Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2021, 65 (137), 72–83
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/462

Received: 10.12.2020
Accepted: 12.03.2021
Published: 31.03.2021

Application of multi-criteria analysis for the introduction of green port management practices: an evaluation of energy efficient mobility in nautical ports

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Keywords: nautical ports, sustainability challenges, green ports, Multi-Criteria Analysis (MCA), multi-criteria model, energy efficient mobility

JEL Classification: Q51, Q56, R40, D71

Abstract

In Europe, at the end of the 20th century, the growth of marinas followed the rapid development of recreational marine activities. This trend has now slowed and today the creation of new marinas or the extension of existing marinas is less common, mainly due to the enforcement of protective environmental regulations. As the port sector is facing some major sustainability challenges, like tackling the pollution generated from port activities, the "green port", or "green marina", concept has now become a requirement. Both types of nautical ports, public ports and private marinas, share the same responsibility to achieve management standards. The term "green port" in practice describes the responsible behavior of all stakeholders in the port's business, with a focus on the long-term vision towards the sustainable and climate-friendly development of the port's infrastructure. This paper aims to confirm the adequacy of multi-criteria analysis (MCA) for the evaluation and introduction of energy efficient mobility options in nautical ports. Within the paper, a multi-criteria based model for energy-efficient mobility selection is presented. This model is tested on two Croatian private marinas and obtained results indicating the most suitable action for both. The output of the model showed that by far the best energy-efficient solution was the installation of electric charging stations (ECS) for cars. The presented model can assist decision-makers in port authorities and marina administrations in planning and finding the best scenario for the development of energy efficient systems and services.

Introduction

In the past decade, within the port industry, an increasing commitment for the implementation of environmentally friendly solutions and the achievement of the "green port" status has been found. Numerous emerging "green" initiatives, that consider both environmental and economic aspects, have been developed. Sustainably managing port operations implies the intersection of the three main sustainability pillars, namely, environmental (to reduce the impact on the environment), social (community management), and economic (to help the organization benefit and enhance its economic performance) (UNCTAD, 2018). To improve their environmental profiles, port authorities often choose green solutions and approaches for the sustainable management of port operations and energy management (Lam & Notteboom, 2014). Achievement of the green port status represents one of the key objectives of many ports worldwide. This "Green Port" status can be achieved through various approaches, such as improving energy efficiency, collecting and recycling rainwater and waste on board, and "zero-emission" policies (Longo et al., 2015). Ports and terminals especially focus on energy efficiency and management issues, which is in the line with top 10 environmental priorities of European ports. Hence, in the past four years (2016–2019) European port authorities marked energy efficiency as the second most important environmental priority (ESPO, 2019). Integration of innovative technologies, renewable energy utilization, and new operational processes have become the main tools for the reduction of energy consumption (Acciaro, Ghiara & Cusano, 2014). Furthermore, goals for the reduction of energy consumption are in the line with key strategic priorities of the European Union. In November 2018, the European Commission presented its long term strategy with seven strategic priorities towards a climate-neutral Europe by 2050, from which the benefits from energy efficiency represents a key part (Sdoukopoulos et al., 2019). On top of the stated goals and priorities within this Strategy, there are also other relevant European documents dealing with environmental problems in seaports (EU, 2002; 2005; 2009; 2014; 2015; 2016; 2019). Within this context, for the achievement of the objectives stated within these European strategic documents, it is clear that the European port sector has an important role to play. Similarly, the role of the nautical tourism sector and the so-called small port/marinas should not be neglected. Overall, the boating industry, with a turnover of 566 billion euros and which employs 3.5 million people, is a significant contributor to the European economy. Furthermore, there are over 6 million boats in the European boat park and 10,000 marinas, which provide over 1 million berths both inland and in coastal areas, which make Europe one of the most competitive destinations globally (EBI, 2020).

Therefore, acknowledging the importance of the boating industry sector, it is thus of extreme importance to think about the implementation of green solutions and innovations in nautical ports. Also, it is important to bear in mind that the port sector is forging ahead with numerous studies which are highlighting the importance of key performance indicators and the measurement of ports' environmental performance. The complexity of the problem is reflected in the fact that ports interface with both sea and land, and therefore serve as a connection between marine and terrestrial interactions (Green Port, 2015).

Therefore, this paper aims to confirm the adequacy of multi-criteria analysis for the evaluation of the most viable investments as part of the green port management concept and energy-efficient mobility. To fulfill the research aim, a model that includes criteria for energy-efficient mobility selection is set. This paper analyses which of the proposed development concepts is the most suitable for the two selected case study areas. The criteria model and methodology used are developed as part of the DEEP-SEA project – "Development of Energy Efficiency Planning and Services for the Mobility of Adriatic MARINAs" (DEEP-SEA*,* 2020).

This paper uses the developed model criteria and tests them on marinas that are not engaged in project partnership. The secondary goal of this study is to demonstrate the possible application of the developed methodology in other areas and locations. The case study areas considered include two privately managed ports which are within close vicinity to each other (Marina Kaštela and Marina and Yacht Service Center Trogir).

The structure of the paper is as follows. After the Introduction section, a *Background* section on the green port management concept in marinas is presented. This section also deals with the pressures of nautical tourism on the environment, and provides the best port practices and policies in nautical port management and their possible implementation in small ports. The next section, *Methodology*, includes a short overview of the application of multi-criteria analysis and the theoretical background of the PROMETHEE method implemented. To carry out the multi-criteria analysis process in this research, the Visual PROMETHEE 1, Academic Edition, software was used. The next two sections are the central parts of the paper, where the *Model for the evaluation and comparison of energy efficient mobility in nautical ports* section presents a model for the evaluation and comparison of energy-efficient mobility in nautical ports. Meanwhile, *The application of MCA for the evaluation of energy efficient mobility actions in nautical ports* section brings the results of the application of MCA for the evaluation of energy-efficient mobility actions in the selected study area. The final section, *Conclusions*, provides a discussion and the concluding remarks for the applied method and obtained results.

Background: green port management concept in marinas

Both types of nautical ports, public ports open for international traffic and private marinas, share the same responsibility to achieve acceptable management standards. The term "green port" relates to sustainability in the context of the maritime industry. Adoption of green initiatives represents a decisive role in the further evolution of the sustainable port concept (Beškovnik & Bajec, 2014).

In general, this term means the production of a long-term strategy for the sustainable and climate-friendly development of the port's infrastructure (Pavlic et al., 2014). However, in practice, a green port is a synonym for the responsible behavior of all stakeholders in the port business, from the individual employees, port managers, port users and the local population. According to The World Association for Waterborne Transport Infrastructure (PIANC), the concept of a green port and a green energy policy means a "shift of thinking", moving away from a reactive approach, and towards a proactive approach with a focus on the long-term vision rather than on short-term thinking.

The key elements part of the green port management concept are (PIANC, 2014):

- A long-term vision towards an acceptable footprint on the environment and nature;
- Transparent stakeholder participation and stakeholder approved strategies;
- Shift from sustainability being a legal obligation to an economic driver;
- Active sharing of knowledge with other ports and stakeholders;
- Continuous striving towards innovation in processes and technology.

One of the key issues of this concept is energy efficiency, or the process of shifting from fossil fuels towards clean fuel sources and renewable energy sources. This influences different players in the nautical tourism sector to act accordingly, namely: Port authorities (including local and/or regional administrations which act as a port authority) – to make a shift from traditional to proactive green port and green energy approaches; Public authorities – to recognize the need of port managing authorities and to support the change; Marina operators – to plan and incorporate sustainable design principles and technologies in development projects and innovative energy-efficient services; Financial institutions – to support the development of green port infrastructure and green services in marina development projects; NGOs – to disseminate the idea and validate implemented results; Researchers – to share the knowledge on innovative technologies, their application, and benefits for the community.

Ports that aim to achieve a "green port" status should establish a system for monitoring energy consumption as well as the overall environmental quality monitoring. Sustainable development also requires a change or upgrade in current port policies and strategies to understand new opportunities, such as the exploitation of alternative fuels and renewable energy sources, can benefit the port. The joint effort of all port and marina stakeholders, as well as the local community, is crucial for the adoption of these changes. Implementation of green-port concepts and practices must be followed by the implementation of energy and Environmental Management Systems (EMS) to enable a port's management to follow accepted decisions, adopt the implementation strategies, and monitor performance (Pavlic et al., 2014).

To improve environmental and energy performance in ports, the European Sea Ports Organization (ESPO) laid down group of actions structured on a "5E" framework which includes following: exemplifying (setting a good example in the port community when managing own operations); enabling (providing conditions for facilitating port users and improving environmental performance within the port area); encouraging (providing incentives to greener port users); engaging (sharing knowledge, means and skills between port users and/or competent authorities); enforcing (using mechanisms to enforce effective environmental practices by port users and ensuring compliance). These pillars may also be used as a guideline for small public nautical ports and marinas as well (ESPO, 2012).

Pressures of the nautical tourism sector and response measures

Generally, the maritime industry generates about 3% of worldwide CO_2 emissions. Boats, yachts, other pleasure crafts and cruisers, as well as maritime tourism activities, contribute to these emissions to some extent. The pressure on coastal areas of the Adriatic Sea is extensive during the summer season. Consequently, reducing Greenhouse gas (GHG) emissions and dependences on fossil fuels, as well as shifting to renewable energy sources is big challenge for the sector. Marinas and nautical public ports are isolated in this matter and should follow common strategies for reducing their impact.

The major issues for this matter are two-fold: 1) how to reduce energy consumption and energy costs while also increasing the efficiency of port activities, and 2) how to develop long-term renewable energy sources. Marine activities have seasonal characteristics, with peak-traffic and energy consumption demands during the summer months. Furthermore, renewable energy sources like solar and wind are unlikely to provide a continuous and secure energy supply. Developing smart grid networks with buffers such as energy storage utilities, can contribute to efficient energy production and bring flexibility in balance between energy supply and demand.

To cope with these challenges, it is necessary to understand what the response options from a port's management perspective are. These options include actions that contribute to better environmental and energy management, and actions to take advantage of available technologies and services.

Where management is concerned, it is necessary to set-up good information sources based on the identification of GHG emissions and energy consumption sources, and their quantities. Then, measurement and control systems should be established. Some ports prepare so called inventories on emissions and fuel consumption as part of their first action for achieving their goals. Another area of action on the management level may be the improvement of port traffic management. Where the reduction of boat speed, reduction of waiting time for boat services, control of inbound and outbound traffic and introduction of smart berth management systems, may contribute to efficient use of energy and less air pollution. Furthermore, an Energy Management Plan should be prepared and adopted, acting as roadmap for implementation of the green port strategies to achieve an energy efficient port system.

Overview of green port initiatives in marina industry

Implementation of different environmental initiatives have proved beneficial for the development of further ports. Some of the initiatives are easily adopted, and some of them require significant investment, but all the initiatives can be divided into the following groups (Beškovnik & Bajec, 2014):

- Green shipping, with the use of green ships;
- Energy consumption and recycling processes;
- Water and land quality;
- Sustainable and clean manipulation and internal transport;
- Sustainable hinterland transport;
- Sustainable accompanying actions in port development, such as dredging, maintenance, etc.;
- Improvements in community and environmental involvement.

Furthermore, to monitor adopted initiatives by the ports, different certified measures can be used, such as: ISO9001 (Quality Management System); ISO 14001 (Environmental Management System). ISO26000 (Social Sustainability); SDM – Self Diagnosis Method; PERS – Port Environmental Review System, which incorporates the general requirements from the ISO14001 standard but adapted to the port management needs and port objectives; EMAS – European Union's Eco-Management and Audit Scheme; Port-Index – developed by ESPO (Adams et al., 2009).

Besides general quality standards and certification systems targeting impacts of activities, there are business driven initiatives which aim to evaluate the quality of operation and services of the marina industry. Compliance with such schemes is optional and involves various quality standards (e.g. water quality, safety and services, tranquility, respect of the environment, energy consumption, etc.). Participation in certification and quality labels increases the number of port visitors and helps distinguish a marina from others by ensuring that its services or locations are of a particular quality.

One of the initiatives of quality labels which exist in the marina industry, and challenges local authorities to achieve higher standards in predefined criteria, is The Blue Flag Program. The Program defines the criteria and requirements for its implementation, covering water quality, environmental management, environmental education and information, safety and services, which a marina needs fulfil in order to be awarded with the Blue Flag certification (Blue Flag, 2020). All Blue Flag marinas can only obtain certification for one season at a time, where for example, in 2019, 27 Croatian marinas were awarded with the Blue Flag. This award indicates that the sea water is clean, the marina has an environmental management plan, it performs certain activities to raise environmental awareness, it has the equipment to meet these needs, and it ensures users' safety. Therefore, obtaining the Blue Flag certification is now characterized as a brand, or an "Eco-Label" (Font, 2002).

Furthermore, the Gold Anchor scheme is another initiative, which provides a template for a customer friendly marina. The link between the Blue Flag, ISO standards and Gold Anchor Scheme is to provide all environmental aspects of a marina's activities, using a logical objective methodology to rank such aspects by their impact on the environment (Gold Anchor, n.d.).

Other programs such as The Blue Star Marina Certification and ADAC Ship's Wheel marina rating system are also used to indicate the quality of certified marinas and services.

Methodology

Ports and marinas are striving for new renewable solutions to improve their services. Each marina has different investment needs and priorities, depending on various factors, such as: how developed the port and its infrastructure is; the need for the improvement of the services for end-users. The in-sight analysis of marinas, which are involved in the DEEP-SEA project identified the need for marinas to make investments regarding energy savings, environmental protection, nautical capacities and infrastructure, and the improvement of the services for end-users. The analysis of investment needs and investment priorities of marinas point out the focus on several sustainability issues: energy resources, environment protection, and sustainable mobility. As part of these needs and priorities, regarding energy resources, marinas are prioritizing investments in energy-saving devices (microgrid, e-charges, LED, solar power…). Meanwhile, for their sustainable mobility goals, getting more e-bikes, e-boats, e-vehicles are a priority (DEEP-SEA, 2020). On top of this, marinas would like to improve their infrastructure and provide more services for users. All these aforementioned measures are decisive in order for marinas to become "Green Marinas".

To implement energy-efficient actions, marinas require a clear, defined strategy and a scenario development is needed. As part of the planning for the sustainable development of energy mobility actions it is necessary to estimate the impacts of each action that would need to be carried out. Within the DEEP-SEA project, these actions were defined during pilot site testing and considered the following activities: investment in facilities, equipment, and e-mobility services. As a result, this paper aims to confirm the adequacy of multi-criteria analysis as a suitable tool to be used as an ex-ante evaluation of the opportunity and impacts estimated by the stakeholders and marina experts.

The application of Multi-Criteria Analysis

Multi-Criteria Decision Analysis, or Making (MCDA/MCDM), is a branch of operation research models and a well-known field of decision making. According to (Belton & Stewart, 2002), MCDA is "an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter". Multi-criteria analysis is a method that is used to solve complex problems, which in most cases consist of contradictory criteria, and different, quantitative and qualitative measures (Deluka-Tibljaš, Karleuša & Dragičevič, 2013; Vilke, Krpan & Milković, 2018).

In the area of multi-criteria decisions, there are two main categorizations of multi-criteria problems (Mendoza & Martins, 2006; Deluka-Tibljaš, Karleuša & Dragičevič, 2013):

- Multi-Attribute Decision Making (MADM), or Multi-Criteria Analysis, which is suitable for so-called "ill-structured problems". In these problems, the objectives are very complex, often unclearly formulated with numerous uncertainties, and the nature of the observed problem is gradually changing over its resolution. MCA functions via the use of a limited amount of previously known alternatives that have to be evaluated and ranked. The problem is solved by finding the best variant, or a set of good variants, concerning the defined attributes/criteria and their weight;
- Multi-Objective Decision Making (MODM) is suitable for well-structured problems. Calculation of a set of unlimited feasible alternatives gives an optimal solution. Unlike predetermined alternatives in MADM, the alternatives in MODM are a set of functions that are optimized according to certain conditions.

To summarize, MCA can be defined as a decision model which contains (Hajkowicz & Collins, 2007):

1) A set of decision options (variants are ranked and scored by the decision maker(s));
2) A set of criteria (typically consisting of multi-dimensional criteria which can only be measured and evaluated in different units);
3) A set of performance measures, which represents the scores for each decision option against each criterion.

MCA/MCDM has been implemented across various application areas solving a wide range of problems like selection, sorting, and ranking (Mladineo, Jajac & Rogulj, 2016).

As energy issues and the sustainable development of energy supply systems are usually complex and involve dealing with uncertainty and different stakeholders, multi-criteria decision analysis represents a suitable decision tool (Løken, 2007;

Braune, Pinkwart & Reeg, 2009). Furthermore, another important aspect of energy planning also regards both ecological and social criteria. These types of criteria are difficult to measure, so, through relative scales, expert opinions can be quantified and included in the decision process (Braune, Pinkwart & Reeg, 2009). The most common multi-criteria decision methods used in energy planning literature are: Analytic Hierarchy Process (AHP), Weighted Sum model (WSM), PROMETHEE, ELECTRE, MAUT, fuzzy methods and decision support systems (DSS) (Pohekar & Ramachandran, 2004). These methods can handle both quantitative as well as qualitative criteria and analyze the conflict between criteria and decision makers.

The theoretical background of the PROMETHEE method

The PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) method, developed by J.P. Brans and B. Mareschal in 1983, represents one of the most noteworthy methods for MCA (Mareschal, Brans & Vincke, 1984).

The main input of the PROMETHEE method, for a multi-criteria ranking, is a matrix which consists of a set of potential alternatives (actions), A, where each element of A has its own evaluation, f (a). The PROMETHEE I method allows the partial ranking of variants, where the different variants can have the same rating, which allows the utilization of certain ranks.

Because this method allows both the partial and complete ranking of a large number of alternatives, the PROMETHEE II method is mostly used in practice, due to concern when a larger number of criteria are involved. The PROMETHEE II method ranks the actions according to a complete ranking; i.e. each variant is ranked in dependence on the function of preference (Mladineo, Jajac & Rogulj, 2016; Vilke, Krpan & Milković, 2018).

For each solution $a \in A$, the net flow is:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{1}$$

and for the solution ranking, it could be applied that:

- a has a higher rank than b:

$$(aP^{(2)}b) \quad \text{if} \quad \phi(a) > \phi(b) \tag{2}$$

- a is indifferent to b:

$$(aI^{(2)}b) \quad \text{if} \quad \phi(a) = \phi(b) \tag{3}$$

According to (Yu, Chen & Ji, 2019), "as the PROMETHEE is very easy and transparent, it can be easily understood by decision-makers. The method can offer reasonable ranking of all alternatives. Therefore, they are widely adopted in energy projects regional tourism competitiveness, and airport location selection".

Model for the evaluation and comparison of energy efficient mobility in nautical ports

Multi-criteria analysis requires decision-makers to consider different impact areas for certain solutions. The impact area of the green port management concept is represented by thematic groups of criteria. To set up a model for the evaluation and comparison of energy-efficient mobility solutions to be implemented into the green port management concept, the criteria group and sub-criteria have to be defined.

The impact area (i.e., the criteria groups for the evaluation and comparison of energy-efficient mobility solutions) in this study, was divided into four thematic groups that are divided into less complex components or sub-criteria. The model for energy-efficient mobility solutions, that include the thematic groups of the criteria and sub-criteria for evaluation, is shown in Table 1.

As seen, the defined sub-criteria for evaluation and comparison of different solutions are divided into four criteria groups or impact areas: environmental, economic, technical, and social. The economic group of criteria comprises six sub-criteria, while the other three thematic groups include four sub-criteria which are relevant for the solution evaluation. A description and explanation for each of the sub-criteria is also presented in Table 1.

In the second phase, the defined model must be evaluated by experts in the management of nautical ports. In this phase, the experts thus settle the importance of the thematic criteria and sub-criteria groups by assigning weighting coefficients (i.e., coefficients of importance). According to the information obtained from experts, the importance of the criteria groups is mutually compared. Meanwhile, the weighting coefficients for these groups are normalized so that their sum amounts to 100%. Furthermore, the weighting coefficients of the sub-criteria within a certain group are also normalized so that the total possible sum within each group is also 100%.

By analyzing the potential solutions to be assessed, and to ensure the implementation of the green port management concept, four possible actions for energy-efficient mobility were selected. Each of them

Table 1. Criteria group and sub-criteria explanation for the evaluation and comparison of energy efficient mobility solutions (prepared by authors – developed within DEEP SEA project)

Criteria group	Sub-criteria	Abb	Description
Environmental	GHG emission reduction	ER	Criteria reflect on the potential of CO_2 emissions reduction as a result of the implementation of a specific action. It analyses the difference in the emissions level before and after the action has been implemented.
	Noise reduction	NR	Criteria reflect on the reduction of noise as the result of the action, mostly caused by maritime or road traffic and operations.
	Spatial impact	SI	Criteria express the impact of the action on land usage, layout occupancy requirement, space limitation, conflict with other activities, and similar issues that may complicate the implementation of the action.
	Reduction in energy consumption	CR	Criteria consider the reduction in energy consumption as the result of the action, mostly as the result of the implementation of the new source of energy or savings resulted from the implementation of new technologies in energy production.
Economical	Cost levels	CL	Criteria consider the overall costs required for the construction and implementation of a specific action. It focuses on cost levels to be estimated according to the expectation and complexity of the investment.
	Cost effectiveness	CE	Criteria is evaluated according to the relationship between monetary inputs and the expected outcome concerning the specific objectives.
	Seasonal dependency	SD	Criteria measures the seasonal dependency of the action. It is generally better that the benefits are equally distributed throughout the year and not limited to the seasonal period.
	Development of business activities	BA	Criteria express the possibility of the expansion of economic activities in the nearby zone as a result of the action.
	Profitability levels	PL	Criteria estimate the profitability levels resulting from the action, or to what extent the action may result in an increment of the profit.
	Funding opportunities	FO	Criteria aim at considering the potential to support the action with a feasible source of funding. If the indicator is low then the action may have financial constraints.
Technical	Mobility benefit	MB	Criteria measure the benefits of improved mobility resulting from the action. It may be improved by introducing new services or by facilitating traffic movements.
	Quality of service impact	QS	Different impacts on service quality may result from the implementation of the action. The target groups are a nautical tourist and other marina end-users.
	Technical feasibility	TF	Criteria consider the technical aspects of the action, where it is assumed that the feasibility is in co-relation with the complexity of the investment, less complex action means higher technical feasibility.
	Implementability	IM	Criteria refer to the capacity of the stakeholders involved in the implementation of the action. It considers potential difficulties, barriers, or conflicts that may occur during the implementation of the action.
Social	Contribution to local/regional development	RD	Criteria focus on the effect on local and regional socioeconomic life activities. It aims at considering the change of dynamics and the potential increase for socio-economic growth in the future.
	Stakeholder acceptance	SA	Criteria reflect the overview of opinions related to the energy-efficient systems and e-services by the local stakeholders and expectations from the action.
	Social consciousness	SC	Criteria measure the opportunity to change the social awareness toward energy efficiency and e-services resulting from the action.
	Enforceability	LE	Criteria focus on the legal basis for enforcement of the implemented action. It aims to evaluate whether the action is supported by an existing legal framework and whether there is an authority responsible for implementing the action.

is defined by the criteria groups, sub-criteria, and weighting coefficients. The four actions chosen for multi-criteria analysis are:
1. Electric charging stations (ECS) for boats/vessels;
2. Electric charging stations (ECS) for cars;
3. E-mobility & sharing services;
4. Micro-grid systems.

It must be also kept in mind that any other alternative solutions for improving the energy efficiency and mobility services in a nautical port may also be added and evaluated through this multi-criteria optimization method, depending on the interest of port stakeholders. The purpose of the multi-criteria analysis is to show the opportunity and direction of the solutions for improving the green port management concept, rather than to choose only one solution with the best result. Furthermore, the most valuable result is achieved when the score is analyzed against different weighting values concerning the strategy and objectives of the nautical port operator.

The application of MCA for the evaluation of energy efficient mobility actions in nautical ports

To optimize the evaluation of energy-efficient actions a process of a multi-criteria ranking of the variants was applied via the so-called PROMETHEE II method, using a computer program for multi-criteria programming, named "Visual PROMETHEE".

Through the use of this software, the multi-criteria analysis for the evaluation and comparison of energy-efficient mobility actions was conducted in four phases in the following order:

1. the determination of the actions for energy-efficient mobility,
2. the evaluation of the actions in accordance with the criteria group and sub-criteria,
3. the comparison and ranking of the options, i.e. the evaluation of the defined actions,
4. the decision-making for the optimal solution for the nautical port.

For the application of the MCA optimization method in this study, two nautical ports were chosen: marina Kaštela and marina Trogir. Each nautical port compares the defined actions to the defined criteria groups. To perform the optimization method for the evaluation and comparison of energy-efficient mobility actions, each criteria group as well as each sub-criterion should be evaluated by assigning weighting coefficients, as explained in the previous section.

In the last step, to evaluate the performance of the action, all the defined criteria in each group explained in Table 1. have to be evaluated by marinas according to a qualitative scale. The evaluator uses the qualitative scale of indicators with ratings from 1 to 5, where 1 is the lowest value and 5 is the highest value.

Description of study areas: Marina Kaštela and Service Center Trogir-Marina Trogir

Marina Kaštela, the first case study considered, is a privately managed marina situated on the south east side of Kaštela Bay, which is shielded from the north by Kozjak Mountain and guarded by the Marjan Peninsula and the Čiovo Peninsula on the bay's southern side. The marina has an outstanding geographical position in the central Adriatic with great connections by air, railroad, bus, and ferry. Marina has 420 berths, each with electricity and water supplies (depth from 2.5 to 8 meters – 8 to 26 feet inside the marina, 10 meters – 33 feet on the outer side of the peer for mega yachts), and 200 dry berths for ships on land. Except for general services, an affiliated charter company is situated in the marina (Marina Kaštela, 2020).

Regarding the second case study marina, Service Center Trogir-Marina Trogir is located in the central part of the Adriatic coast, in a protected bay which is surrounded by numerous islets and walls of the ancient town of Trogir. The marina offers 260 sea berths for all types of vessels ranging from 10 m to 60 m in length. During the winter months, the marina has 20,000 m^2 at its disposal for storing 150 vessels (10–50 m length). Except for general services, Service Center Trogir provides complete and high-quality outboard motor servicing for all types of vessels. The Marina's business activities are certified by ISO 9001 and ISO 14001 standards (Service Center Trogir, 2020).

By using computer software, and the aforementioned case studies, an optimal solution regarding the green port management concept was selected.

To select the optimal action from the four proposed solutions, the values of the criteria obtained from the marina management interview were entered in the computer program "Visual PROMETHEE". Furthermore, the values of the importance of certain criteria groups and the criteria evaluated have also been included. Where, the importance of a certain criteria group, the sub-criteria, and the values of the attributes of individual criteria for the four defined actions will be used as input data.

Results

The results from the interviews show that both marinas give the greatest impact to the economic criteria group (value of 50%). In second place is the environmental criteria group (value of 30% for the Marina Trogir and value of 35% for Marina Kaštela). For the social impact criteria group, both marinas gave the same results (value of 10%), while for the technical group there was a slight difference (Marina Kaštela scores with 5% of impact and Marina Trogir with 10%). This shows that in this scenario, private port operators give the majority of the importance to the economic impact. To further assess this outcome,

Rank	Car		Phi	Phi+	Phi–
1	ECS cars		0.1700	0.3650	0.1950
2	E-mobility/sharing		0.0267	0.2283	0.2017
3	ECS boats		−0.0067	0.2167	0.2233
4	Micro-grid systems		−0.1900	0.1833	0.3733

Rank	Car		Phi	Phi+	Phi–
1	ECS cars		0.1600	0.3650	0.2050
2	E-mobility/sharing		0.0267	0.2317	0.2050
3	ECS boats		0.0033	0.2267	0.2233
4	Micro-grid systems		−0.1900	0.1867	0.3767

Figure 1. An overview of the result of the multi-criteria analysis for the evaluation of energy efficient mobility actions in the nautical port Kaštela (left) and marina Trogir (right)

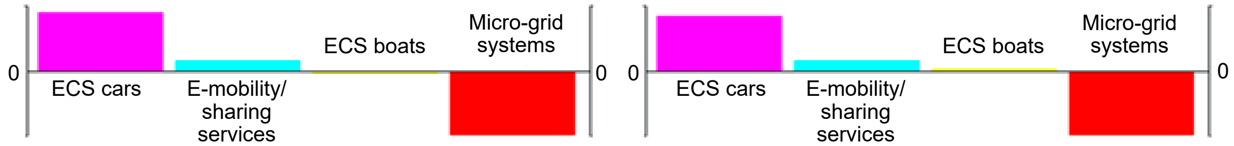

Figure 2. An overview of the multi-criteria analysis for the evaluation of energy efficient mobility actions in the nautical port Kaštela (left) and marina Trogir (right)

a sensitivity analysis could be performed for port strategies and development objectives.

The multi-criteria optimization method PROMETHEE I calculated the Phi values of two preference flows (Phi+ and Phi−) (i.e., the relations of the dominance of certain pairs of actions). The PROMETHEE II gave the final rankings for the actions based on the net preference flow (Phi).

In Figure 1, the obtained results for each individual energy-efficient mobility action and their positive and negative values of Phi are shown. Figure 2 brings a graphic overview of the numerical values of net flows.

From the above-presented results, the ranking of analyzed energy-efficient mobility actions is similar for both marinas. The Electric charging stations (ECS) for cars, with a value of the net flow of 0.17 (Kaštela) and 0.16 (Trogir), is the most highly ranked action; while E-mobility and sharing services take second place, with a net flow ranking of 0.0267 for both marinas. The differences between marinas is highlighted for the action which can in third place. While the results for Marina Trogir for the Electric charging stations (ECS) for boats were close to zero (0.0033), but positive, the results for Marina Kaštela expressed negative results with a net flow of −0.0067. The final action (micro-grid systems), expressed negative values for both marinas, with a net flow of −0.1900. From the elaborated results, the most suitable action (for both marinas), which presents no weaknesses with respect to the other actions, is the electric charging stations (ECS) for cars. Where, of course, the final choice according to the set goals is dependent on the decision-maker.

To provide detailed insight into the problem of choosing an appropriate energy-efficient mobility action, the GAIA ("Geometrical Analysis for Interactive Aid") plane was used as a descriptive complement to the PROMETHEE rankings. It functions via a standard two-dimensional GAIA plane, and a direct interpretation of a multiple-criteria analysis in a "u, v" can be made. Also, on the plane, both, the actions and criteria are visible, and so an analysis of the conflicting criteria can be carried out significantly faster. Each criterion is represented by an axis drawn from the center of the GAIA plane. Criteria that express similar preferences are grouped together with each other, while the conflicting criteria are in opposite directions (dispersed). The same applies to the actions (i.e., actions with similar numerical characteristics will be closer to each other).

Again, and as seen in Figure 3, the best results are shown for the "ECS for cars" action for both marinas. This was largely as a result of the higher weighting of the economic criteria, which includes cost-effectiveness, development of business activities, profitability levels, funding opportunities, investment and operation cost level, and seasonal dependency; where as seen previously both marinas prioritized the economic criteria group. Similarly, the "ECS for cars" option also scored the highest for the environmental section (second highest weighting) for the Marina Trogir results.

The direction of the majority of the "ECS cars action" criteria vectors for both marinas, implies its dominance over the other energy-efficient mobility actions. Also, the direction of the decision axis (red vector) for both marinas, prioritizes "ECS cars action" over the other options. It must also be noted that the vector axes of individual criteria are dispersed (i.e., they influence the respective action with different intensities). Where, the closing or conflicting sub-criteria equally affect the respective action.

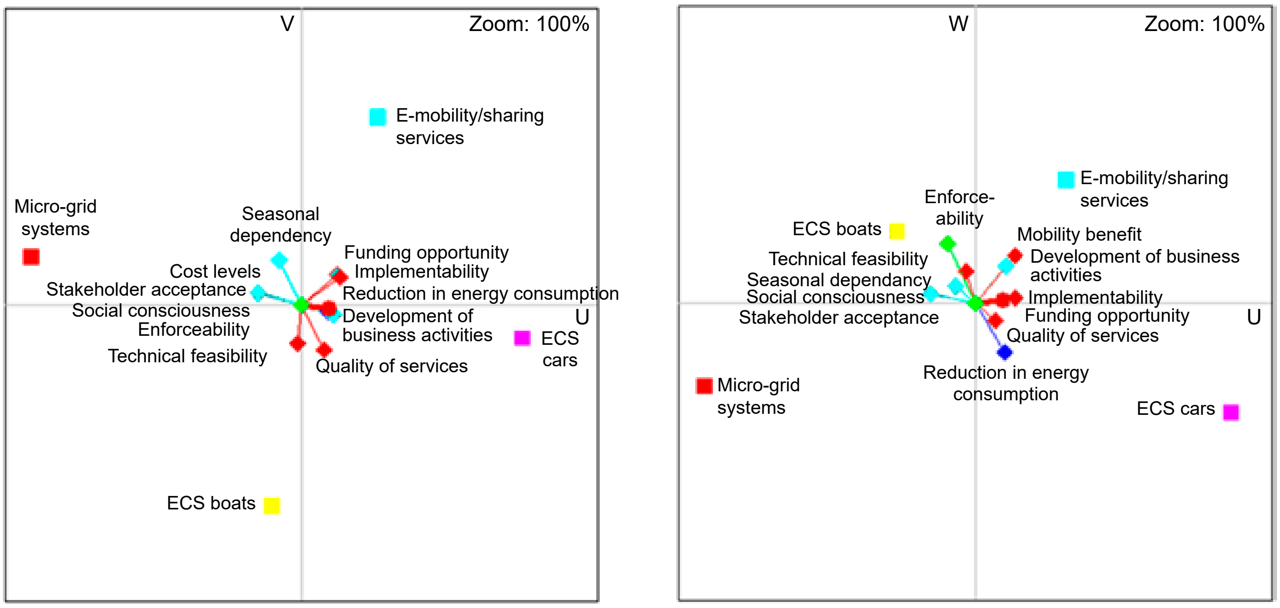

Figure 3. An overview of the multi criteria analysis in the GAIA plane for the Marina Kaštela (left) and Marina Trogir (right)

Conclusions

Many port authorities are now implementing Environmental Management Systems (EMS) to systematically and sustainably manage their seaports. A major, current priority for the environmental management of marina infrastructures is to minimize consumption, especially of water and electricity, and prevent water and air pollution; without compromising user comfort. As a result, the basic requirements of EMS for marinas are typically based on standards, such as ISO 14001, EMAS, and the PERS methodology.

Port development strategies are one of the key issues involved in their management planning. And when the "greening" concept is included as part of a port's strategic development, its effectiveness and success depend on the tools adopted by the port authorities and/or administrations. According to (Lam & Notteboom, 2014) each management authority may choose one or several tools among the following: charging and pricing; monitoring and measuring; market access control; environmental standard regulation.

Different modes of marina management and diversity in marina establishment and organization impose differences in objectives, functions, market position, competencies, and investment capabilities. That is also a case with environmental and energy considerations, depending on the specific location and characteristics of each marina.

As marinas are decisive in their goal to become "Green Marinas", further investments regarding energy saving and environmental protection are needed. To properly invest in energy-efficient solutions it is necessary to estimate the impacts of the actions which need to be carried out. As part of this, the evaluation of the energy-efficient mobility actions can be done with Multi-Criteria Analysis, as confirmed in the present study. As part of this study, the defined criteria groups for the MCA evaluation and the comparison of energy-efficient mobility solutions have been done based on the information collected for the case studies considered, including from representatives of the two case study marinas, experts, scientific researchers, and other relevant stakeholders in the marina industry. Analyzing the obtained MCA results, for the introduction of the energy-efficient mobility actions in nautical ports, both marinas gave priority to electric charging stations (ECS). These results were derived from the higher-weighted economic criteria in the model developed, which includes cost-effectiveness, development of business activities, profitability levels, funding opportunities, investment and operation cost level, and seasonal dependency considerations. This study also provides a characteristic scenario for private port operators; who give major importance to the economic impact of green port management practices.

A multi-criteria-based optimization model, such as the one used in this study, which includes criteria for energy-efficient mobility selection, can also be applied in other nautical ports where new solutions are needed to improve energy efficiency and mobility services. This model can assist decision-makers in port authorities and marina administrations in planning and finding the best scenario for the development of energy-efficient systems and services. The background goal of the paper, which included the testing of the model on more than one study area, was also achieved.

Finally, it is important to highlight that both types of nautical ports (public ports and private marinas) share the same responsibility to achieve acceptable management standards. This means that both business and industry growth targets, and social and environmental acceptability, should be achieved through sustainable development. Ports are not just service providers, but also energy consumers and potential energy production centers.

Acknowledgments

The submitted paper was prepared within the framework of the project Development of Energy Efficiency Plan and SErvices for the mobility for the Adriatic MARINAs (DEEP SEA), No. 10047821. The Interreg HR-ITA 2014/2020 is the Program's main coordinator.

References

1. Acciaro, M., Ghiara, H. & Cusano, M.I. (2014) Energy management in seaports: A new role for port authorities. *Energy Policy* 71, pp. 4–12; doi: 10.1016/j.enpol.2014.04.013.
2. Adams, M., Quinonez, P., Pallis, A.A. & Wakeman, T.H. (2009) Environmental issues in port competitiveness. Working Paper No. 7 of the Atlantic Gateway Working Paper series. Dalhousie University, Centre for International Trade and Transportation, Halifax, Canada, January.
3. Belton, V. & Stewart, T.J. (2002) *Multiple Criteria Decision Analysis*. Springer: Boston, MA; doi: 10.1007/978-1-4615-1495-4.
4. Beškovnik, B. & Bajec, P. (2014) Determination of environmental initiatives and measures for port systems: The case of Koper Port. *Scientific Journals Maritime University of Szczecin, Zeszyty Naukowe Akademia Morska w Szczecinie* 39 (111), pp. 16–24.
5. Blue Flag (2020) *Blue Flag marina criteria and explanatory notes 2020*. [Online] Avaliable from: https://www.blueflag.global/criteria [Accessed: December 09, 2020].
6. Braune, I., Pinkwart, A. & Reeg, M. (2009) *Application of multi-criteria analysis for the evaluation of sustainable energy systems – A review of recent literature*. In Proceedings of 5th Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems.
7. DEEP-SEA (2020) *Development of Energy Efficiency Planning and Services for the Mobility of Adriatic MARINAs*. [Online] Avaliable from: https://www.italy-croatia.eu/web/deep-sea [Accessed: December 09, 2020].
8. Deluka-Tibljaš, A., Karleuša, B. & Dragičevič, N. (2013) Pregled primjene metoda višekriterijske analize pri donošenju odluka o prometnoj infrastrukturi. *Gradjevinar* 65, 07, pp. 619–631; doi: hrcak.srce.hr/106196.
9. EBI (2020) *European Boating Industry*. [Online] Avaliable from: https://www.europeanboatingindustry.eu/ [Accessed: December 09, 2020].
10. ESPO (2012) Annex 1: Good practice examples in line with the 5 Es. In *ESPO Green Guide: Towards excellence in port environmental management and sustainability*. [Online] Avaliable from: https://www.espo.be/publication/espo-green-guide-towards-excellence-in-port-enviro [Accessed: December 09, 2020].
11. ESPO (2019) *EcoPortsinSights 2019*. ESPO Environmental Report 2019. [Online] Avaliable from: https://www.espo.be/media/Environmental%20Report-2019%20FINAL.pdf [Accessed: December 09, 2020].
12. EU (2002) Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise – Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise. *Official Journal of the European Union* L 189.
13. EU (2005) Directive 2005/35/EC of the European Parliament and of the Council of 7 September 2005 on ship-source pollution and on the introduction of penalties for infringements. *Official Journal of the European Union* L 255/11.
14. EU (2009) Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union* L 140/16.
15. EU (2014) Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure. *Official Journal of the European Union* L 307/1.
16. EU (2015) Regulation (EU) 2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC. *Official Journal of the European Union* L 123/55.
17. EU (2016) Directive (EU) 2016/802 of the European Parliament and of the Council of 11 May 2016 relating to a reduction in the sulphur content of certain liquid fuels. *Official Journal of the European Union* L 132/58.
18. EU (2019) Directive (EU) 2019/883 on port reception facilities for the delivery of waste from ships. *Official Journal of the European Union* L 151/116.
19. Font, X. (2002) Environmental certification in tourism and hospitality: Progress, process and prospects. *Tourism Management* 23, 3, pp. 197–205; doi: 10.1016/S0261-5177(01)00084-X.
20. Gold Anchor (n.d.) *Gold Anchor. General Infomation and Application Form*. [Online] Avaliable from: https://www.marinas.net.au/documents/item/7 [Accessed: December 09, 2020].
21. Green Port (2015) *KPIs and measuring environmental performance*. [online] Avaliable from: https://www.greenport.com/news101/Projects-and-Initiatives/kpis-and-measuring-environmental-performance-at-ports-and-terminals [Accessed: December 09, 2020].
22. Hajkowicz, S. & Collins, K. (2007) A review of multiple criteria analysis for water resource planning and management. *Water Resources Management* 21, pp. 1553–1566.

23. Lam, J.S.L. & Notteboom, T. (2014) The Greening of Ports: A Comparison of Port Management Tools Used by Leading Ports in Asia and Europe. *Transport Reviews* 34 (2); doi: 10.1080/01441647.2014.891162.
24. Løken, E. (2007) Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews* 11, 7, pp. 1584–1595; doi: 10.1016/j.rser.2005.11.005.
25. Longo, F., Padovano, A., Baveja, A. & Melamed, B. (2015) *Challenges and opportunities in implementing green initiatives for port terminals*. 3rd International Workshop on Simulation for Energy, Sustainable Development and Environment, SESDE 2015.
26. Mareschal, B., Brans, J.P. & Vincke, P. (1984) *Prométhée: a new family of outranking methods in multicriteria analysis.* ULB Institutional Repository 2013/9305, ULB – Universite Libre de Bruxelles.
27. Marina Kaštela (2020) *Marina Kaštela official web page*. [Online] Avaliable from: https://www.marina-kastela.hr/ [Accessed: December 09, 2020].
28. Mendoza, G.A. & Martins, H. (2006) Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. *Forest Ecology and Management* 230, 1–3, pp. 1–22; doi: 10.1016/j.foreco.2006.03.023.
29. Mladineo, M., Jajac, N. & Rogulj, K. (2016) A simplified approach to the PROMETHEE method for priority setting in management of mine action projects. *Croatian Operational Research Review CRORR* 7 (2), pp. 249–268; doi: 10.17535/crorr.2016.0017.
30. Pavlic, B., Cepak, F., Sucic, B., Peckaj, M. & Kandus, B. (2014) Sustainable port infrastructure, practical implementation of the green port concept. *Thermal Science* 18, 3, pp. 935–948; doi: 10.2298/TSCI1403935P.
31. PIANC (2014) *Sustainable Ports – A Guide for Port Authorities*. *Raport No. 150*. The World Association for Waterborne Transport Infrastructure.
32. Pohekar, S.D. & Ramachandran, M. (2004) Application of multi-criteria decision making to sustainable energy planning – A review. *Renewable and Sustainable Energy Reviews* 8, 4, pp. 365–381; doi: 10.1016/j.rser.2003.12.007.
33. Sdoukopoulos, E., Boile, M., Tromaras, A. & Anastasiadis, N. (2019) Energy efficiency in European ports: State-of-practice and insights on the way forward. *Sustainability* 11(18), 4952; doi: 10.3390/su11184952.
34. Service Center Trogir (2020) *Service Center Trogir – Marina Trogir*. [Online] Avaliable from: https://sct.hr/ [Accessed: December 09, 2020].
35. UNCTAD (2018) *Review of Maritime Transport 2018*. [Online] Avaliable from: https://unctad.org/system/files/official-document/rmt2018_en_pdf [Accessed: December 09, 2020].
36. Vilke, S., Krpan, L. & Milković, M. (2018) Application of the multi-criteria analysis in the process of road route evaluation. *Tehnicki Vjesnik* 25, 6, pp. 1851–1859; doi: 10.17559/TV-20170530085451.
37. Yu, X., Chen, H. & Ji, Z. (2019) Combination of probabilistic linguistic term sets and PROMETHEE to evaluate meteorological disaster risk: Case study of southeastern China. *Sustainability* 11 (5), 1405; doi: 10.3390/su11051405.

Cite as: Ukić Boljat, H., Vilke, S., Grubišić, N. & Maglić, L. (2021) Application of multi-criteria analysis for the introduction of green port management practices: an evaluation of energy efficient mobility in nautical ports. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 65 (137), 72–83.