero emissions of GHGs in the second half of the century, which implies that GHG emissions must be significantly reduced by 2070. This goal reflects the latest scientific evidence on the need to limit global warming to well below 2°C above the pre-industrial levels and to pursue efforts to limit it to 1.5°C. To meet the criteria determined under the Paris Agreement, the IMO must meet the zero-emission criteria, which has been included in its long-term measures, until 2070 (Business Bliss Consultants FZE, 2018).

1.1.2. Motivation for Study Regarding Green Technologies

The concepts of green ships and green shipyards require high investment costs in the beginning as they introduce new technologies and environmentally friendly products. However, green technologies will make a significant contribution to the development of key industries in the medium and the long term. After the industrialization of green technologies, there will be a paradigm shift in the shipbuilding industry as there will be a significant technological leap in shipbuilding. The aim of this study is to determine the criteria that will be effective in the gradual transformation, the gaps among green, clean, and smart criteria of ship production technologies, and to prioritize the most effective course of action.

1.1.3. Limitations of the Study

Within the limitations of this research, a medium-sized green shipyard based on almost 200 acres, which can build up to 32,000 DWT dry bulk carriers equipped with green technologies, is taken as the optimum reference.

1.1.4. Research Objectives

The research has three main objectives:

- STEP 1: Scrutinize green technologies related to shipyards and determine the operational requirements;
- STEP 2: Determine the main criteria and sub-criteria related to green shipyards;
- STEP 3: Prioritize shipyard conversion requirements to meet green criteria.

2. LITERATURE REVIEW

The literature on green technologies is mainly divided into two sets. While one of them is zero emission and the other is zero waste, digitalization and automation also support these two main concepts. Therefore, the issue of decarbonization comes to the forefront. The focus is on scrapping that can be recycled for the industry, and digitalization and automation issues for energy-efficient zero-defect production are included in the green concept. As part of the IMO's regulations to reduce greenhouse gases from ships, the entry into force of the Energy Efficiency Existing Ship Index (EEXI) and Annual Operational Carbon Intensity Indicator (CII) and CII Rating from 1 January

2023 will have a significant impact on the design and operations of merchant vessels (IMO, 2023). Thus, a correlation is created between the cargo carried by the ship and the ship's emissions, and efforts to reduce the emissions gain concrete meaning (DNV, 2021). Alternative energy sources will play an important role in gradually reducing emissions from ships or shipyards (DNV, 2022). Carbon emissions are increased despite all the regulations adopted in the Paris Agreement (12 December 2015). But the zero-emission goal is now being met by today's technology (BP, 2022). In this regard, wind and solar energy, biofuels, blue and green hydrogen, CCUS (carbon capture, use, and storage), and CO2 abatement have made important strides toward industrialization (Zurich, 2023).

International companies pioneering decarbonization contribute to the maritime industry and offer solutions that can meet the IMO criteria. Some of those are fuel flexible engines, battery, energy saving and emission reduction technologies, thermal balancing and energy storage, energy efficiency and power system optimization, the industry's widest service network and digital solutions. (Wärtsilä, 2021). Green technology innovations are advancing rapidly. However, since the volatile and risky nature of the maritime market and the ongoing global economic recession create additional risk, it does not seem possible for the shipowners, shipyard traders, equipment suppliers, and service providers to make high investments in green technologies in the short term. To accelerate the process, there is a need to support the sector and take concrete and effective steps.

In this context, strategic infrastructure supports such as establishing a CO2 fund, strengthening maritime finance, increasing cooperation mechanisms between the actors of the maritime industry, and establishing a market for green technologies and an adequate fuel infrastructure are required (Bernt and Aaby, 2016). Although the green ship standards have not been concretely determined yet, it is stated that the eco-friendly ships whose criteria are regulated by the IMO are in status of green ships (Lee and Nam, 2017).

Shipowners, who are forced to have eco-friendly vessels by the regulations that require penalization, fill the order books of the shipyards for the construction of energy-efficient vessels that provide fuel savings and lower operational expenditures despite the high initial investment costs and competitive disadvantage in terms of high freight rates.

Shipyards also must renew their facilities and capabilities to build vessels with green technologies and gradually complete their modernization processes by making a long-term conversion plan. The choice of the shipyard location where the green ship is requested by the shipowner will be built and the layouts of this shipyard are very important. It is an important requirement to determine a shipyard location close to the intersections of logistics hubs and transportation lines, especially ports, which are a part of the global logistics supply chain and integrated with the sub-industry and organized industry. Constructing suitable buildings and workshops for a green shipyard within an optimized layout and equipping them with appropriate equipment necessitates a high initial investment cost (Song and Woo, 2013). For this reason, the feasibility of the investment cost of the green shipyard should be examined in the long term, while the existence of a financial infrastructure compatible with the strategies of holding in the short term should also be considered.

The two important milestones that will meet the IMO criteria and customer needs will be the smart and clean technologies. New technologies such as decarbonization, digitalization, automation, artificial intelligence, robotics, and the internet of things (IoT) will bring many innovations that will make the green concept meaningful. The existing shipyards should adapt to the innovative technologies of the future and financial mechanisms should be established to support these huge investments (Marine Digital, 2023). The IoT infrastructure and Building Information Modeling (BIM), which facilitate "increasing operational efficiency, reducing waste, and maximizing asset and resource tracking and utilization" (Cil, et al., 2021), will not only optimize the internal production processes of the shipyards but will also be integrated into the global logistics supply chain. As eco-friendly technologies that will create a paradigm shift in the shipbuilding industry become widespread, they will also be feasible in terms of cost-effectiveness.

3. RESEARCH METHODOLOGY

The research methodology is composed of nine stages. These stages are: defining the green concept and technologies, reviewing literature and previous research findings, defining the research problem, formulating the hypothesis, determining the gaps, designing the research model, collecting the data, analyzing the data, interpreting the data, and reporting the data.

3.1.1. Composing Research Methodology and Limitations

The ultimate goal of the green concept is to provide zero waste and zero emissions in the production, operational activities, and the scrapping of industrial products. However, innovation is required in a variety of sectors, from biodiversity to digitalization and decarbonization, to reach the zero waste and zero emission goals.

In this study, limitations have been made on which technologies will come to the forefront and with what prioritization these technologies should be implemented gradually to convert conventional shipyards into green status. The study is limited to a 32,000 DWT dry bulk carrier at a medium-sized (50,000 m2) shipyard.

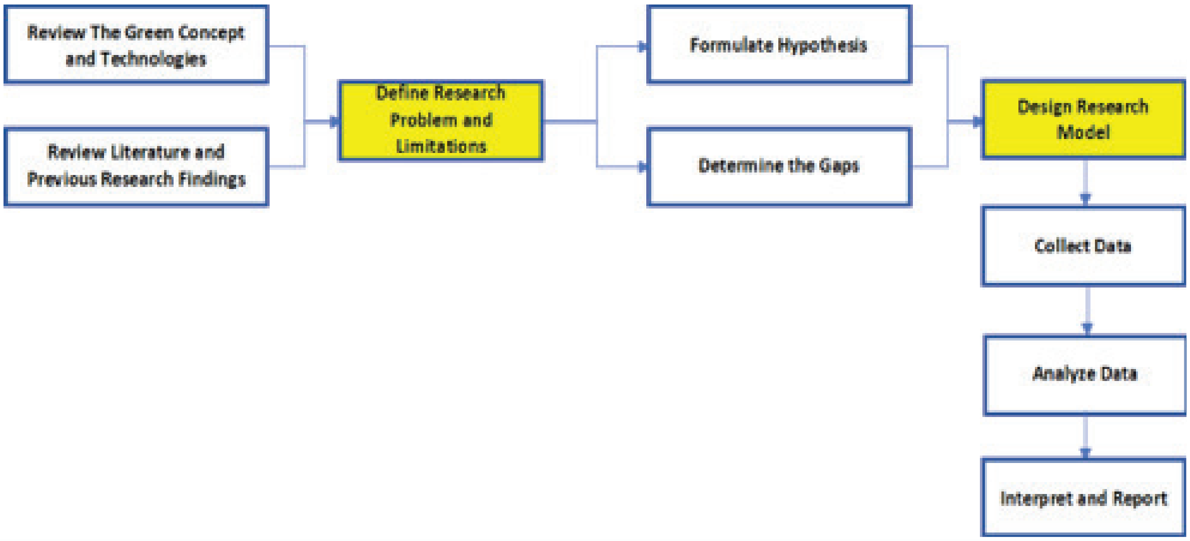

Figure 1.
Research methodology.

3.1.2. Formulating Hypothesis and Determining the Gaps

The H0 hypothesis of the research is the fact that prioritization is not necessary for the conversion of shipyards. If the H0 hypothesis is rejected, prioritization is necessary for the transformation to be done gradually; otherwise, there will be no need for prioritization with a holistic approach to the H1 hypotheses.

Many technological developments will result in cleaner environment and efficient use of energy. Some of them are under development. However, since some of these innovations have not yet turned into industrial products, they are not at a level to meet operational needs. For this reason, it will be normal to prioritize other products that will meet the green criteria, until the mature industrial products that meet these needs are realized, no matter how high-priority the needs are.

Within the scope of this research model, these gaps will be considered. The issue of what mature industrial products should be prioritized in terms of quality, budget, and man-hours are of utmost importance in transforming the yards into green-status. Prioritizing should be based on the experience of field experts. Therefore, the fuzzy-logic-based analytical hierarchical model is needed to solve the research problem and cover the gaps regarding shipyards.

4. DESIGNING RESEARCH MODEL AND CASE STUDY

Figure 2.
Process of designing the research model.

4.1.1. Data Collection

The research consists of two main surveys: scientific and industrial. In this context, five different medium-sized shipyards to produce 32,000 DWT dry bulk carriers are examined and the experienced field experts are asked for their opinions on green conversion. Although conventional shipyards are conservative in nature, strategic decisions need to be taken to replace obsolete technologies with sophisticated or cutting-edge technologies.

Table 1.
Thomas L. Saaty's 1–9 scale for AHP (Saaty and Vargas, 2006).

Intensity Level	Importance
1	Equal
3	Moderate
5	Strong
7	Very Strong
9	Absolute
2,4,6,8	Intermediate Values

Within the scope of the analytical hierarchy process, weight criteria are determined by comparing each of the main criteria and sub-criteria defined by consulting the field experts and reviewing the literature. In AHP, pairwise comparisons on a scale are used to assess the relative weight and intensity of the effects on a particular element. In Table 1, Saaty's scale of 1-9 is displayed as intensity and importance levels.

4.1.2. Determining Green Shipyard Conversion Criteria

Fuzzy-based Analytical Hierarchy Process (AHP) is a decision-making tool that can be used to evaluate and prioritize different options when converting a third-generation shipyard to a fifth-generation shipyard. The AHP method begins by defining the goal of the conversion process. Then, a hierarchical structure is created with the main criteria and sub-criteria. After the hierarchical structure is established, the relative importance of each main criterion and sub-criterion is determined using pairwise comparisons. The results of these comparisons are used to create a priority matrix that can be used to transform the shipyard. Within the scope of green shipyard conversion considering limitations, 5 main criteria and 34 sub-criteria are determined. Green shipyard conversion main and sub-criteria are shown below.

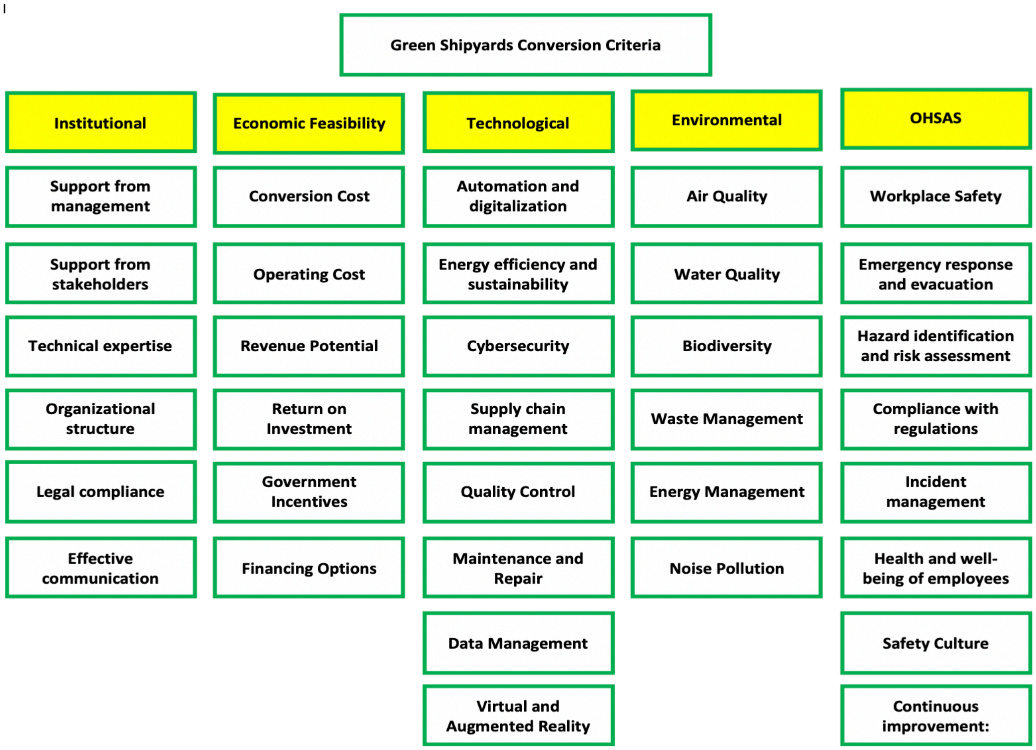

Figure 3.
Green shipyards conversion criteria.

4.1.3. Calculating Equalized and Normalized Weights

Main criteria and sub-criteria are determined as in Figure 3 to calculate the equalized and normalized weights regarding the fuzzy-based AHP. A binary comparison matrix is created. This matrix reflects the relative importance of each criterion. The matrix is normalized by dividing the sum of the rows corresponding to each cell by the number of criteria. Next, the eigenvector of the normalized matrix is calculated. This eigenvector represents the weights of each criterion.

Each weight is normalized by dividing by the sum of all weights. The weights are equalized by multiplying each weight by a constant so that the sum of the weights equals one. Using these steps, equalized and normalized weights are calculated for each criterion that can be used to convert conventional shipyards to green shipyards in the fuzzy-based AHP method.

The following formula is used for normalization.

$$\text{Comparison Matrix } (A) = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{1}$$

$$\rightarrow a_{ij'} = \frac{a_{ij'}}{\sum_{i=1}^{n} a_{ij}} \rightarrow A_1 = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

After the comparison matrix is normalized, the eigenvector (w) is calculated using the following formula.

$$A_1 = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{2}$$

$$\rightarrow w_1 = \frac{\sum_{i=1}^{n} a_{ij}}{n} \rightarrow w = \begin{bmatrix} w_{1n} \\ w_2 \\ \dots \\ w_n \end{bmatrix}$$

where, n = # of criteria

Following the calculation of the eigenvector, the eigenvalue (w') is calculated by multiplying the comparison matrix with the eigenvector, as shown in the formula below.

$$\text{Comparison Matrix } (A) \cdot \text{Eigenvector } (w) =$$

$$\text{Eigenvalue } (w') = A_w = \begin{bmatrix} w_{1n} \\ w_2 \\ \dots \\ w_n \end{bmatrix} \tag{3}$$

One of the reasons for calculating the eigenvalue and eigenvector is to determine the lambda-max (λ_{max}) value so that consistency can be tested. (λ_{max}) can be calculated as the following formula;

$$\frac{\text{Eigenvalue } (w')}{\text{Eigenvector } (w)} = \lambda_{max} = \frac{1}{n} \cdot \left(\frac{w_1'}{w_1} + \frac{w_2'}{w_2} + \dots + \frac{w_n'}{w_n} \right) \tag{4}$$

The consistency Index (CI) can be formulated as follows;

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

where n = # of criteria

It is possible to calculate ***Consistency Index*** and Random Index values ***Consistency Ratio*** according to the formula below.

$$\text{Consistency Ratio (CR)} = \frac{\text{Consistency Index (CI)}}{\text{Random Index (RI)}} \tag{6}$$

The Random Index value is included in the aforementioned formula, considering the number of requirements specified in Table 2.

Table 2.
Random Index (RI).

Number of Requirements	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

If CR < 0,10 → Consistent, if CR ≤ 0,10 → Inconsistent. For example, A is more important than B, if A is more important than C → Consistent, B is more important than C, if C is more important than A → Inconsistent.

The five main criteria are institutional criteria (INS), economic feasibility criteria (EF), technological criteria (TECH), environmental criteria (ENV), and occupational health and safety criteria (OHSAS). Thirty-four sub-criteria are determined.

Sub-criteria of the institutional criteria are support from management (SFM), support from stakeholder (SFS), technical expertise (TE), organizational structure (OS), legal compliance (LC), and effective communication (EC).

Sub-criteria of the economic feasibility criteria are conversion cost (CC), operating cost (OC), revenue potential (RP), return on investment (ROI), government incentives (GI), and financing options (FO).

Sub-criteria of the technological criteria are automation and digitalization (AD), energy efficiency and sustainability (EEAS), cybersecurity (CSEC), supply chain management (SCM), quality control (QC), maintenance and repair (MAR), data management (DM), and virtual and augmented reality (VAR).

Sub-criteria of the environmental criteria are air quality (AQ), water quality (WQ), biodiversity (BIOD), waste management (WM), energy management (ENV), noise pollution (NP).

Sub-criteria of occupational health and safety are air workplace safety (WOS), emergency response and evacuation (ERAE), hazard identification and risk assessment (HIRA), compliance with regulation (CWR), incident management (IM), health and well-being of employees (HWE), safety culture (SAC), continuous improvement (CONI).

International institutions and organizations and international legislation were also considered in determining the criteria as it would not be sufficient to take only the opinions of the shipyard managers and employees within the scope of the transformation of conventional shipyards into green shipyards.

R&D units developing green technology and scientific publications on the subject were also taken into consideration. One of the most important documents containing the Green Shipyard Standards is ISO 14001 and the related standards (ISO, 2023). It contains an international environmental management system standard that sets out the requirements of an effective environmental management system and helps organizations to improve their environmental performance.

There is a joint industry program Green Ship of the Future developed by the Danish Maritime Cluster to promote the development of green technologies in the shipping industry (OECD, 2023). The Environmental Shipboard Index (ESI) is a tool that is accepted by the European Community Shipowners' Associations (ECSA) and the European Community Shipbuilders' Association (ECASBA) to measure and promote the environmental performance of ships. There is the Green Award Certification Program that recognizes the ships and the ship management companies that demonstrate high environmental standards. In addition, Clean Shipping Index (CSI) encourages cargo owners to operate more eco-friendly ships. Moreover, Green Marine, Blue Angel, and Environmental Class Classification also define the criteria of green ship production (Faber, Kleijn and Sturiale, 2021). The Green Shipyard Concept has been developed by DAMEN and focuses on the application of environmentally sustainable practices in the shipbuilding and repair industry (Janson, 2016). As can be seen, although there are green standards developed in different parts of the world, international standards have not been established by combining them under a single umbrella organization. There is an important gap in this area that has not yet been covered.

Consistency values regarding the main criteria and sub-criteria are presented in the table below.

Table 3.
Consistency table of the main criteria and sub-criteria.

Main Criteria	Eigenvector	Eigenvalue	λmax_Main	CI_Main	CR_Main
INS	0.014	0.029	0.617518399	-1.0956204	-0.987045406
EF	0.092	0.025			<010 Consistent
TECH	0.085	0.024			
ENV	0.038	0.010			
OHSAS	0.038	0.009			
Sub Criteria_INS	Eigenvector	Eigenvalue	λmax_Sub_INS	CI_Sub_INS	CR_Sub_INS
SFM	0.016	0.061	1.555872434	-0.88882551	-0.711060411
SFS	0.034	0.073			z010 Consistent
TE	0.066	0.049			
OS	0.094	0.009			
LC	0.059	0.055			
EC	0.043	0.069			
Sub Criteria_TECH	Eigenvector	Eigenvalue	λmax_Sub_EF	CI_Sub_EF	CR_Sub_EF
CC	0.072	0.125	1.351666147	-0.92966677	-0.743733416
OC	0.041	0.095			<010 Consistent
RP	0.067	0.106			
ROI	0.130	0.097			
GI	0.168	0.186			
FO	0.180	0.115			
Sub Criteria_ENV	Eigenvector	Eigenvalue	λmax_Sub_ENV	CI_Sub_ENV	CR_Sub_ENV
AQ	0.17	0.15	0.948134697	-1.01037306	-0.808298448
WQ	0.19	0.02			<010 Consistent
BIOD	0.34	0.31			
WM	0.10	0.13			
ENM	0.14	0.07			
NP	0.09	0.18			
Sub Criteria_OHSAS	Eigenvector	Eigenvalue	λmax_Sub_OHSAS	CI_Sub_OHSAS	CR_Sub_OHSAS
WOS	0.13	0.06	1.165701177	-0.9763284	-0.697377431
ERAE	0.15	0.09			<010 Consistent
HIRA	0.10	0.07			
CWR	0.08	0.08			
IM	0.19	0.13			
HWE	0.18	0.15			
SAC	0.05	0.09			
CONI	0.03	0.08			

The equalized and normalized weights are determined after each main criterion was compared with its own sub-criteria, and then calculated so that the sum of the weights of 34 sub-criteria would be equal to one.

The weight coefficients were ordered from the largest to the smallest, and the prioritization of the sub-criteria was ensured. The prioritized criteria are illustrated in Figure 4.

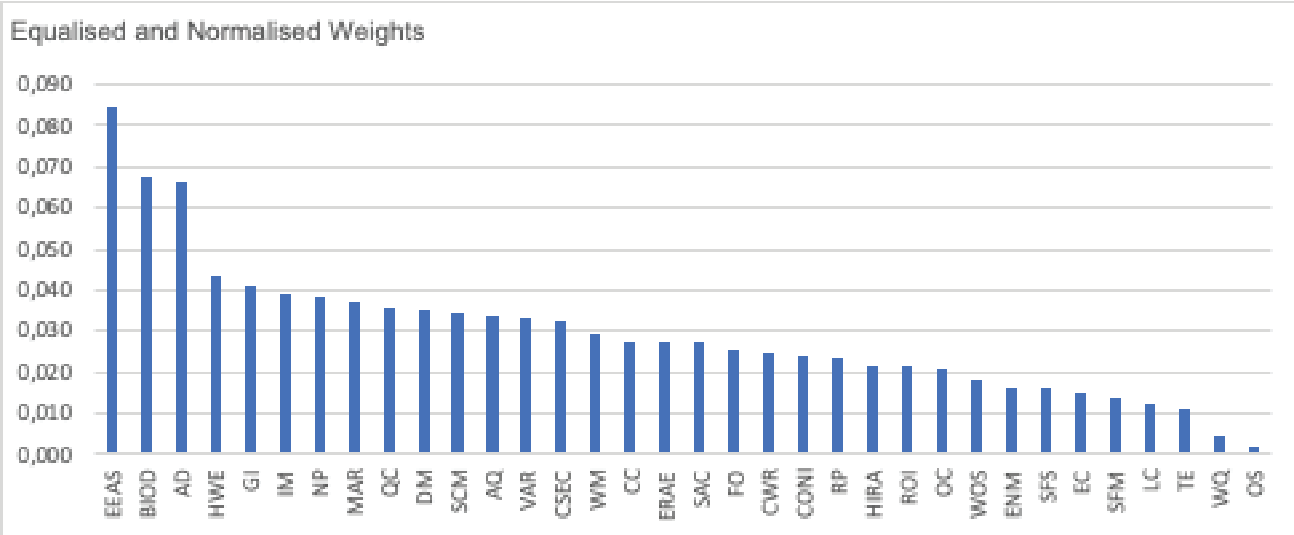

Figure 4.
Prioritized criteria.

4.1.4. Interpretation and Reporting of Prioritized Criteria

The first five of 34 prioritized sub-criteria displayed in Figure 4 are: energy efficiency and sustainability (EEAS), biodiversity (BIOD), automation and digitalization (AD), health and well-being employees (HWE), and government incentives (GI). Considering the main green shipyard conversion criteria displayed in Figure 5, it can be seen that the criteria of economic feasibility (EF), technological (TECH), environmental (ENV), occupational health and safety (OHSAS), and institutional (INS) are prioritized.

Among the main criteria in Figure 5, economic feasibility and technical criteria came to the fore. This is because the initial investment costs of new technologies are high. However, when the sub-criteria are examined, the government incentives and the biodiversity are remarkable. Because without a subsidy, a green ship to be produced until 2034 will not be feasible.

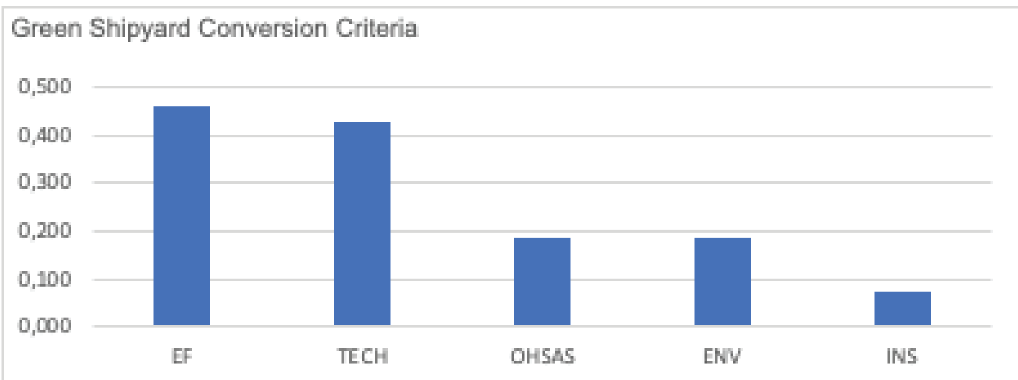

Figure 5.
Green ship conversion main criteria.

The lack of technological products will also bring the green ship standard closer to the conventional ship. At this stage, it is reasonable for these criteria to come to the fore, as new materials within the scope of biodiversity will also be needed. Economic feasibility as the main criterion would assess the financial viability of the shipyard conversion, including the cost of the conversion and the potential return on investment. Government incentives as a sub-criterion as in Figure 6 would evaluate the availability of incentives for green shipyard conversion, including tax breaks, subsidies, and other financial support. After the necessary financing is provided by an angel investor for an initial investment as well as procuring government incentives, the sub-criteria of ***energy efficiency and sustainability*** and ***automation and digitalization*** would be playing a vital role as seen in Figure 7. Energy efficiency and sustainability as a sub-criterion would consider the shipyard's ability to reduce its energy consumption and minimize its environmental impact using renewable energy sources, energy-efficient equipment, and sustainable building materials. Of course, the sub-criterion of OHSAS, of the environment demonstrated in Figure 8 and Figure 9 will continue to be the indispensable elements of green shipyards. Green shipyard's concept should prioritize human well-being to improve occupational health and safety, enhance indoor air quality, reduce stress and promote well-being, and refine work-life balance. The institutional criterion, as in Figure 10, is important to ensure the successful implementation of the green shipyard conversion as it involves the coordination of resources, the alignment of objectives and compliance of regulations.

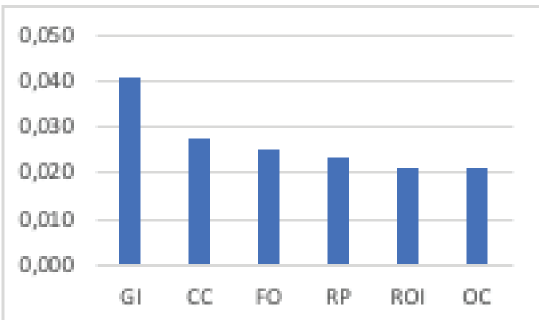

Figure 6.
Economic Feasibility sub-criteria.

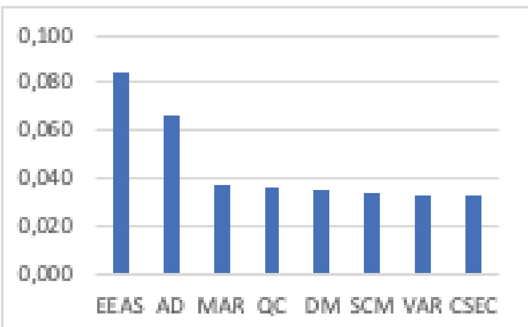

Figure 7.
Technological sub-criteria.

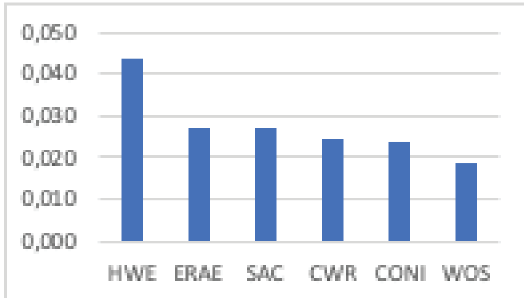

Figure 8.
OHSAS sub-criteria.

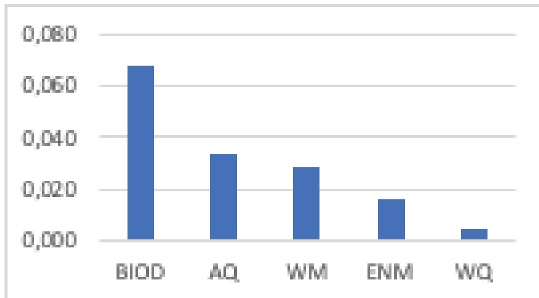

Figure 9.
Environmental sub-criteria.

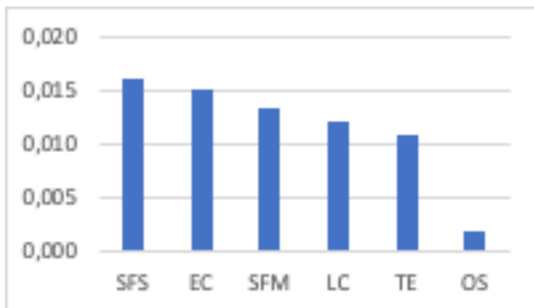

Figure 10.
Institutional sub-criteria.

5. CONCLUSION AND RECOMMENDATIONS

Green technologies, green ships, and green shipyards will create a paradigm shift in the maritime industry, realize the technological leap and make an important contribution to the goal of leaving a cleaner world to new generations when the zero emission and zero waste target are achieved in the future.

The fuzzy-based AHP method provided a consistent method for prioritizing the requirements for the transformation of green shipyards. However, the aim of the study achieved, each set of sub-criteria should be considered in a broader context, including all stakeholders and partners, such as the Green Shipping Program established by Norway, and green standards should be transformed into international standards.

Prioritized criteria and concrete results are interpreted in 4.1.4. If these prioritized criteria are considered in the transformation of a medium-sized shipyard, it is estimated that it will exceed 200 million €. It is foreseen that gradual transformation can be achieved in the management of large-scale projects, where environmental green transformation will reach one billion €, especially in the ports located in the hinterland of the green shipyards.

As a result of this research, ***economic feasibility, energy efficiency, biodiversity, and government incentives*** were determined as prioritized criteria. All sub-criteria are closely related to each other.

While transforming green shipyards, the prioritization determined within the scope of the study should consider the cost-effectiveness and the rate of return on investment. It is vital that investments, which are likely to have a very positive and productive transformation in the long run are implemented gradually with rational and strategic approaches. In the medium-term, the issues of ***energy efficiency and sustainability and automation and digitalization*** will play a vital role. For this reason, shipyards that cannot prepare their infrastructure for this process and complete their conversion will be unable to compete in the maritime industry.

CONFLICT OF INTEREST:

No financial, commercial, legal, or professional relationship exists within the conflict of interest.

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