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Renewable energy source selection for a green port with AHP

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Abstract. In view of the need to reduce the greenhouse gas emission causing global climate change coupled with the necessity to protect the environment around port vicinities, the green port concept receives considerable attention. This concept's motivation is to balance environmental challenges with economic demands such that seaports improve their financial, commercial, and operational performances. In this regard, the use of renewable energy is one of the viable solutions. Based on the analytical hierarchy process (AHP) method, this paper presents a systematic approach for selecting the most suitable alternative of renewable energy sources. The results show that for the case of Kuala Tanjung Port, solar energy is the most favored alternative, followed by wind energy, biomass, and wave energy. It is hoped that this paper provides a starting point to plan for a long-term renewable energy strategy in the context of a green port.

1. Introduction

Seaports are connecting a nation as well as the world through the maritime transport networks. The well being of its seaport can measure the prosperity of a city or a country. As the hubs for the maritime transport network, seaports consume a considerable amount of energy for its daily operation, especially for the different ships' activities [1]. Coupled with the nearby industrial activities, seaports inevitably negatively impact the environment [2]. Clott and Hartman [3] reveal that most seaports depend on diesel-powered engines leading to a considerable amount of exhaust emissions, including particular matters (PMs), sulphur dioxide (SO₂) and nitrogen oxide (NO_x) emissions, carbon monoxide (CO) and carbon dioxide (CO₂). Viana et al. [4] stressed that ship emissions could affect nearby communities within the range of 400 m around ports. In the spirit of balancing the environmental challenges with economic demands, this paper promotes the concept of green ports by proposing the likely usage of renewable energy sources.

This study develops a systematic approach for assessing renewable energy based on the Analytic Hierarchy Process (AHP) method. Selecting the most suitable renewable energy source is a complex decision-making situation for which AHP is a powerful tool. AHP is a popular multi-criteria decision-making tool that has been used in numerous applications in various fields of economics, politics, and engineering. Numerous researchers have applied AHP for various purposes [5]-[13]. Specifically, Kabir



and Shihan [14], Tasri and Susilawati [15], Budak et al. [16], and Ahmad et al. [17], among others, have applied AHP for selecting renewable energy.

The most common renewable energy sources are solar, wind, hydro, geothermal, biomass, tide, and waves. But all of them may not suitable for any particular place or industry. For a seaport located on open coastal waters with a micro or meso-tidal environment, renewable energy sources' viable options are solar, wind, biomass, and waves. This paper deals with selecting the best suited renewable energy sources in the context of a green port.

2. Green Port and Kuala Tanjung Port

Seaports connect national, regional, and international trades and support national, regional, and global economic growth, respectively. Maritime transport carries out 80% of global trade by volume and over 70% by value, with seaports worldwide handling most of the cargo; the shares are even higher in the case of most developing countries.

Seaports provide numerous services that are most likely related to passenger and cargo transport. The busiest the port is, the better is the economy for a country. On the wrong side, seaports are the most common entry point of anthropogenic environmental pollution resulting from maritime transport-related activities. There we can observe conflicts between human act and the environment, resulting in danger not only to the environment but also to humans. The fact that seaports are often positioned close to residential areas, urban localities, industrial complex, and environmentally sensitive areas, make the following problems most frequently reported: a) air, water, and soil pollution b) the loss or degradation of habitat, c) sea level rise, coastal erosion, and coastal flooding [18], d) noise and light pollution, e) loss of social and cultural values, f) land subsidence, and g) traffic congestion. The sources of the problems mentioned above can be traced from three different activities: in-port operations, maritime (ship) activities, and in-land transport.

As we become aware of global climate change, the notion of green infrastructure becomes a trending topic and is thought to be a critical solution. Therefore its key performance indicators are beginning to be utilized in the competition of the world market. Within the new green infrastructure concept, economic growth and environmental protection are no longer considered and interpreted as two different, possibly conflicting aspects. The concept of sustainable green development adopts a positive synergy that shall be regarded as an opportunity rather than a threat. While the main drivers were mostly labor and capital in the past, sustainable green growth focuses on new ideas and innovations benefitting the economy and the environment.

Hence, in light of the above reasons, seaport operators and authorities shall embrace the concept of green port development which demands an economically sustainable and environmentally friendly seaport. They should emphasize the environmental issues related to ship operations, cargo handling activities, energy consumption, infrastructure projects related to port terminals' expansion and port hinterland connections. However, implementing green port development is helpless without efficient cooperation between public entities and private companies which are the key to the successful treatment of waste in seaports and its surrounding area.

A green port can also be called an eco-friendly port, representing a sustainable port development that meets the environment's demands and increases the port's economic interest. The so-called green port development shall be based on three aspects of work and port system planning: energy conservation, environmental protection, and environmental care. This idea should then be converted into activities that enable the synergetic coordination of environmental protection and sustainable economic development.

Chiu, Lin, and Ting [19] assessed the green port factors and applied AHP in order to evaluate three seaports in their performance of green port operation. Figure 1 shows the major factors (criteria) with their weights found using AHP. It can be seen from the figure that the use of the energy and resource (with weight = 0.214) is the second priority (after environmental quality) among the five major criteria

shown. Badurina, Cukrov, and Dundovic [20] pointed out that renewable energy sources, such as solar panels on the roofs of port building and warehouses, can be a solution for seaports to be green as they can provide energy independently. This study focuses on developing a decision support system using AHP to select the priority of livable renewable energy sources.

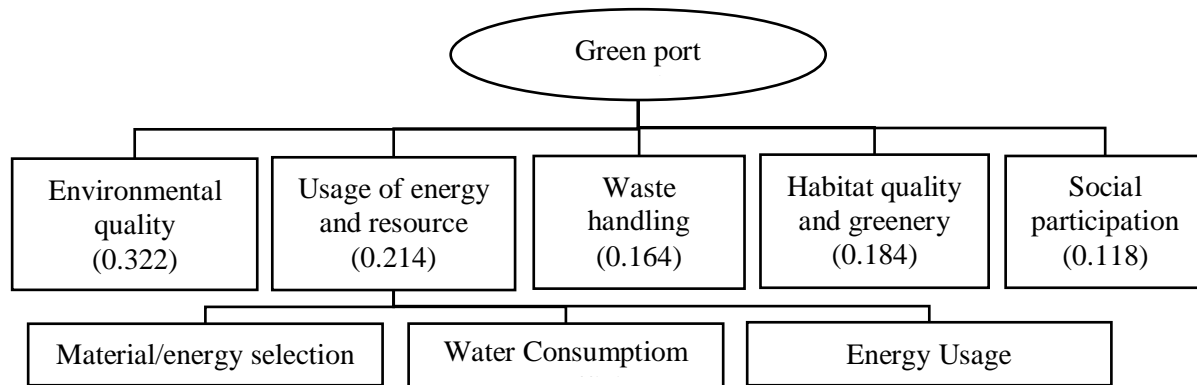


Figure 1 The major criteria for green port assessment (adopted from Chiu, Lin, and Ting [19])

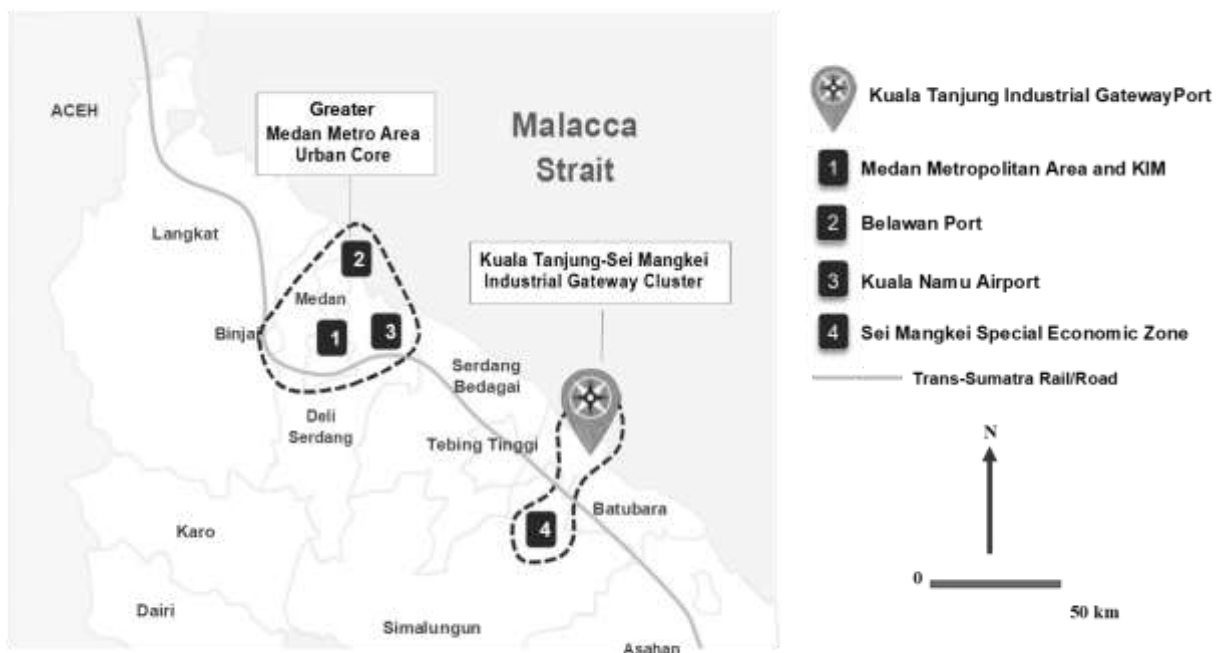


Figure 2 Location of Kuala Tanjung Port

The methodology developed in this study is tried for the Port of Kuala Tanjung located on the eastern coast of North Sumatra province as shown in Figure 2. Kuala Tanjung Port is a newly operated multi-terminal seaport where its current jetty is positioned 3 km from the shoreline and has a minimum depth of 15 m. With such relatively deep water berths, it is intended to serve large ships requiring deep draft. Hence, it is expected to become a hub, a major gateway of transport networks for Indonesia's western region, after the industrial estate can be established in the second stage of its development. In this 2nd stage, the electrical energy demand is predicted to increase from 10 MW in the first stage to 400 MW.

3. Methodology

This study aims to develop a systematic approach for assessing renewable energy using AHP in the context of a green port. AHP is a decision-making tool to handle a multiple attribute problem in a systematic pairwise comparison fashion developed by Saaty [21]. It at least has the following main features: a) hierarchy that shows the goal, criteria, and the alternatives, b) pairwise comparison matrices (PCMs) developed based on the professional judgment, c) eigenvectors and eigenvalues to calculate for the priority (weight) vectors and consistency ratios of the PCM, respectively, and d) linear combination of the weights to calculate for the overall weight of each alternative.

The steps of performing AHP can be concisely stated as follows: 1) define the problem and the goal, 2) develop the hierarchy, 3) prepare the PCM, 4) obtain expert judgments to fill out for the PCM, 5) calculate the priority vector from the eigenvector of PCM, 6) Compute and check the consistency ratio of the PCM, and 7) repeat steps 3 thru 7 for all levels in the hierarchy. In the following section, an example of the computation process is given for the main criteria (level 2).

To obtain expert judgments, it appears that the relative comparison of the renewable energy source given in Table 1 played a critical role. With reference to the table, the acquisition of expert judgments can be conducted smoothly and objectively. Overall, five different surveys were performed to complete the study. The surveys can be conducted by interviewing the experts individually or having group discussions. Ten experts with diverse backgrounds have been inquired in the surveys, but all have adequate knowledge of renewable energy sources.

Table 1 Relative comparison of the renewable energy sources with regards to the main criteria

		Solar	Wind	Biomass	Wave
Economy	Investment	\$ 0.085 / KWH	\$ 0.056 / KWH	\$ 0.062 / KWH	\$ 0.5 / KWH
	Operation & maintenance cost	Minimum	Minimum	High	Moderate
Environment	Noise	None	Minimum	Very High	Minimum
	Impact on ecosystem	Minimum	Minimum	High	Moderate
Technology	Capacity factor	27%	38%	50%	NA
	Resource availability/ reliability	High and predictable Lifetime 25 years	Moderate, unpredictable Lifetime 25 years Min. wind speed 8 kph	Moderate Lifetime 25 years	Moderate Min. wave height 1 m
Society/ locality	Job creation	Medium	Minimum	High	Minimum
	Port locality	High Relatively no obstruction Spacious land available	Moderate Relatively no obstruction	Moderate Abundant palm oil waste	Moderate Significant offshore waves on the jetty

4. Results

The computation of AHP can be processed in the following steps: 1. compiling the pairwise comparison matrix (PCM) from the questioner forms, 2. calculating the eigenvalues and eigenvectors; 3. calculating the normalized eigenvector as the priority vector; 4. calculating maximum eigenvalue λ_{max} ; 5. computing the consistency index CI; 6. opting the appropriate value of the random consistency index RI from the table given by Saaty; and 7. checking the consistency ratio CR of the pairwise comparison matrix to check whether $CR < 0.10$. Note that if $CR < 0.10$, then the PCM is OK.

Following the above aforementioned steps, the PCM of the main criteria is given in Table 2. Note that we use MATLAB to accomplish the computation process.

Table 2 PCM for the main criteria

	Economy	Environment	Technology	Society/port locality	Priority vector (weight)
Economy	1	1	2	2	$W_{ec} = 0.33$
Environment	1	1	2	3	$W_{en} = 0.36$
Technology	1/2	1/2	1	1	$W_{te} = 0.16$
Society/port locality	1/2	1/3	1	1	$W_{po} = 0.15$

$\lambda_{max} = 4.02, CI = 0.007, RI = 0.90, CR = 0.008$

Now we proceed with the PCMs for level 3, which is the subcriteria, including economy, environment, technology, and society/locality. Based on the consensus of the expert judgment the PCMs for the subcriteria are as follows (Table 3):

Table 3 PCM for (a) economy, (b) environment, (c) technology, and (d) society/locality

(a)				(b)			
	Investmen	Operation & maintenance	Priority vector (weight)		Noise	Impact on ecosystem	Priority vector (weight)
Investmen	1	3	$w_{in} = 0.75$	Noise	1	1/3	$w_{no} = 0.25$
Operation & maintenance	1/3	1	$w_{op} = 0.25$	Impact on ecosystem	3	1	$w_{im} = 0.75$

(c)				(d)			
	Maximum Capacity	Resource availability/reliability	Priority vector (weight)		Job creation	Port locality	Priority vector (weight)
Maximum Capacity	1	1	$w_{ma} = 0.50$	Job creation	1	1/2	$w_{jo} = 0.33$
Resource availability / reliability	1	1	$w_{re} = 0.50$	Port locality	2	1	$w_{po} = 0.67$

Note that the size of PCM n in level 3 is two, meaning that it is always consistent. Hence, the computation of consistency ratio CR is unnecessary.

The computation of level 4 is given for each energy alternative. There are four renewable energy sources evaluated for eight subcriteria; thereby, we have 8 PCMs with size $n = 4$ as follows: Tables 4 until 11 are PCMs for investment, operation and maintenance cost, noise, impact on ecosystem, capacity factor, resource availability/reliability, job creation, and port locality, consecutively. Note that the process of computation previously performed for level 2, the main criteria, is repeated here to check the

consistency ratio CR. The results for λ_{max} , CI, RI, and CR are shown at the bottom of each table of Tables 4 until 11.

Table 4 PCM for investment

	Solar	Wind	Biomass	Waves	Priority vector (weight)
Solar	1	1/3	1/2	5	$w_{so-in} = 0.18$
Wind	3	1	2	7	$w_{wi-in} = 0.48$
Biomass	2	1/2	1	6	$w_{bi-in} = 0.29$
Waves	1/5	1/7	1/6	1	$w_{wa-in} = 0.05$

$\lambda_{max} = 4.08$, CI = 0.03, RI = 0.90, CR = 0.03

Table 5 PCM for operation and maintenance cost

	Solar	Wind	Biomass	Waves	Priority vector
Solar	1	1	7	3	$w_{so-op} = 0.40$
Wind	1	1	7	7	$w_{wi-op} = 0.40$
Biomass	1/7	1/7	1	1/5	$w_{bi-op} = 0.05$
Waves	1/3	1/7	5	1	$w_{wa-op} = 0.16$

$\lambda_{max} = 4.07$, CI = 0.26, RI = 0.90, CR = 0.03

Table 6 PCM for noise

	Solar	Wind	Biomass	Waves	Priority vector
Solar	1	3	7	3	$w_{so-no} = 0.53$
Wind	1/3	1	5	1	$w_{wi-no} = 0.21$
Biomass	1/7	1/5	1	1/5	$w_{bi-no} = 0.05$
Waves	1/3	1	5	1	$w_{wa-no} = 0.21$

$\lambda_{max} = 4.07$, CI = 0.03, RI = 0.90, CR = 0.03

Table 7 PCM for impact on ecosystem

	Solar	Wind	Biomass	Waves	Priority vector
Solar	1	2	7	3	$w_{so-im} = 0.49$
Wind	1/2	1	5	2	$w_{wi-im} = 0.29$
Biomass	1/7	1/5	1	1/4	$w_{bi-im} = 0.06$
Waves	1/3	1/2	4	1	$w_{wa-im} = 0.17$

$\lambda_{max} = 4.07$, CI = 0.26, RI = 0.90, CR = 0.03

Table 8 PCM for capacity factor

	Solar	Wind	Biomass	Waves	Priority vector
Solar	1	1/2	1/4	5	$w_{so-ca} = 0.17$
Wind	2	1	1/2	5	$w_{wi-ca} = 0.28$
Biomass	4	2	1	5	$w_{bi-ca} = 0.49$
Waves	1/5	1/5	1/5	1	$w_{wa-ca} = 0.06$

$\lambda_{max} = 4.19$, CI = 0.06, RI = 0.90, CR = 0.07

Table 9 PCM for resource availability/reliability

	Solar	Wind	Biomass	Waves	Priority vector
Solar	1	3	1/2	3	$w_{so-re} = 0.31$
Wind	1/3	1	1/3	1	$w_{wi-re} = 0.12$
Biomass	2	3	1	3	$w_{bi-re} = 0.44$
Waves	1/3	1	1/3	1	$w_{wa-re} = 0.12$

$\lambda_{max} = 4.06$, CI = 0.20, RI = 0.90, CR = 0.02

Table 10 PCM for job creation

	Solar	Wind	Biomass	Waves	Priority vector
Solar	1	3	1/4	5	$w_{so-jo} = 0.24$
Wind	1/3	1	1/5	3	$w_{wi-jo} = 0.11$
Biomass	4	5	1	6	$w_{bi-jo} = 0.59$
Waves	1/5	1/3	1/6	1	$w_{wa-jo} = 0.06$

$\lambda_{max} = 4.22, CI = 0.07, RI = 0.90, CR = 0.08$

Table 11 PCM for port locality

	Solar	Wind	Biomass	Waves	Priority vector
Solar	1	3	2	3	$w_{so-po} = 0.44$
Wind	1/3	1	1/3	1	$w_{wi-po} = 0.12$
Biomass	1/2	1/3	1	3	$w_{bi-po} = 0.31$
Waves	1/3	1	1	1	$w_{wa-po} = 0.12$

$\lambda_{max} = 4.06, CI = 0.02, RI = 0.90, CR = 0.02$

The final computation of AHP is to calculate overall priority vector using the linear combination formula with the weights tabulated in Table 12. From the last column in Table 12, it can be inferred that for the Port of Kuala Tanjung solar energy is the most preferred option. It is followed in second place by wind, third place by biomass, and last place by wave. It appears that this result is consistent with previous research and development in energy alternatives and show a trend for the future development for energy alternatives at the so-called green port.

Table 12. Priority matrix for the overall weights of renewable energy sources

	Economy (0.33)		Environment (0.36)		Technology (0.16)		Society/locality (0.15)		Overall Priority Vector
	Invest- ment (0.75)	Operation and maintenance (0.25)	Noise (0.25)	Impact on ecosys- tem (0.75)	Capacity factor (0.50)	Resource availability/ reliability (0.50)	Job creation (0.33)	Port locality (0.67)	
Solar	0.18	0.40	0.53	0.49	0.17	0.31	0.24	0.44	0.35
Wind	0.48	0.40	0.21	0.29	0.28	0.12	0.11	0.12	0.30
Biomass	0.29	0.05	0.05	0.06	0.49	0.44	0.59	0.31	0.23
Waves	0.05	0.16	0.21	0.17	0.06	0.12	0.06	0.12	0.12

5. Discussion

If evaluated at level 2, solar energy is ranked 1 in the environmental aspect. Wind energy is rated 1 in the economic aspect, whereas biomass rated 1 in two aspects, i.e., the technology and society aspects. In this sense, biomass is superior compared to other forms of energy. In contrast, wave energy comparatively lost the competition in all aspects.

Sensitivity analysis indicates that solar energy's position would be overtopped by wind energy if the weight of environmental criteria were lowered to become 0.24 while the weight of economy is raised to become 0.45. This significant change in the weight needed to defeat solar means that solar energy selection is relatively stable.

Biomass would climb to be ranked 2 if the economy aspect were neglected ($w_{ec} = 0$) while the weight composition of the others is normalized to maintain the AHP initial judgment i.e. $w_{en} = 0.54, w_{te} = 0.24,$ and $w_{po} = 0.22$. Biomass would then go up to rank 1, if the environmental aspect were neglected ($w_{en} = 0$) while the weight composition of the others is normalized as before to maintain the AHP initial judgment i.e. $w_{ec} = 0.52, w_{te} = 0.25,$ and $w_{po} = 0.23$. This means that biomass has the potential to be superior among others.

The approach demonstrated in this study provides detailed and well-justified rankings of different energy alternatives for a particular port, i.e., the port of Kuala Tanjung based on experts' input and a systematic AHP. It is expected that total weights and priority may change if they are evaluated for different ports. It is hoped that this methodology helps port operators and authorities form long-term energy strategies. They may use this study's outcome as a starting point and consider other factors such as budget, collaboration with adjacent municipalities, and stakeholders' common interest to adjust the priority of energy alternatives.

6. Conclusion

This paper has presented the AHP based decision-making method to assess the selection of renewable energy sources in the context of a green port. Based on the results calculated for Kuala Tanjung Port, it is found that solar energy is selected best of the others. Different priority selections may occur if the method is applied for different ports, depending much on the port characteristics (society and locality aspect in this study). Nevertheless, the results obtained in this study are in line with the previous studies on similar topics and the trend that solar technology has continuously improved to be more efficient and cheaper.

Although the best option is solar energy, it is found from the sensitivity analysis that, except for wave energy, the importance of the other sources of renewable energy cannot be neglected. The mixed usage among them may give a more optimal solution to a long-term energy problem. Also, energy efficiency is another option a green seaport should take as of considerable interest; hence, it can be added to the criteria of AHP for further research.

The renewable energy selection in this paper is conducted in the spirit of introducing the concept of green ports. It is hoped that this will encourage the implementation of the green port concept, as it is not merely about protecting the environment but mostly adopting healthier working conditions in the complexity of seaport operations in order to achieve a better competitive advantage.

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