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COMPARATIVE ANALYSIS BETWEEN AHP MOORA AND AHP-ELECTRE METHOD FOR OPTIMAL ELECTRIC AND SOLAR-POWERED SHIPYARD SITE SELECTION

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ABSTRACT

Transportation is the second largest emitter of CO2 in the world, accounting for 25% of total CO2 emissions. To achieve a zero-carbon shipping industry, Indonesia can use its high sun exposure to generate electrical energy by using solar cell technology, which converts solar energy into electrical power. To answer the challenge, this research will start with the site selection of electric and solar-powered shipyards. This research tries to solve the problem of selecting the best location for electric and solar-powered shipyards by using the Multi-Criteria Decision Making (MCDM) method. The purpose of this research is to get the optimal location of electric and solar shipyards using AHP-MOORA and AHP-ELECTRE methods. There are three alternative locations in the location selection. Alternatives 1 and 3 are in Paciran District, Lamongan Regency, East Java Province, and alternative 2 is in Serang Regency, Banten Province. Alternative site 1 has an area of 38 ha and is located in Sidokelar Village, Paciran Sub-district. Decision-makers determine the parameters that will be evaluated from each alternative location, such as slope, soil type, rainfall, and 18 other criteria. In determining the weighting of parameters, a method that has a consistency test is needed so that the weight results obtained are consistent and objective. The study result shows that alternative location 1 is the best location for the electric and solar-powered shipbuilding industry, the same conclusion using the AHP-MOORA Integration approach and the AHP weighting ELECTRE Integration approach.

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1. INTRODUCTION

Indonesia is the world's fourth most populous country. The Central Bureau of Statistics of the Republic Indonesia (BPS) estimates that Indonesia's population will be 278.696,2 thousand people in 2023, with a population growth rate of 1.13%. However, as the population expands, so does the demand for economic energy. As a result, economic growth will rely significantly on fossil energy demand, causing catastrophic changes in our climate (SDG 7). Transportation is the world's second-greatest CO2 emitter, accounting for 25% of total CO2 emissions [1]. Greenhouse gas (GHG) emissions from the marine transportation sector increased from 977 million tons in 2012 to 1,076 million tons in 2018 (a 9.6% increase), including carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), in CO2e, from total transportation (international, domestic, and fisheries). 2012 there were 962 million tons of CO2 emissions, which climbed by 9.3% to 1,056 million tons in 2018 [2]. As a result, one of the transportation sector's aspirations is for the shipping industry to become zero-carbon [1].

To achieve a zero-carbon shipping industry, the International Maritime Organization (IMO) has set a goal to reduce total GHG emissions by at least 20% per year by 2030 [3]. One of the projects that can be undertaken is the development of electric ships. Indonesia can use its high sun exposure to produce electrical energy using solar cell (Photovoltaic / PV) technology, which converts solar energy into electric power [4]. The sunlight obtained in Indonesia may produce 5.1 kWh per day when solar cells are used [5]. According to the Ministry of Industry, there will be 250 national shipyards by 2020, with a capacity of around 1,000,000 DWT/year for new constructions and 12,000,000 DWT/year for ship repairs. 71% of Indonesia's various shipyards have met the standards for production facilities [6]. The objective is that by producing electric ships, it will be possible to conserve fuel, minimize pollution from auxiliary engines, and save power from shaft generators [7]. Given the importance of the need for electric ships and the state of the shipyard in Indonesia, the production of electric and solar-powered ships is something that should be explored. Technological advancements will help electrical technology realize the all-electric ship [8].

Establishing an electric shipyard is one of the first steps in developing electric ship technology. This requires special attention because many shipyards around the world have failed to meet the IMO's 2030 objective. As a result, a green shipyard must be built or an existing shipyard converted to create a green ship [9]. The shipping industry, often known as shipyards, is a vital component of the national economy. The hope is that the electric and solar-powered shipyard sector will be able to meet the needs of the national fleet of ships and respond to the IMO challenge for 2030.

To overcome these challenges, this research tries to solve the site selection problem of electric and solar-powered shipyards. With several alternative decisions and many complex criteria, decision-makers can find it hard to make an objective decision. Therefore, we can use mathematical models to support decision-making to decide the optimal site. This research tries to solve the site selection problem for an electric and solar-powered shipyard using the Multi-Criteria Decision Making (MCDM) method. The MCDM is a decision-making method for a problem that selects the best decision based on certain criteria that are often conflicting. Some MCDM methods used in site selection research include AHP, TOPSIS, SAW, ELECTRE, and SIMOS Procedure. Multi-Objective Optimization based on Ratio Analysis (MOORA) is a method introduced as an objective (non-subjective) method by Brauers et al. [10], [11]. Elimination Et Choix Traduisant la Realitè (ELECTRE) method, was first proposed by Bernard Roy in Europe in mid-1965 [12]. The ELECTRE eliminates unfavorable choices or alternatives to obtain the best option [13]. The Analytical Hierarchy Process (AHP) is one of the MCDM decision support methods developed in 1980 by Thomas L., Saaty [14]–[16]. In this method, the existing problems are described in the form of a hierarchy, consisting of several levels starting with goals, criteria, and alternatives [17].

Numerous previous studies used the integration between MCDM methods. Mangalan et al. used MOORA for ranking and Simos procedure for weighting [18]. Cahyapratama & Sarno integrate Simple Additive Weighting (SAW) as a ranking approach and AHP as a weighting method in the vocalist selection process [19]. Parkhan & Vatimbing used AHP and TOPSIS integration in choosing a shipyard location [20]. Fatema et al. used AHP combined with the General Feature Extraction Technique (GFEA) for choosing the location of a trauma center [21]. Kumar et al. combined AHP and MOORA to optimize the characteristics of electrical discharge machining [22]. Another study combined ELECTRE with AHP in the decision-making process for the cycling routes in Franciacorta for sustainable tourism [23], [24]. Prahesti et al. compared the AHP-ELECTRE and SAW method to give school recommendation based on criteria that student wants with applying [25]. The results of these studies showed that combined weighting and ranking techniques gave an improvement in decision-making objectivity.

Therefore, the purpose of this research compare the integration of weighting and ranking methods to determine the optimal location of electric and solar-powered shipyards. This research will compare the calculation results of MOORA and ELECTRE, integrated with AHP, respectively, as a weighting method [26]. Comparison results are used to improve the objectivity of the electric and solar-powered shipyard industry site selection.

2. RESEARCH METHODS

There are three alternative decisions for shipyard site selection as shown in (Figure 1). Alternatives 1 and 3 are in Paciran District, Lamongan Regency, East Java Province, while alternative 2 is in Serang Regency, Banten Province. Alternative location 1 has an area of 38 Ha and is located in Sidokelar Village, Paciran District. Currently, alternative location 1 is a shipyard owned by PT Dock Pantai Lamongan (DPL), a shipping company whose major business is handling large ships for maintenance and repair. Site 2 is located in Bojonegara, Serang, Banten. Currently, alternative location 2 is a shipyard built in 2021 by PT Armada Bangun Samudera (ABS) in the PT Gandasari Energi region. Alternative site 3 is in the Paciran District of the Lamongan Regency of East Java Province. Alternative location 3 is a shipyard of PT Lintech Seaside Facility (LSF), a PT Lintech Duta Pratama subsidiary.

Figure 1. Alternate sites for the shipbuilding sector that use solar and electricity

The framework stage used for electric and solar-powered shipyard site selection is shown in (Figure 2). First, we determine the parameters for making industrial site selection decisions. Then we collect the data of each parameter for the alternative decisions. Data collection is performed using a field survey for primary data and a desk study for secondary data. After the data is complete, we analyze the data to obtain a decision matrix. Next, the weight for each parameter is calculated using the AHP method. The ranking of decision alternatives is performed using ELECTRE and MOORA. Finally, we compare and analyze the results of these two methods.

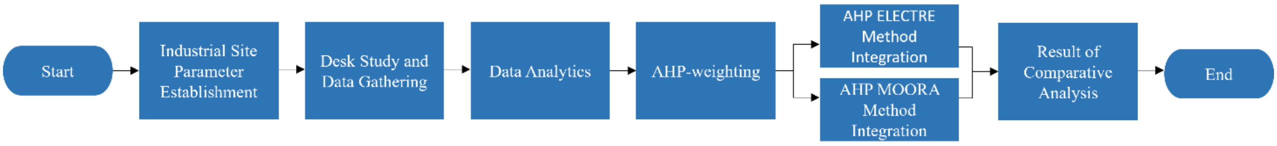

Figure 2. The framework stage for this research

2.1 Industrial Site Parameter Establishment

The assessment of relevant criteria is essential to determine optimal site selection. Moreover, the solar and electric shipyard industries must minimize environmental and social damage at the lowest feasible cost with optimal site location. In this study, twenty-one (21) parameters are used to determine the location of the electric and solar-powered shipyard industry based on regional characteristics and data availability, while also satisfying a set of constraints and requirements: Industry Law No. 3 of 2014, Ministerial Regulation No. 13 of 2017 concerning the National Spatial Plan, and Minister of Industry Regulation No. 30 of 2020 concerning Technical Criteria for Industrial Designation Areas (KPI). Parameters to determine the location of the electric and solar-powered shipyard industry include slope parameters, soil type parameters, rainfall parameters, flood-prone potential parameters, landslide-prone potential parameters, sustainable food agricultural land designation (LP2B) parameters, land area parameters, land transportation availability parameter, railway station availability parameter, toll road availability parameter, port availability parameter, airport availability parameter, regional dock availability parameter, raw water source availability parameter, availability of sewage disposal plants, availability of regional transmission lines, parameter water depth conditions, parameter water wave conditions, parameter availability of maritime universities, parameter distance of settlements from industry, and parameter suitability of regional superior industries (**Table 1**). (**Figure 3**) depicts the conditions for identifying the location of the electric and solar-powered shipyard industries.

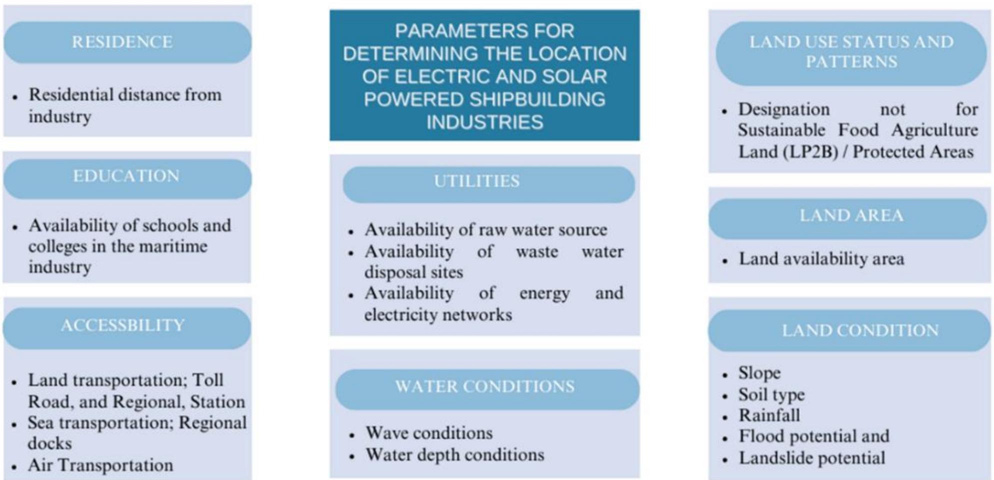

Figure 3. Parameters For Determining The Location Of Electric And Solar-Powered Shipyard Industries

Table 1. Parameters and Score Point of Determining the Location of Electric and Solar-Powered Shipyard Industries

Parameters	Type / Description / Score				
Slope (%)	(0 – 8) / Flat / 5	(8 – 15) / Ramp / 4	(15-25) / Rather Steep / 3	(25-45) / Steep / 2	(>45) / Very Steep / 1
Soil Type	Alluvial, Gley, Palnosol, Gray Hydromorphic / Insensitive / 5	Latosol / Rather Sensitive / 4	Non-marshy brown forest soil, Mediterranean / Less Sensitive / 3	Andosol, Laterite, Grumusol, Podsol, Podzolic / Sensitive / 2	Regosol, Lithosol, Organosol, Renzina / Very Sensitive/ 1
Rainfall Intensity (mm/Year)	0 – 1500 / 5	1500 – 2000 / 4	2000 – 2500 / 3	2500 – 3000 / 2	>3000 / 1
Potential Flood Hazard (m)	Low / <1 / 3	Medium / 1 – 3 / 2	High / >3 / 1	-	-
Landslide Potential (cm/Year)	Low / <0,9 / 3	Medium / 0,9 – 1,8 / 2	High / >1,8 > 1	-	-

Parameters	Type / Description / Score				
LP2B Designation	Industrial designation area / 2	Designated Areas for Sustainable Food Agriculture or Protected Areas / 1	-	-	-
Land Availability (Ha)	Big Industry / >50 / 3	Small and Medium / 5 – 50 / 2	Industry Not Available / <5 / 1	-	-
Land Transportation Availability	Primary arterial road / 4	Primary Collector Road / 3	Primary local road / 2	Village Road / 1	-
Railway Station Availability (km)	<5 / 4	5 – 25 / 3	25 – 50 / 2	>50 / 1	-
Toll Road Availability (km)	<5 / 4	5 – 25 / 3	25 – 50 / 2	>50 / 1	-
Port Availability (km)	<5 / 4	5 – 25 / 3	25 – 50 / 2	>50 / 1	-
Airport Availability (km)	<5 / 4	5 – 25 / 3	25 – 50 / 2	>50 / 1	-
Availability of Regional Jetty	There is an area jetty / 3	There is a regional jetty development / 2	No jetty development in the region / 1	-	-
Availability of Raw Water Source	Alternative site surface water / 4	Regional Drinking Water Company / 3	Industrial wastewater reprocessing (reuse) / 2	Supplies from other companies or local government / 1	-
Availability of Sewage Disposal Installation	There is an Area Sewage Treatment Plant / 4	Temporary Storage Building (TPS) / 3	Temporary Storage Site (TPS) / 2	There is no Waste Temporary Storage Site (TPS) / 1	-
Regional Transmission Line Availability (kV)	Extra High Voltage Air Line (SUTET) / 200 – 500 / 3	High Voltage Air Line (SUTET) / 30 – 150 / 2	No Transmission line yet / 0 / 1	-	-
Wave Condition of Water (m)	Calm (Rippled) / 0 – 0,1 / 4	Smooth (Wavelets) / 0,1 – 0,5 / 3	Slight / 0,5 – 1,25 / 2	Moderate / 1,25 – 2,5 / 1	-
University Availability in Maritime Study	Superior / 5	Excellent / 4	Good / 3	Not Accredited / 2	Not University / 1
Residential Distance to Industry (km)	<2 / 2	≥2	-	-	-
Suitability of Regional	Industry entry with regional	Industries not included with	-	-	-

Parameters	Type / Description / Score							
Leading Industries	leading industry / 2	regional leading industries / 1						
Water Depth Condition / Ship Weight (DWT)	80.000 – 150.000 / 8	50.000 – 80.000 / 7	30.000 – 50.000 / 6	15.000 – 30.000 / 5	8.000 – 15.000 / 4	3.000 – 8.000 / 3	1.000 – 3.000 / 2	*to* 000 / 1

***Data source**: Processed from Various Sources*

2.2 Desk Study and Data Gathering

The desk study aims to obtain various kinds of references related to the selection of the location of the electric and solar-powered shipyard industry. To provide an overview and verify the data from the desk study, a field survey was then conducted in the alternative location area of the electric and solar-powered shipyard industry.

2.3 Data Analytics

Data analysis aims to determine the best location mathematically by using the AHP MOORA Integration method and the AHP ELECTRE method. Parameter weights were first calculated using the Analytic Hierarchy Process (AHP) **[19]**, and then the MOORA and ELECTRE methods were used to rank potential locations for the electric shipbuilding and solar shipbuilding industries, calculating the indexes of suitability and incompatibility between pairs of alternatives. Weighting using the AHP approach can provide the optimal value of each index, calculation formula, and statistical data, as well as a quantitative transformation method for processing qualitative indices to achieve a scientific and fair evaluation of the indices **[27]**. After the weighting is completed, the MOORA method and the ELECTRE method are implemented. ELECTRE is a collection of decision-making approaches that present sequential and superior alternatives to make trustworthy decisions **[28]**. Weighing using AHP weights **[19]**, **[29]** and ranking using MOORA and ELECTRE methods are part of the AHP MOORA integration method and AHP ELECTRE integration method.

2.3.1 Weighting in the Analytic Hierarchy Process (AHP)

- Step 1. Compare each criterion in pairs to establish the criteria weight. The precedence scheme outlined in **Table 2** is utilized for this comparison procedure **[24]**, **[30]**, **[31]**.

Table 2. Priority Arrangement Table

Degree of concern	Specific details	Comprehensive Overview
1.	Both elements are equally essential	Two factors have the same impact on achieving an objective.
3.	One component is marginally more significant than the other	Experience and discernment provide marginally more support than other factors.
5.	One component is more essential than the other.	Experience and discernment strongly favor one element over another.
7.	One element is more essential than all others.	One of the most powerful elements is maintained and predominates in practice.
9.	One of the most essential components of the other components.	With the maximum degree of dependability, the evidence favoring a task relative to another.
2,4,6,8	Consideration values between two adjacent values	This value is assigned when two compromises exist between two options.
Inverse	If activity "i" receives one more point than activity "j," then "j" has the opposite value of "i."	

***Data source**: Adapted from "How to make a decision: The Analytical Hierarchy Process" by T.L. Saaty. Eur J Oper Res 1990; 48, 9–26*

- Step 2. Normalize a pairwise comparison matrix by aggregating the value of each matched pair matrix column and dividing each value in the column by the sum of the corresponding columns.

$$\bar{\alpha}= \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \quad (1)$$

- Step 3. Computes the weight of synthesis by adding each column within the same row of the comparison normalization result matrix.

$$\sum column= c1 + c2 + c3 + \ldots\ldots+cn \quad (2)$$

- Step 4. Calculates the eigenvalues by multiplying each matched matrix column in the same row by a predetermined criterion number.

$$\lambda_1= (c1 + c2 + c3 + \ldots\ldots+ cn)^{1/n} \quad (3)$$

- Step 5. The priority weight of each criterion is calculated by dividing the eigenvalues for each criterion by the total number of eigenvalues.
- Step 6. Determines the significance of every factor by dividing synthesis weight by priority weight.
- Step 7. Determine the highest Eigenvalue (λmax) by dividing the number of criteria by the total number of importance values.
- Step 8. Determines the consistency of use to ensure that discernment for decision-making is highly consistent.

$$CI = \frac{(\lambda_{maks} - n)}{n} \quad (4)$$

- Step 9. If the consistency ratio (CR) is less than or equal to 0,10. the result of the calculation is declared to be true [31].

$$CR = \frac{CI}{IR} \quad (5)$$

where CI= Consistency Index; IR= Index Random Consistency (0,63).

2.3.2 Multi-Objective Optimization based on Ratio Analysis (MOORA) Method

Brauers was the first to introduce the MOORA technique [11]. This approach is a multi-objective optimization technique that can be utilized to effectively resolve several challenging decision-making issues. The key benefits of the MOORA approach are simplicity and ease of implementation, low mathematical calculations, and relatively short execution time [32].

The MOORA technique seeks to maximize two or more competing objectives while satisfying a set of constraints by ranking several possible solutions. The MOORA method entails five main steps, including establishing objectives to identify evaluation attributes, creating a decision matrix, normalizing the decision matrix, deducting the desired maximum and minimum values, and ranking [11].

- Step 1. Construct the decision matrix that shows the performance of different alternatives against various criteria, like all multi-criteria decision-making approaches.

$$X = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \quad (6)$$

Where X_{ij} is the performance measure of i_{th} alternative on j_{th} criterion, m is the number of alternatives ,and is the number of criteria.

- Step 2. Decision Matrix Normalization: Normalize the decision matrix using

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=j}^{m} x_{ij}^2}} \quad (7)$$

where n_{ij} is the value of alternative i_{th} from the j criterion and is always in the range [1,0].

- Step 3. Construct the weighted decision matrix after determining the criterion weights. In this work, the criterion weights are determined using the AHP approach. Latest knowing the criterion weight, we multiply the weight of each criterion with the normal decision matrix and form the weighted normal decision matrix.

- Step 4. Determine the assessment values by finding the difference between the sum of beneficial and non-beneficial (cost) criteria as given in **Equation (8).**

$$Y_i = \sum_{j=1}^{g} x_{ij}^* - \sum_{j=g+1}^{n} x_{ij}^* \tag{8}$$

Where g represents the number of desirable criteria that should be maximized, and $(n-g)$ represents the number of non-beneficial criteria that should be minimized.

- Step 5. Rank the assessment values in decreasing order to get the global rank of the alternatives.

2.3.3 Elimination Et Choix Traduisant la Realite (ELECTRE) Method

- Step 1. Constructing the decision matrix **[13]**, **[23]**, The Determination Matrix is a matrix that displays the factor values for every alternative. Each column of the Decision Matrix represents the value of all factors associated with a particular alternative. While each column of the Decision Matrix displays the value of each alternative for a given factor, each row displays the value of each alternative for that factor. The Decision Maker establishes the Decision Matrix's values.

- Step 2. Normalize the decision matrix, in this phase, each parameter is converted into a comparable value. The formula is used to normalize any x_{ij} values **[13]**.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad R = \begin{vmatrix} r_{11} & r_{12} & r_{....} & r_{1n} \\ r_{21} & r_{22} & r_{....} & r_{2n} \\ r_{....} & r_{....} & r_{....} & r_{....} \\ r_{m1} & r_{m2} & v_{m3} & v_{mn} \end{vmatrix} \tag{9}$$

r_{ij} is the normalized matrix of the problem's base matrix, with $i = 1,2,3,\ldots,m$ and $j = 1,2,\ldots,n$. The base matrix to be normalized is x_{ij}. Each i represents a row of the matrix, whereas each j represents a column.

- Step 3. Weighting the normalized matrix, When the R matrix has been normalized, each column is multiplied by the weight (W_j) resulting from the AHP weighting. Thus, the Weight-normalized matrix is $V = R \times W$, which is represented as follows:

$$V = \begin{vmatrix} v_{11} & v_{12} & v_{....} & v_{1n} \\ v_{21} & v_{22} & v_{....} & v_{2n} \\ v_{....} & v_{....} & v_{....} & v_{....} \\ v_{m1} & v_{m2} & v_{m3} & v_{mn} \end{vmatrix} \qquad RW = \begin{vmatrix} wr_{11} & wr_{12} & wr_{....} & wr_{1n} \\ wr_{21} & wr_{22} & wr_{....} & r_{2n} \\ wr_{....} & wr_{....} & wr_{....} & wr_{....} \\ wr_{m1} & wr_{m2} & wr_{m3} & wr_{mn} \end{vmatrix} \tag{10}$$

- Step 4 Determine the set of concordance and discordance on the index, by estimating the ranking relation, the concordance index and discordance index for each alternative pair are calculated. For each pair of alternatives k and l $(k, l = 1, 2, 3, \ldots., m$ and k is not equal to l) the set of j criteria is divided into 2 subsets namely concordance and discordance.

- Step 5. Determines the set of concordance and discordance on the index. A Criterion in an alternative belongs to Concordance if: $Ckl = \{ j \mid vkj \geq vij \}$ for $j = 1,2,3\ldots n$. A Criterion in an alternative includes Discordance if: $Dkl = \{ j \mid vkj < vij \}$ for $j = 1,2,3\ldots n$.

- Step 6. Calculating matrices of concordance and discordance.

To ascertain the values of the elements in the concordance matrix, one must add the weights contained within the concordance set, namely:

$$C_{kl} = \sum_{j \in C_{kl}} w_j \tag{11}$$

To determine the value of the elements in the discordance matrix, divide the greatest difference between the criteria included in the discordance set and the greatest difference between the criteria. The variance is:

$$d_{kl} = \frac{\max\{|v_{kj} - v_{lj}|\}_{j \in D_{kl}}}{\max\{|v_{kj} - v_{lj}|\}_{\nabla j}} \tag{12}$$

- Step 7. Calculating concordance and discordance dominant matrix

  Calculating the dominant concordance matrix, the *f* matrix as the dominant concordance matrix can be built with the help of the threshold value, namely by comparing each concordance matrix element value with the threshold value ($Ckl \geq c$). The threshold value ($\underline{c}$) is

$$\underline{c} = \frac{\sum_{k=1}^{n}\sum_{l=1}^{n} c_{kl}}{m\,(m-1)} \quad (13)$$

  where $m = alternative$, so the matrix element *f* is determined as follows: $fkl = 1\ if\ Ckl \geq \underline{c}$ and $fkl = 0\ if\ Ckl < \underline{c}$

  Calculating the dominant discordance matrix. g matrix as the dominant discordance matrix can be constructed with the help of values, namely by comparing each discordance matrix element value with the threshold value ($dkl \geq \underline{d}$). With threshold ($\underline{d}$) value is

$$\underline{d} = \frac{\sum_{k=1}^{n}\sum_{l=1}^{n} d_{kl}}{m\,(m-1)} \quad (14)$$

- Step 8. Determine the aggregate dominance matrix

  Matrix e as the aggregate dominance matrix is a matrix in which each element is the result of the elements of matrix *f* and the corresponding elements of matrix *g*, so it can be written as follows:

$$e_{kl} = f_{kl}\ x\ g_{kl} \quad (15)$$

- Step 9. Elimination of less favorable alternatives

  Matrix E specifies the ranking of each alternative, so if $Ekl = 1$, then Ak is a superior alternative than Al. Therefore, the row of matrix E with the fewest instances of $Ekl = 1$ can be eliminated. Therefore, the row of matrix E with the fewest occurrences of $Ekl = 1$ can be eliminated. Therefore, the greatest option is the option that dominates other options.

3. RESULTS AND DISCUSSION

Three alternative locations for electric and solar power shipyards are determined by the decision maker, hereinafter referred to as alternative location 1 (L1), alternative location 2 (L2), and alternative location 3 (L3). Decision-makers determine the parameters that will be evaluated from each alternative location, such as Slope (C1), Soil Type (C2), Rainfall (C3), Flood Prone Potential (C4), Landslide Prone Potential (C5), Land Use (C6), Land Area (ha) (C7), Availability of Land Transportation (C8), Distance to Railway Station (km) (C9), Distance to Toll Road (km) (C10), Distance to Port (km) (C11), Availability of Regional Jetty (C12), Availability of Raw Water Source (C13), Availability of Sewage Plant (C14), Availability of Sewage Plant (C15), Availability of Regional Transmission Line (C16), Water Depth Condition (C17), Water Wave Condition (C18), Presence of Maritime Education Institution (C19), Residential Distance (km) (C20), Conformity of regional development plan (C21).

The Value of Each Parameter for Each Candidate is Determined by the Decision Maker, and the Results are Displayed in **Table 3** of the Decision Matrix.

Table 3. Decision Matrices

	L1	L2	L3
C1	4	3	3
C2	5	1	5
C3	5	5	5
C4	3	3	3
C5	3	3	3
C6	3	3	3
C7	38	20	18
C8	3	3	3
C9	40.4	10.1	46.2

	L1	L2	L3
C10	46.7	7.2	52.2
C11	9	8.3	5.4
C12	88.7	95.8	98.3
C13	3	3	3
C14	1	1	1
C15	3	2	2
C16	2	3	2
C17	7	4	9
C18	0.53	0.47	0.53
C19	5	4	5
C20	2.5	1.4	0.5
C21	2	2	2

3.1 AHP Weighted Calculation

Based on the explanation of step 1. the weighting method with AHP, the decision maker constructs a comparison matrix. Next, the matrix is normalized as in step 2 **Equation (1).** By applying the AHP weighting calculation steps 3 to 7, The Synthetic Weight Value, Eigenvalue, Priority Weight Value, And Value of Interest are obtained in **Table 4**.

Table 4. The Synthetic Weight Value, Eigenvalue, Priority Weight Value, And Value of Interest

	Weight Synthesis	Eigenvalues	Priority Weight Value	Value of Interest
C1	1.83	2.308026077	0.08636199455	21.24633394
C2	1.77	2.338603563	0.08750614658	20.22041464
C3	1.82	2.431984323	0.09100027896	20.0491474
C4	1.53	2.007768897	0.07512693564	20.36929658
C5	1.35	1.781318367	0.06665358274	20.20997859
C6	2.52	2.742221062	0.1026087542	24.541967
C7	1.15	1.564629496	0.05854549279	19.7149118
C8	0.97	1.312779308	0.04912173247	19.80313789
C9	0.37	0.4565405403	0.0170828883	21.71965896
C10	0.47	0.5878760579	0.02199721633	21.290917
C11	0.97	1.254371094	0.04693620697	20.72655758
C12	0.23	0.2879275083	0.01077370579	21.36410401
C13	0.28	0.3325213701	0.01244232422	22.74812723
C14	0.39	0.4703878231	0.01760102757	22.01055112
C15	0.67	0.8493335886	0.03178046535	21.12739808
C16	0.63	0.7950762415	0.02975025748	21.28249207
C17	0.78	1.013033429	0.03790580546	20.58715905
C18	0.74	0.9729736361	0.03640684337	20.22751202
C19	0.13	0.1670194408	0.006249553324	20.09698151
C20	0.95	1.237304447	0.04629760514	20.60559095
C21	1.43	1.813324252	0.06785118279	21.14751044
			Total	441.0897479
			λmax	21.00427371

In the initial step of calculating the CI value, the maximum eigen value obtained in the preceding calculation step is used to test the consistency of the calculated value. Then proceed with the final calculation to verify the consistency value, which is to calculate the CR value.

Calculating the value of CI using **Equation (4)**, the initial counting procedure is as follows:

$$CI = \frac{(\lambda_{maks} - n)}{n} = \frac{(21{,}00427371 - 21)}{21} = 0.0002136853593 \quad (16)$$

Using **Equation (5)**, the CR value is computed as the final step in the AHP method application. 1.63 is used as the IR value. The calculation of the CR value is as follows:

$$CR = \frac{CI}{IR} = \frac{0.0002136853593}{1,63} = 0.0001310953124 \quad (17)$$

Consequently, the consistency test is valid since the consistency ratio (CI/IR) is less than 0.1

3.2 AHP – MOORA Integration

Step 2. Decision Matrix Normalization: normalize the decision matrix using **Equation (7)**.

Table 5. Normalize Decision Matrix

Criteria	A1	A2	A3
C1	0.686	0.514	0.514
C2	0.700	0.140	0.700
C3	0.577	0.577	0.577
C4	0.577	0.577	0.577
C5	0.577	0.577	0.577
C6	0.577	0.577	0.577
C7	0.816	0.430	0.387
C8	0.577	0.577	0.577
C9	0.650	0.162	0.743
C10	0.663	0.102	0.741
C11	0.673	0.620	0.404
C12	0.543	0.586	0.601
C13	0.577	0.577	0.577
C14	0.577	0.577	0.577
C15	0.728	0.485	0.485
C16	0.485	0.728	0.485
C17	0.579	0.331	0.745
C18	0.599	0.531	0.599
C19	0.615	0.492	0.615
C20	0.860	0.481	0.172
C21	0.577	0.577	0.577

Step 3. Construct the weighted decision matrix after determining the criterion weights. In this work, the criterion weights are determined using the AHP approach.

Table 6. Weighted Decision Matrix

	A1	A2	A3
C1	1.259	0.944	0.944
C2	1.239	0.248	1.239
C3	1.053	1.053	1.053
C4	0.884	0.884	0.884
C5	0.778	0.778	0.778
C6	1.454	1.454	1.454
C7	0.942	0.496	0.446
C8	0.562	0.562	0.562
C9	0.241	0.060	0.276
C10	0.311	0.048	0.347
C11	0.654	0.603	0.393
C12	0.125	0.135	0.138
C13	0.163	0.163	0.163
C14	0.224	0.224	0.224
C15	0.489	0.326	0.326
C16	0.307	0.461	0.307

	A1	A2	A3
C17	0.452	0.258	0.581
C18	0.441	0.391	0.441
C19	0.077	0.062	0.077
C20	0.820	0.459	0.164
C21	0.828	0.828	0.828

Step 4. Determine the assessment values by finding the difference between the sum of beneficial and non-beneficial (cost) criteria as given in **Equation (8)**.

Step 5. Rank the assessment values in decreasing order to get the global rank of the alternatives.

Table 7. Assessment value and alternative's rank

Alternative	Benefit	Cost	Yi Benefit - Cost	Ranking
A1	11.530	1.772	9.758	1
A2	9.199	1.238	7.961	3
A3	10.030	1.595	8.435	2

3.3 AHP - ELECTRE Integration

This result and discussion will describe the outcomes of applying a combination of AHP and ELECTRE methods to aid in the selection of the optimal location for the electric and solar-powered shipyard industry. The subsequent step is to normalize the decision matrix using **Equation (9)**. The results are then displayed as shown in the Decision Matrix Normalisation **Table 8**.

Table 8. Normalizing the Decision Matrix

	L1	L2	L3
C1	0.6859943406	0.5144957554	0.5144957554
C2	0.700140042	0.1400280084	0.700140042
C3	0.5773502692	0.5773502692	0.5773502692
C4	0.5773502692	0.5773502692	0.5773502692
C5	0.5773502692	0.5773502692	0.5773502692
C6	0.5773502692	0.5773502692	0.5773502692
C7	0.8161198812	0.4295367796	0.3865831016
C8	0.5773502692	0.5773502692	0.5773502692
C9	0.6495369924	0.1623842481	0.7427873528
C10	0.6632579328	0.1022581824	0.7413718221
C11	0.6725976518	0.6202845011	0.4035585911
C12	0.5427516437	0.586196251	0.601493648
C13	0.5773502692	0.5773502692	0.5773502692
C14	0.5773502692	0.5773502692	0.5773502692
C15	0.7276068751	0.4850712501	0.4850712501
C16	0.4850712501	0.7276068751	0.4850712501
C17	0.579324122	0.3310423554	0.7448452997
C18	0.5990708704	0.5312515266	0.5990708704
C19	0.6154574549	0.4923659639	0.6154574549
C20	0.8595177052	0.4813299149	0.171903541
C21	0.5773502692	0.5773502692	0.5773502692

The weight of each parameter that has been analysed using AHP is then used to multiply by the normalisation value of the Decision matrix using **Equation (10)**. Then the results are displayed in the Weighted Normalisation of Decision Matrix table as in the **Table 9.**

Table 9. Weighted Normalization of Decision Matrix

	L1	L2	L3
C1	1.258714398	0.9440357982	0.9440357982
C2	1.238835189	0.2477670378	1.238835189
C3	1.053362868	1.053362868	1.053362868
C4	0.8835092059	0.8835092059	0.8835092059

	L1	L2	L3
C5	0.7777297724	0.7777297724	0.7777297724
C6	1.453895376	1.453895376	1.453895376
C7	0.9419812581	0.4957796095	0.4462016486
C8	0.5616258121	0.5616258121	0.5616258121
C9	0.2410006383	0.06025015958	0.2755997399
C10	0.310630822	0.0478916899	0.3472147518
C11	0.6543204807	0.6034288877	0.3925922884
C12	0.1249254557	0.1349251258	0.1384461364
C13	0.1634129745	0.1634129745	0.1634129745
C14	0.2236702962	0.2236702962	0.2236702962
C15	0.4885432999	0.3256955333	0.3256955333
C16	0.3071275277	0.4606912916	0.3071275277
C17	0.4520888137	0.258336465	0.5812570462
C18	0.4411676875	0.3912241757	0.4411676875
C19	0.07729970697	0.06183976557	0.07729970697
C20	0.8199708773	0.4591836913	0.1639941755
C21	0.8284304308	0.8284304308	0.8284304308

The concordance index set could be obtained as shown in the **Table 10**.

Table 10. The Index Set of Concordance

	L1	L2	L3
L1	{}	{1,2,3,4,5,7, 8,9,10,11,13,14, 15,17,18, 19,20,21}	{1,2,3,4,5,6, 7,8,11,13, 14,15,16,18, 19,20,21}
L2	{3,4,5,6,8,12, 13,14,16,21}	{}	{1,3,4,5,6,7,8,11, 13,14,15,16,20,21}
L3	{2,3,4,5,6,8,9,10,12, 13,14,16,17,18,19,21}	{1,2,3,4,5,6,8,9,10,12, 13,14,15,17,18,19,21}	{}

The discordance index set could be obtained as shown in the **Table 11**.

Table 11. The Index Set of Discordance

	L1	L2	L3
L1	{}	{12,16}	{9,10,12, 17}
L2	{1,2,7,9,10,11, 15,17,18,19,20}	{}	{2,9,10,12, 17,18,19}
L3	{1,7,11,15,20}	{7,11,16,20}	{}

The construction of the concordance matrix was processed by determining the element values of the concordance index set using **Equation (11)**, with the following result:

$$C = \begin{vmatrix} 0 & 20,14 & 19,15 \\ 11.1614751 & 0 & 16,52 \\ 15.41265095 & 17,29 & 0 \end{vmatrix}$$

The construction of the discordance matrix was processed by determining the element values of the discordance index set using **Equation (12)**, with the following result:

$$D = \begin{vmatrix} 0 & 0,15 & 0,20 \\ 1 & 0 & 1 \\ 1 & 0.2978498658 & 0 \end{vmatrix}$$

The step of calculating the threshold value before determining the dominant concordance matrix and the dominant discordance matrix. By using **Equation (13)**, the threshold value c is obtained and **Equation (14)**, the threshold value d is obtained as follows:

$$\underline{c} = \frac{99,67}{3\,(3-1)} = 16,611$$

$$\underline{d} = \frac{3,65}{3\,(3-1)} = 0,6083$$

Then the matrix f as the dominant concordance matrix is as follows:

$$f = \begin{vmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{vmatrix}$$

Then the matrix g as the dominant discordance matrix is as follows:

$$g = \begin{vmatrix} 0 & 0 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{vmatrix}$$

The step to determine matrix e as the total dominant matrix. Using **Equation (12)**, matrix e is obtained as follows:

$$e = \begin{vmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{vmatrix}$$

Due to the fact that e is a value of zero, the classification is determined by the values of C and D. Listed below are the results of the ranking.

Table 12. Alternative Location Value Ranking

Alternative location	C		D	Total Value	Rank
L1	20,14 19,15	-	0.15 0.20	38.93	1
L2	11.1614751 16.52	-	1 1	25.68012868	3
L3	15.41265095 17.29	-	1 0.2978498658	31.40	2

From the results of the table, it can be seen that candidate L1 has the highest total value, so candidate L1 is decided to be the best location for the electric and solar-powered shipyard industry using the Electre approach with AHP weighting.

3.4 Results of Comparative Analysis

In this research, two different MCDM integration methods namely AHP-MOOORA and AHP-ELECTRE were successfully adopted to determine the optimal alternative location for the electric and solar-powered shipyard industry. **Figure 4** is a summary of the AHP - MOORA ranking results and the AHP – ELECTRE Integration results.

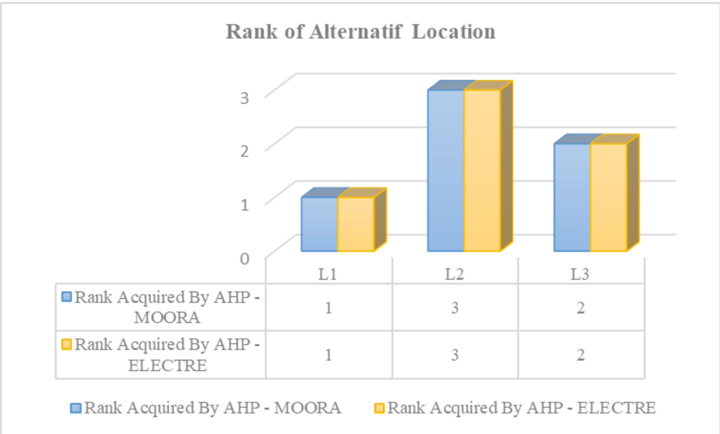

Figure 4. Comparison of AHP-MOORA method, AHP-ELECTRE method and ranking

After the fulfillment of the proposed comparative study, the following observations can be made:

- The resulting ranking results are the same both using the AHP-MOORA and AHP-ELECTRE methods.
- Alternative location 1 is the best location based on the results of AHP-MOORA and AHP-ELECTRE analyses.
- alternative location 3, is in third place based on the results of AHP-MOORA and AHP-ELECTRE analyses.

- Among all other methodologies, AHP-MOORA is the simplest algorithm. It is merely a matter of summing up and contrasting positive and negative factors.
- Compared to AHP-MOORA, AHP-ELECTRE requires a substantial amount of computation. Given the additional information, it is evident that the computation of the set of concordance-discordance intervals, matrix intervals, and index matrix intervals requires additional time.

4. CONCLUSIONS

This research attempts to solve the problem of selecting the best location of three alternative locations (L1, L2, and L3) for an electric and solar-powered shipyard. It takes twenty-one (21) parameters (Table 1 to Table 21) based on regional characteristics, data availability, and satisfying constraints and requirements. Two different MCDM integration methods, AHP-MOOORA and AHP-ELECTRE, were adopted to determine the optimal alternative location. Based on the calculation using the AHP-MOORA and AHP-ELECTRE methods, both have the same results. Alternative location 1 (L1) has the first place as the best location, alternative location 3 (L3) has the second place, and alternative location 2 (L2) has the third place. Using a combination of these methods ensures that location 1 (L1) is the best location that best meets the criteria. Future research may consider adding other criteria that influence shipyard site selection more significantly. In addition, other MCDM methods with an ensemble approach can be used to integrate weighting or ranking methods to obtain more comprehensive decisions.

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