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Conceptual Framework For Integration On Renewable Energy Sources For Marine Port Electrification

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1. ABSTRACT: In our days electrical energy demand for marine ports in order to cooperate climate change related with zero emissions exhaust gases for the ships has been increased. In order to adapt the situation for the marine port and not use the main grid powered by traditional power stations using fossil fuels, the insertion of renewable energy sources is recommended. The situation created many problems due to variable energy output of renewables and storage system required to be integrated. The authors of this paper propose a decision support framework for the identification and evaluation of the various renewable energy sources and their integration into marine port grid using the Analytic Hierarchy Process and taking into account a number of criteria, as well as, the energy requirements of port activities (i.e.: cold ironing, electrical moving assets, electrical handling devices, etc.). The Kaliningrad sea fishery port (Russia) is used as a case study. The use of hydrogen and hi- pressure as a storage of excessive energy is also to be considered. The proposed framework will advise decision-makers and port stakeholders on choosing the most suitable renewable energy source in the context of a zero-emission port.

Keywords: ***green ports, green logistic, intelligent methods, energy management, zero emissions.***

2. INTRODUCTION

Marine ports connect a nation as well as the world through the maritime transport networks. Often the prosperity of a marine port is considered a measure for the prosperity of a city or a country. Ports and cities are considered interdependent, where the development of port activity leads to urban development and conversely. Marine ports consume a substantial amount of energy for their everyday operations, particularly for the various ship's activities such as loading, uploading, lighting, cooling, etc. In combination with the nearby industrial activities, ports have an expected negative impact on the environment. Nowadays, most ports use diesel engines that lead to a substantial amount of pollutant gases [1]. Furthermore, marine port operations are often associated with a variety of consequences such as noise and light pollution, water and soil pollution, sea level rise, coastal erosion and coastal flooding, traffic congestion, accidents, vibrations, and land take, resulting from port and ship activities and land transport. All these factors negatively affect the work and living conditions of residents living in cities near the port [1, 2]. In this context, the paper proposes the concept of a zero-emission port, encouraging the use of renewable energy sources.

The study presents a conceptual framework for the evaluation of renewable energy sources based on the Analytic Hierarchy Process (AHP). Choosing the most suitable renewable energy source is often considered a complicated decision-making issue, which AHP can resolve. The AHP firstly developed by Saaty (1980) [3] is considered one of the most notable representatives of Multi-Criteria Decision Analysis (MCDA) techniques and its application is very often in the literature in various fields such as politics, economics, spatial planning, etc. Many studies apply AHP for a variety of purposes, including selecting the most appropriate renewable energy source [1, 4-10]. Even though there is a variety of renewable energy sources (e.g. solar, wind, tidal, wave, geothermal, biomass, and hydro) this does not mean that they are appropriate for a specific site or an industrial sector.

This paper presents a decision support framework for selecting the most suitable energy alternative in the light of the zero-emission port. The paper is set out as follows: the concept of zero-emission port together with a brief description of the case study are presented in section 3. Section 4 presents in detail the proposed methodology. The results and conclusions are discussed in sections 5 and 6 respectively.

3. THE CONCEPT OF ZERO-EMISSION PORT AND THE PORT OF KALININGRAD AS A CASE STUDY

Nowadays, more environmentally friendly solutions are increasingly being considered in marine ports due to the challenges of climate change and the adoption of environmental regulations. In order to reduce air pollution and comply with international environmental regulations, in 2011 the IMO set a 50% reduction in greenhouse gas emissions from ships by 2050, despite increases in freight and passenger transport to date. To achieve these goals, several changes must be made in the shipping sector, both for ships and for ports [11]. In addition to the choice of green fuels, scrubbers, and electric ships that can be powered by renewable sources and the use of storage systems, ports are coming to add another alternative solution: Cold ironing.[1]

During cold ironing, ships shut down their engines while berthed and plug into a land-based power source. During this process, all main operations of the ship can still receive continuous electricity while

the vessel is loading or unloading its freight. Although cold ironing is a good alternative, there are some challenges to consider, such as cold ironing infrastructure at marine terminals, lack of standardization, absence of concrete legislation/regulation. Despite the challenges and technical difficulties that may occur, major ports (e.g. Los Angeles, Long Beach, Seattle, Antwerp, Hamburg, Rotterdam, etc.) have already adopted the cold ironing solution, offering important benefits in terms of limited emissions and costs [12].

Although, cold ironing is a way to reduce ships' emissions the fact that is connected with the grid is a drawback for its holistic approach. So, in order to reduce the environmental footprint of cold ironing ships and to avoid the use of the main grid, the use of RES such as wind turbines, mainly offshore due to land limitations in the port, wave devices, solar panels on building roofs and warehouses or floating, etc.as well as storage solutions are increasingly being considered in marine ports. In order to be able to manage all these different aspects (sources, storage solutions, and loads) the development of microgrids in ports is examined in the last decade [11].

[1] It can also be found in the international literature with the terms: shore-side electricity supply, shore-to-ship power.

The microgrid or smartgrid can be considered as a self-healing system that reduce workload. The control and distribution center has many renewable energy sources depending on the availability of port resources. The center is connected to a fixed electricity network that is used as needed and a digital metering system to record the energy requirements of the marine port and thus to distribute the required available electricity. The surplus energy generated from renewable energy sources is converted to hydrogen and can be used in electric vehicles for marine port activities or stored in high-capacity batteries of new technologies. [2]. Even though, microgrids have been extensively used around the world, in different types and areas (e.g. cities, remote communities, etc.) they are still rare in ports due to the diversity of loads. This condition includes technical challenges, which can now be addressed with Artificial Intelligence (AI) techniques [2, 11].

The proposed methodology in this study is applied to the Kaliningrad sea fishery port, which operates in the port of Kaliningrad, the westernmost port in Russia (Fig.1).

Figure 1. Geographical location and territory plan

Kaliningrad marine port is located in the northern side of the Kaliningrad Sea canal as well as at the estuary of the Pregolya River, offering berths of 17 Km. The length of the canal is 43 Km, the width is 50-80 m and the depth between 9 to 10.5 m. The canal can be used to transport a ship up to 200 meters long [13]. Kaliningrad fishery port provides a range of services including cold ironing and shore power supply [14]. Figure 2 provides detailed data on average power consumption (kW) [2].

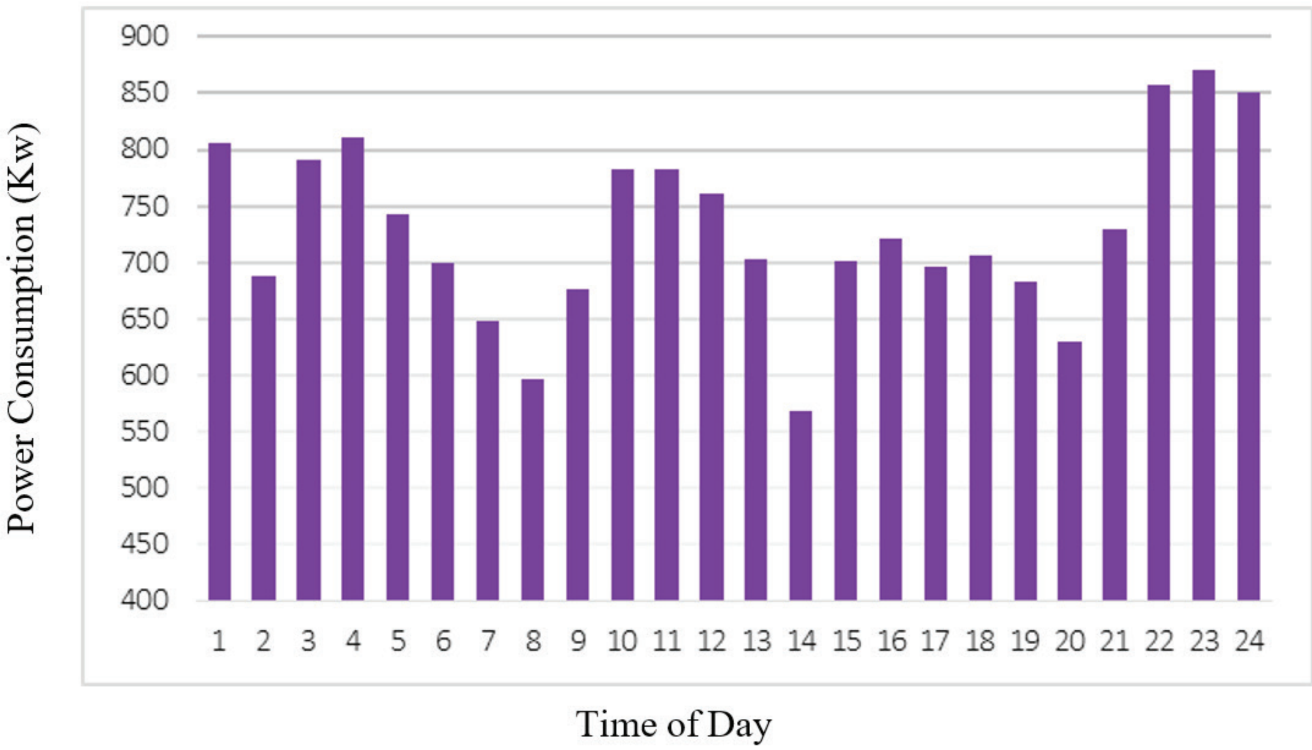

Figure 2. Average power consumption (Kw).

The Kaliningrad sea fishery port has a good resource availability for the development of renewable energy sources. The average wind speed is 7 m/sec (50 m) and 8 m/sec (100 m), and the average solar radiation is 2.8 kWh/m2 [14]. The possibility of developing wave energy is also being explored.

4. METHODOLOGY

4.1 Evaluation criteria for the selection of renewable energy technology

Choosing the most suitable energy alternative can be a challenging issue as many criteria have to be considered, such as technical, economic, social, spatial, and environmental that may be in conflict with each other. Such a selection problem can be resolved using multi-criteria analysis techniques and AHP which is a powerful technique that handles such multiple attribute issues.

Although, there are many types of renewable energy sources, they may not all be suitable for a particular site or industrial sector such as a port. Based on the case study resource availability, and previous studies on the potential for development of renewable energy sources in the port area, the following technologies have been selected for further consideration: wind turbines (onshore and offshore), solar panels (onshore and offshore) and wave devices.

In order to select the most appropriate energy alternative for marine port electrification, this initial stage of methodology accepts that there are graduations in the five (5) renewable energy technologies, which essentially arise from the evaluation of energy options in various parameters. Ten (10) evaluation criteria are used based on the literature review and the opinion of experts through interviews, as follows: (Table 1) [1, 4-10]:

- Resource availability: Availability of renewable sources for energy production.
- Technological maturity: is the degree of diffusion of a technology at regional, national and international level, and shows that a specific technology has reached the theoretical performance limit or that the technology still needs improvements.
- Know-how: Availability of specialized human resources in the region/country for
- installation, operation, and maintenance purposes.
- Capacity factor: it is an indicator that essentially shows the amount of energy we can get from a source.
- Investment cost: is the total cost resulting from the installation of an energy unit, including equipment, labor, and infrastructure and commissioning costs.
- O&M cost: is the operating cost of the energy unit, including employees' salaries, the cost of spare parts required for maintenance purposes, etc.
- Land requirements: Each energy unit takes up space. Conflicts can occur if the space is used by other (sea) users. These barriers may hinder the licensing and development of the unit.
- Job creation: The possibility of creating employment opportunities, especially for local communities.
- Social acceptance: is the public opinion toward a type of power unit.
- Impact on ecosystem: is a measure of the potential impact of the energy plant on the (marine) environment.

Table 1. Evaluation criteria

Evaluation criteria	*Abbreviation*	*Type of criterion*
Resource availability	RA	**Technical**
Technological maturity	TM	**Technical**
Know-how	K-H	**Technical**
Capacity factor	CF	**Technical**
Investment cost	IC	**Economic**
O&M cost	O&M	**Economic**
Land requirements	LR	**Spatial**
Job creation	JC	**Social**
Social acceptance	SA	**Social**
Impact on ecosystem	**IOE**	**Environmental**

1.1 The Analytic hierarchy process

In addition, the ten (10) evaluation criteria may not be of equal importance. Therefore, the most important criteria should be weighted more than the others. This can be achieved through the AHP and the pair-wise comparison matrix.

The initial stage of AHP includes developing the hierarchical structure of the selection problem, as shown in Figure 3. The general objective of the selection problem is at the upper level, the ten (10) predefined evaluation criteria at the second level and the five (5) energy options at the lower level.

Next step is the creation of the pair-wise comparison matrix of the ten (10) evaluation criteria listed above according to 9-point scale of Saaty (1980). In this way, the preferences of stakeholders who participate in the procedure are decoded and incorporated in the methodology.

Third step is to calculate the weights of the ten evaluation criteria, including a number of individual steps. The results as obtained from the above steps are presented in Table 2.

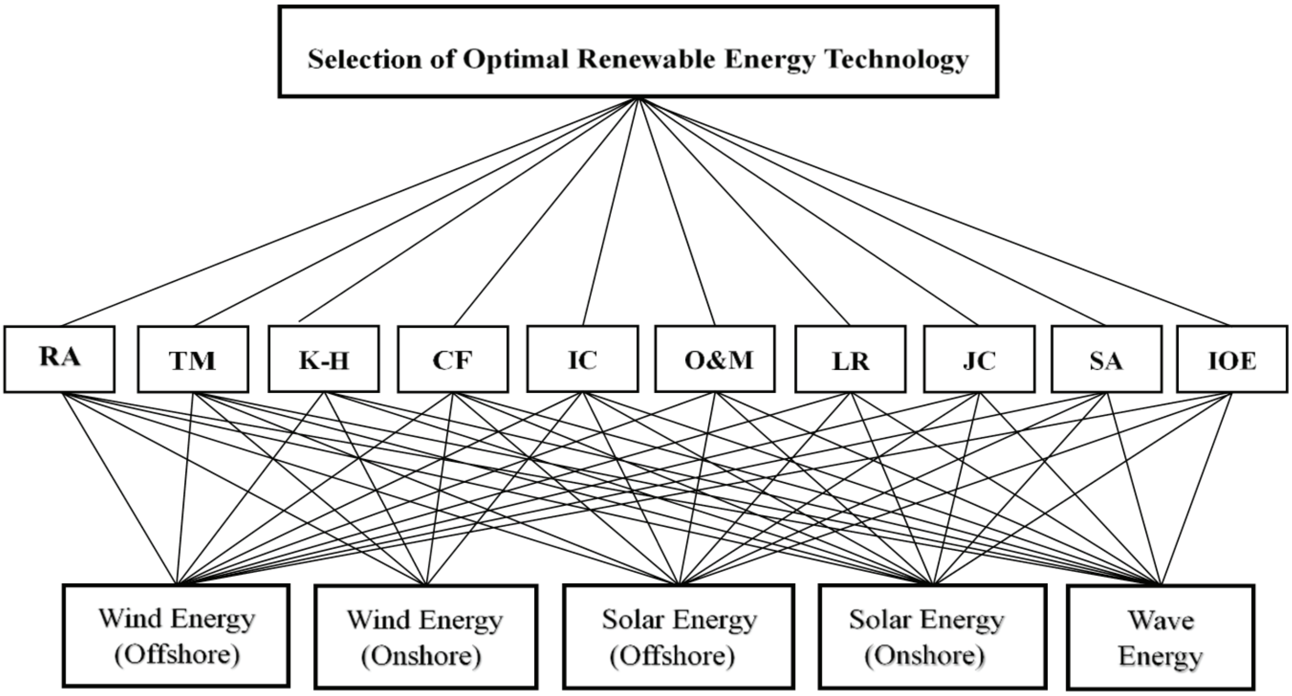

Figure 3. Hierarchical structure for the selection of the most appropriate RES technology

The final stage of AHP is the calculation of Consistency Ratio (CR). CR is a very useful indicator, as it ensures that the opinions taken into consideration were correct. Firstly, the Consistency Index (CI) is calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{10.37-10}{10-1} \quad (1)$$

Where n= the number of evaluation criteria, and □_max= maximum eigenvalue Finally, the Consistency Ratio (CR) is calculated from the following formula:

$$CR = \frac{CI}{RI} = \frac{0.041}{1.49} = 0.027 \quad (2)$$

Where RI = Random Consistency Index of a random-like matrix. The CR must not be greater than 0.1.

Table 2. Pair-wise comparison matrix and weights

Criteria	*RA*	*TM*	*IC*	*O&M*	*IOE*	*SA*	*LR*	*JC*	*K-H*	*CF*	*Weights (%)*
RA	0.316	0.383	0.349	0.349	0.297	0.259	0.23	0.206	0.188	0.173	*27.5*
TM	0.158	0.191	0.232	0.232	0.223	0.207	0.191	0.177	0.164	0.154	*19.4*
IC	0.105	0.097	0.116	0.116	0.148	0.155	0.153	0.147	0.141	0.134	*13.2*
O&M	0.105	0.097	0.116	0.116	0.148	0.155	0.153	0.147	0.141	0.134	*13.2*
IOE	0.079	0.063	0.058	0.058	0.074	0.103	0.115	0.118	0.117	0.115	*9*
SA	0.063	0.048	0.038	0.038	0.037	0.051	0.076	0.088	0.094	0.096	*6.3*
LR	0.052	0.038	0.029	0.029	0.024	0.026	0.038	0.059	0.07	0.077	*4.5*
JC	0.045	0.032	0.023	0.023	0.018	0.017	0.019	0.029	0.047	0.057	*3.1*
K-H	0.039	0.027	0.019	0.019	0.014	0.013	0.012	0.014	0.023	0.038	*2.2*
CF	**0.035**	**0.024**	**0.016**	**0.016**	**0.012**	**0.01**	**0.009**	**0.009**	**0.011**	**0.019**	*1.6*

4.3 Performance score of energy alternatives

Once the ten (10) evaluation criteria of energy alternatives have been identified based on the literature review and expert's judgments, and weighted through the AHP, the next step is to evaluate the performance of the renewable energy alternatives for each evaluation criterion using a scale of 0-10 (Table 3).

Table 3. Performance scores of ten evaluation criteria

Evaluation criteria	*Scores*	
	0	*10*
RA	Low and unpredictable	**High and predictable**
TM	Technology is still relatively new	**Technology has been used for a long time**
IC	Most expensive	**Least expensive**
O&M	Most expensive	**Least expensive**
IOE	Significant impact on the environment	**Minor/negligible impact on the environment**
SA	Negative public attitude towardspecific renewable energy source	**Positive public attitude toward specific renewable energy source**
LR	No land available/Conflicts with otherusers	**Spacious land available/No conflicts**
JC	Few/negligible job opportunities	**Substantial job opportunities**
K-H	Lack of specialized human resourcesin the region/country	**Availability of specialized human resourcesin the region/country**
CF	**Low**	**High**

Experts were asked through interviews to evaluate the performance of each energy option in each evaluation criterion for the Kaliningrad sea fishery port, taking into consideration the hypothetical question "What would be the performance e.g. of first energy option in the first evaluation criterion, if the first energy option is used in the fishery port of Kaliningrad;" and so on, as described in the study by Budak et al. (2019).

The weights in the above methodology step (§ 4.2) are not geographically dependent. On the contrary, the process of performance score of each energy alternative is site-specific, which means that the involvement of experts, who not only know about renewable energy sources, but also have in-depth knowledge of the techno-economic, spatial, and environmental aspects of a place, is important. The performance score of the above process is presented in Figure 4.

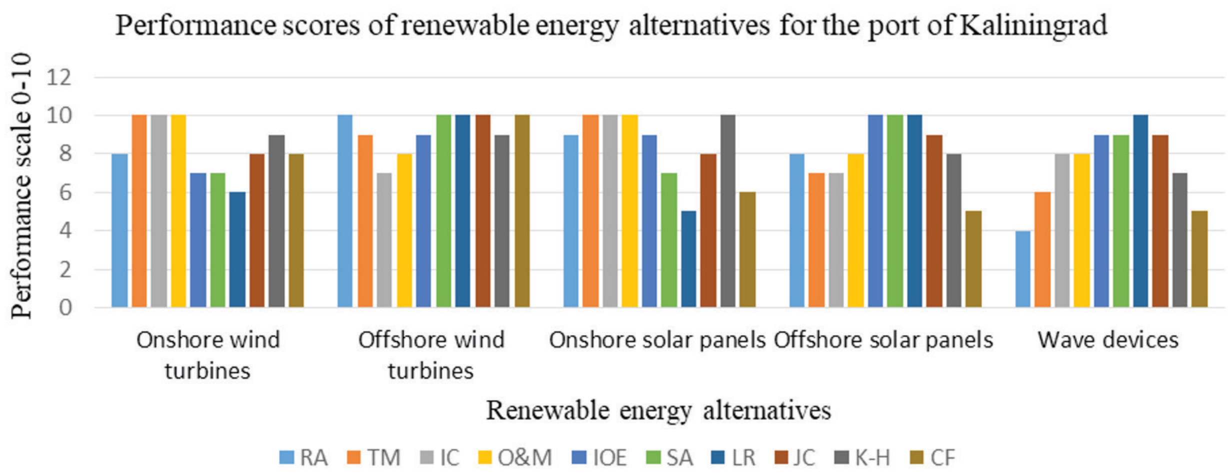

Figure 4. Performance scores of renewable energy alternatives for the port of Kaliningrad

5. RESULTS

In this last stage of methodology, in order to determine the weighted total performance score of the five(5) renewable energy alternatives for the case study, the results in Table 2 and Figure 4 are summed through multiplications (Table 5, Figure 5). At this point, it is important to point out that the five (5) renewable energy sources are not mutually exclusive, but are classified, as one or more technologies can be chosen for a specific place depending on a number of parameters (e.g. restrictions, availability of resources, etc.).

Table 5. Individual overall performance scores of the five renewable energy technologies

Evaluation Criteria	*Weight Factor(%)*	*Energy alternatives*				
		Onshore wind turbines	***Offshore wind turbines***	***Onshore Solar panels***	***Offshore Solar panels***	*Wave devices*
RA	27.5	2.2	2.75	2.475	2.2	**1.1**
TM	19.4	1.94	1.746	1.94	1.358	**1.164**
IC	13.2	1.32	0.924	1.32	0.924	**1.056**
O&M	13.2	1.32	1.056	1.32	1.056	**1.056**
IOE	9	0.63	0.81	0.81	0.9	**0.81**
SA	6.3	0.441	0.63	0.441	0.63	**0.567**
LR	**4.5**	**0.27**	**0.45**	**0.225**	**0.45**	**0.45**
JC	3.1	0.248	0.31	0.248	0.279	0.279
K-H	2.2	0.198	0.198	0.22	0.176	0.154
CF	**1.6**	**0.128**	**0.16**	**0.096**	**0.08**	**0.08**

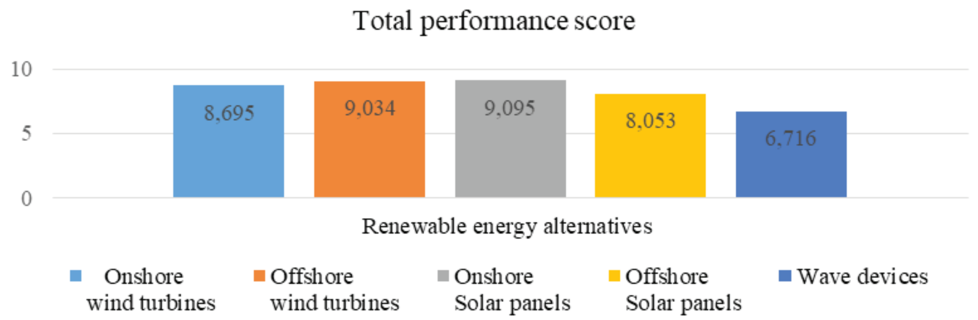

Figure 5. Total performance scores of the five renewable energy technologies

Onshore solar panels are ranked as the top choice for the Kaliningrad sea fishery port among all energy alternatives, as results from the matrixes multiplications, and aggregations, an expected result, as the port has good resource availability, solar panels are considered a highly mature technology, with low investment and O&M costs, while land requirements can be met with their placement on the roofs of buildings and warehouses, without the need for a completely new space, something that it not necessary for the installation of offshore solar panels, as they can be placed further offshore provided that there are no conflicts with other sea users.

Offshore wind turbines are ranked as a second alternative, as the case study has good resource availability, with stronger offshore winds compared to onshore, the technology has been used for a long time, while due to land restrictions in the port can be placed further offshore, and this is one of the main reasons for the lower ranking of onshore wind turbines. In addition, offshore installations (e.g. offshore wind turbines or solar panels) are considered preferable options than onshores, due to the less potential environmental impacts, while there is evidence that the submerged parts of their structures contribute to the restoration of damaged ecosystems by acting as artificial reefs [15, 16].

Finally, wave energy is the last preferable option. The low resource availability in the area and the low technological maturity of this type of technology combined with the lack of specialized human resources in the region/ country, among others, make this alternative the least acceptable. The scores and classification of energy alternatives resulting from the methodology are in line with previous research studies on the development of alternative energy solutions in the light of the zero-emission port.

6. CONCLUSIONS

The study presented a decision support framework for the identification and evaluation of the various renewable energy sources and their integration into marine port grid using the Analytic Hierarchy Process and the input of experts, and taking into account a number of criteria as well as the energy requirements of port activities. The output of the decision support model provides scores and well-justified classifications for the various alternative renewable energy sources, which allow decision-makers, port stakeholders, and other interested parties (e.g. neighboring communities) to select the most appropriate energy alternatives for a greener port and in the light of the common interest.

Based on the analysis for Kaliningrad sea fishery port, onshore solar panels, offshore wind turbines and onshore wind turbines are the three preferred options, while wave devices are the least acceptable alternative. Different classifications may arise if the proposed methodology is applied to different marine ports, due to different port characteristics (e.g. spatial and environmental constraints, availability of resources, etc.). However, the results are in line with previous research studies on the development of alternative energy solutions in the light of the zero-emission port, and show a clear trend in this direction. Indeed, solar technology is a mature technology, with low investment and O&M costs, and easily adoptable by ports, as solar panels can be installed on the roofs of buildings and warehouses, without the need for a completely new space. Furthermore, offshore wind turbines are an equally good alternative, due to the land restrictions in ports, whose technology has been used for a long time.

Although onshore solar panels are the top choice, the other energy alternatives should not be ignored. Using a mix of renewable energy sources can offer a more comprehensive approach to a long- term energy problem. In this context, the concept of microgrids or smartgrids can encourage marine ports to invest in more environmentally friendly solutions, such as cold ironing, storage solutions, electric vehicles for marine port activities, etc. and to manage the various aspects (sources, storage solutions, and loads) that result from their operation.

In this framework, the paper proposes the concept of a zero-emission port, encouraging the use of renewable energy sources. The proposed methodology can be used for other complicated decision- making issues that include expert's involvement and extensive analysis, as it is characterized as extremely flexible and could incorporate a variety of criteria and alternatives.

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