Determination of Solar-Powered Shipyard Location Using Integrated-MCDM Method

Nanda Yustina
Research Center for Transportation Technology, National Research and Innovation Agency (BRIN)

Ade Ratih Ispandiari
Research Center for Transportation Technology, National Research and Innovation Agency (BRIN)

Annissa Roschyntawati
Research Center for Transportation Technology, National Research and Innovation Agency (BRIN)

Zulfa Qonita
Research Center for Geological Disaster, National Research and Innovation Agency (BRIN)

他

https://doi.org/10.5109/7326983

出版情報：Evergreen. 11 (4), pp.3470-3483, 2024-12. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Japan
バージョン：

EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 11, Issue 04, pp3470-3483, December, 2024

Determination of Solar-Powered Shipyard Location Using Integrated-MCDM Method

Nanda Yustina[1,*], Ade Ratih Ispandiari[1], Annissa Roschyntawati[1], Zulfa Qonita[2], Noor Muhammad Ridha Fuadi[1], Dwitya Harits Waskito[1], Nanda Itohasi Gutami[1], Iskendar[1], Siti Sadiah[1], Faisal Rahman[3]

[1]Research Center for Transportation Technology, National Research and Innovation Agency (BRIN), Puspiptek-Serpong, Tangerang Selatan, Indonesia

[2]Research Center for Geological Disaster, National Research and Innovation Agency (BRIN), Jl. Sangkuriang, 40135 Jawa Barat, Indonesia

[3]Ministry of Investment/BKPM or Indonesian Investment Coordinating Board, Jl. Gatot Subroto No.44, Jakarta 12190, Indonesia

*Author to whom correspondence should be addressed:
E-mail: nand013@brin.go.id

(Received May 15, 2024; Revised October 15, 2024; Accepted November 26, 2024).

Abstract: Maritime shipping contributes nearly 3% of global greenhouse gas emissions. To achieve zero-carbon shipping, Indonesia, with its abundant sunlight, can use solar cell technology for electric-powered ships, necessitating carefully selecting shipyard locations. To address this challenge, this research integrates DEMATEL with six MCDM ranking methods (CoCoSo, MOORA, TOPSIS, ARAS, OCRA, and WASPAS). Using 23 comprehensive criteria, the study identifies the most suitable locations for solar-powered shipyards. The analysis showed PT Dok Pantai Lamongan and PT Armada Bangun Samudra as the top locations, consistently ranked by all methods. A significant contribution of this research lies in its application of objective decision-making methods and new parameters related to the shipyard selection process. Sensitivity analysis confirmed the robustness of the results, with DEMATEL-MOORA identified as the most straightforward approach. This study advances Indonesia's pursuit of a sustainable maritime industry by offering reliable, objective decision-making methods for site selection.

Keywords: Solar-Powered Shipyard; DEMATEL; Comparison of MCDM; Site selection; Integrated method

1. Introduction

Indonesia is an archipelagic country where sea transportation is an essential part of daily life in Indonesia, providing connectivity between the country's islands and supporting sustainable development and economic integration in various regions. Therefore, the availability of ships is an important part of the domestic shipping fleet for transporting goods and people. Along with the emergence of world regulations and agreements regarding climate change, it is hoped that the implementation of maritime decarbonization will accelerate. By exploiting this global trend for Indonesia's national interests, developing electric and solar-powered ships becomes an economic opportunity directly related to ships. Moreover, the issue of electrification of Indonesia's small ship fleet has also been stated in document[1]. Also, the sunlight obtained in Indonesia can produce 5.1 kWh per day if solar cells are used[2]. According to[3], the life cycle emissions from power generation from solar energy are much smaller than the life cycle emission levels for natural gas and coal, at only 0.07 and 0.18 pounds of carbon dioxide equivalent per kilowatt-hour.

On the other hand, the shipbuilding industry is probably the sector facing the most drastic changes from 2030 onwards, when the International Maritime Organization (IMO) green goal target of stopping any fuel-burning ships delivered by shipyards on or after January 1, 2030, is set to come into force. In essence, shipyards stand at the nexus of both challenge and opportunity, tasked with aligning their efforts with the industry's dual imperatives of emission reduction and the development of markedly more innovative vessels[4].

Meanwhile, the development of electric and solar-powered ships must be followed by the availability of maritime infrastructure in the form of shipyards for electric and solar-powered ships. This is because shipyards for electric and solar-powered ships have different qualifications from shipyards in general. Currently, there is no information regarding the availability of vessels from Indonesian shipyards as producers of electric and solar-powered ships. The current number of shipyards in Indonesia is 250, which is considered insufficient to handle the ship population in Indonesia[5]. This is because the distribution of shipyard locations is not evenly distributed, of which 88% are in the western region of Indonesia, only 12% are in the eastern region, and most are small-scale[5].

From this problem, we can see that the location of electric and solar-powered shipyards needs to be planned carefully to align with specified criteria, thereby supporting the achievement of a sustainable and independent maritime industry in Indonesia. To identify alternative locations for electric shipyards, the parameters that influence the selection of these locations are determined based on relevant previous studies and expert reviews from the maritime sector, policymakers, and the shipyard industry. Based on the identification results, this study considered four alternative shipyard locations and 23 parameters to determine the most suitable location for an electric and solar-powered shipyard. Given the complexity and number of parameters involved, the Multi-Criteria Decision Making (MCDM) method is considered appropriate for addressing this problem.

Previous research has applied various MCDM methods to different contexts. For example, a study[6] applied some well-known MCDM methods (SAW, WPM, AHP, TOPSIS (Technique for Others Preference by Similarity to Ideal Solution), VIKOR, ELECTRE III) to an existing small run-of-the-river hydropower plant for the selection of the optimal flow release scenario, and compared these methods statistically. Similarly, the CoCoSo (Combined Compromise Solution) method, developed by Yazdani et al.[7], can compete with previously well-known MCDM tools and is useful in several areas such as the supply chain, construction sector, and engineering fields. It solves uncertain decision problems where experts deal with less quantitative information about candidate suppliers[8] and has been successfully used for personnel selection[8]. The WASPAS (Weighted Aggregated Sum Product Assessment), method is known to increase ranking accuracy[9] and has been commonly employed in energy and sustainability contexts, often integrated with other MCDM methods[10]. Conversely, methods like OCRA (Operational Competitiveness Assessment)[11] and ARAS (Additive Ratio Assessment)[12] are less frequently used but have been validated and extended by various studies to address performance selection problems, efficiency analysis, and productivity[13–21].

This research proposes a two-stage approach, including the weighting of each parameter using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to analyze the correlation between factors to obtain a weight value for each criterion, considering their interrelationships[7,22–24]. The DEMATEL method was first developed to identify causal relationships[25,26] and has since been adapted for multi-criteria decision-making. By analyzing the structural relationship between parameters, DEMATEL can effectively weigh the parameters.

Following this, we analyze the ranking of alternative site assessments using six MCDM methods: TOPSIS, CoCoSo, MOORA (Multi-Objective Optimisation by Ratio Analysis), OCRA, WASPAS and ARAS. Each of these MCDM methods uses different approaches for ranking alternatives. CoCoSo combines the sum and product of criteria values, while MOORA uses the ratio of beneficial and non-beneficial criteria. TOPSIS evaluates alternatives based on their distance from the ideal and negative-ideal solutions. ARAS aggregates normalized criteria values to assess utility, OCRA measures operational competitiveness, and WASPAS combines weighted sum and product models. The main difference between these MCDM methods lies in how each method processes the decision matrix and ranks the alternatives.

The significant contribution of this research lies in the application of various ranking methods to compare the assessment results in the shipyard site selection process, making the decision-making process much more objective than using a single method alone. Each method provides distinct insights and advantages, enhancing their value for comparative analysis in determining the most suitable locations for solar-powered shipyards. Moreover, each method is integrated with the DEMATEL weighting method. Then, the results were compared using a statistical approach to analyze the correlation and robustness. Another contribution of this research is the introduction of new criteria or parameters for selecting shipyard locations, compared to earlier studies[27,28], to better serve electric and solar-powered ships. These new parameters include the distance to raw materials and ship parts and the hours of sunlight. By leveraging these MCDM methods and comprehensive parameters, this research encourages the development of a specialized shipyard industry for solar and electric ships in appropriate locations, fostering the advancement of green ship technology and contributing to maritime decarbonization.

2. Materials and Methods

Figure 1 shows the entire workflow in this research, it explains the method used in making multi-criteria decision-making method. The MCDM method is used in various aspects, including social, economic, and environmental[29,30]. The initial stage in selecting locations for solar-powered shipyards is to determine the criteria through literature studies. The next stage determines the relationship between the criteria and the weight of each parameter using DEMATEL. A structural modeling method for analyzing cause-and-effect interactions among complex factors is the DEMATEL method[31]. Furthermore, a ranking analysis was conducted to determine the location of the solar-powered shipyard industry using the DEMATEL-COCOSO, DEMATEL-MOORA, DEMATEL-TOPSIS, DEMATEL- ARAS, DEMATEL-OCRA, and DEMATEL-WASPAS methods. The results were evaluated by determining the Spearman rank correlation coefficient.

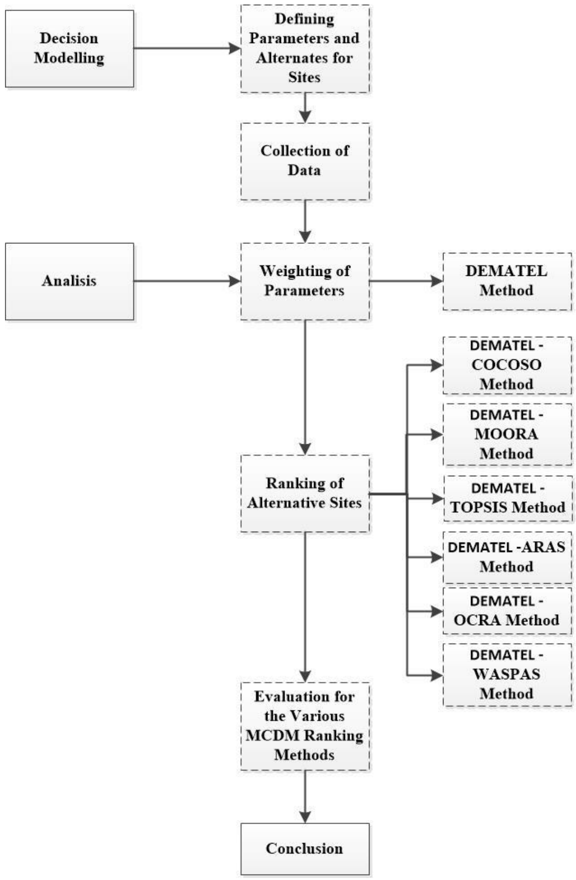

Fig. 1: Frameworks for Locating Solar-Powered Shipyards Using the Ensemble Method.

2.1 Study Area

The alternative locations for the solar shipbuilding industry consist of four locations, as shown in Fig. 2. The first four alternative locations are PT Dok Pantai Lamongan in Lamongan Regency, East Java; the second alternative location of PT Armada Bangun Samudra in Serang Banten; the third alternative location of Lintech Seaside Facility in Lamongan Regency, East Java; and finally the fourth alternative location is PT Sumber Marine Shipyard in Batam Riau Islands.

2.2 Site Parameters for Solar-Powered Shipyard Industry

The parameters used to select alternatives play an important role in determining the location of the shipbuilding industry. Therefore, a review has been conducted of various references, papers, and regulations relevant to the selection of shipyard industry sites to obtain and classify the most appropriate factors to be used in this problem. The parameters used in this solar-powered shipyard selection consist of 23 parameters. As we can see in Table 1, we provide a detailed explanation of parameters, such as characteristics, details of value/scale used, and reference sources. Some parameters use actual values, such as ‘land area’ (in hectares), ‘distance to the port’ (in kilometers), ‘distance to the airport’ (in kilometers), and wave height (in meters). Meanwhile, other parameters use a scale for the actual value of alternative locations. As with the parameter 'distance to train station', we found some alternative locations do not have train access. At the same time, ‘distance’ should have cost characteristics, where a smaller value is preferred. Therefore, we changed the parameter characteristics to benefits (greater value is preferred) and created a scale for the parameter ‘distance to the train station’, namely a distance of less than 5km with a value of 4, a distance of 5-10 km with a value of 3, a distance of 10-50 km with a value of 2, and ' no train station' with a value of 1. Furthermore, we also used scale for parameters with non-quantitative data, such as the use of land, flood vulnerability, the existing source of raw water, the accessibility of a wastewater plant, etc.

2.3 Parameters Weighting Analysis using the DEMATEL Method

In recent years, DEMATEL has been widely used as a Multi-Criteria Decision Making (MCDM) approach in many decision analyses. DEMATEL, developed by the Battelle Memorial Institute in Geneva, is a more extensive and sophisticated version of AHP based on matrix theory[32]. Like mind mapping, this method helps determine the optimal course of action for resolving problems in real-world circumstances by organizing expert replies to the barriers into a visual impact map[33]. Compared to other methods, one of the advantages of this method is the ability to identify interdependencies from the decision-maker's point of view. The stages comprising the DEMATEL method are as follows[33–35]

Step 1: Initiation of initial construction of direct relationship matrix (Z): Matrix ixj Z is the result of pairwise comparison scaling. Pairwise comparisons were made using a Likert scale, with 0 to 4 representing “No influence,” “Low influence,” “Same influence,” “High influence,” and “Very high influence,” respectively. This matrix construct consists of the average value of each assessment. The Likert scale is generally used with 5 or 7 points[36]. In this study, we used a 5-point scale. The 5-point Likert scale is easy for both, survey administrators and respondents, to understand and use, allowing respondents to remain neutral. Additionally, questionnaires with more than 5 points can make it difficult for respondents to identify their opinions accurately, leading to confusion, lower response rates, and unreliable results[37].

Step 2: The process of generating the normalized direct-relation matrix (X) involves dividing each element of the Direct Relationship matrix by the line or column containing the smallest value (k). The Direct Relationship Matrix (X) is computed using Equations (1) and (2).

$$X = k\,x\,Z \quad (1)$$

$$k = Min\left(\frac{1}{\max \sum_{j=1}^{n}[Z_{ij}]}, \frac{1}{max \sum_{i=1}^{n}[Z_{ij}]}\right) \quad i,j = 1,2,3,\ldots,n \quad (2)$$

Step 3: The total effect matrix (T) is generated through the application of equation (3). The entity that I symbolize is the Unit Matrix.

$$T = X + X2 + X3 + n \quad (3)$$

Step 4: To ascertain the vectors D and R, the sum of the $i.$ rows, denoted as di, represent the cumulative impact of the $i.$ criteria on the remaining criteria. Denoted as rj, the sum of the $j.$ columns indicate the overall influence of the criteria when adjusted for other factors.

$$D = [di]nx1 = \left[\sum_{j=1}^{n} tij\right]_{nx1} \quad (4)$$

$$R = [rj]nx1 = [\sum_{i=1}^{n} tij]_{nx1} \quad (5)$$

By utilizing Equations (4) and (5), (D) and (R) are computed. A high $D + R$ value indicates that the factor or criterion in question has a significant relationship with others and plays a crucial role. When the value of the criterion ($D - R$) is positive, it exerts a substantial influence on the remaining criteria and assumes a more significant role; this group is known as the cause group. The group of criteria whose influence is greatest relative to the others is referred to as the effect group ($D - R$).

Step 5: Determine the weights of criteria that contain influence. Equation 6 generates the weight vector $w = (w1, w2, \ldots, wn)$ for the evaluation criteria.

$$w = \frac{\sqrt{(r_j + d_j)^2 + (r_j + d_j)^2}}{\sum_{j=1}^{N}\sqrt{(r_j + d_j)^2 + (r_j - d_j)^2}} \quad (6)$$

2.4 Ranked Assessments

We applied the six integrations of MCDM approaches to the site selection problem (solar-powered shipyard sites) in the current study and compared the results. The integrated methods are DEMATEL-CoCoSo, DEMATEL-MOORA, DEMATEL-TOPSIS, DEMATEL-ARAS, DEMATEL-OCRA, and DEMATEL-WASPAS.

2.4.1 DEMATEL - CoCoSo Method

The MCDM method, known as CoCoSo, was introduced by[7)] As a result of combining the exponentially weighted product (EWP) and simple additive weighting (SAW) techniques, this method has emerged. This approach entails the computation of utility values from various corners. Then, an aggregation function combines the utility values of each alternative to arrive at a compromise option[7,38,39)]. For solving a CoCoSo decision problem, the subsequent stages will be to verify the identification of the alternatives and the following parameters: (1) determine a decision matrix. (2) normalize parameter values for benefit and cost parameters. (3) calculate the sum of the combined power weight of comparability sequences for each alternative and sum the total power weight of the weighted comparability sequences. (4) Apply the subsequent aggregation strategies to approximate three distinct appraisal scores for the alternatives. (5) Rank the alternatives according to their on the compromise ranking index.

2.4.2 DEMATEL - MOORA Method

The MOORA technique has the potential to be effectively utilized as a suitable method for arranging and rating options among a multitude of available alternatives[40)]. It is also known as multi-criteria or multi-attribute optimization. This methodology simultaneously optimizes several competing objectives[41)]. By Balezentis and Balezentis[42)], The ranking of condensation factors is determined in this stage, considering the criterion weightings computed in step 2.3 utilizing the MOORA approach. the MOORA procedures are detailed below. (1) A decision matrix is utilized to delineate various alternatives. (2) normalize the matrix. (3) evaluate both positive (benefit) and negative (cost) consequences by calculating the ratio system (sum of beneficial criteria minus the sum of cost criteria). When there is an increase in performance, a criterion assigns positive values; conversely, negative values are regarded as negative aspects. (5) After the results have been ranked, the optimal alternative can be selected.

2.4.3 DEMATEL - TOPSIS Method

TOPSIS was initially introduced in the field of performance assessment by Hwang and Lin in 1987[43,44)]. Numerous objective decision-making issues about diverse regions may be resolved by utilizing TOPSIS[45)]. The following are the principal stages comprising TOPSIS. (1) The initial stage involves the construction of a decision matrix, (2) decision matrix normalization, (3) calculation of the normalized weighted decision matrix, (4) determine the positive and negative ideal solutions, (5) calculation of the separation measures (distance to ideal and negative-ideal solutions), (6) calculate the relative closeness to the ideal solution. (7) rank the alternatives based on the relative closeness.

2.4.4 DEMATEL - ARAS Method

Zavadskas and Turskis initially introduced the ARAS method to mitigate the impact of varying measurement units and optimization orientations in MCDM[46–48)]. The following are the principal stages comprising ARAS. (1) construct the decision matrix, (2) normalize the decision matrix for all criteria, (3) determine the normalized weighted matrix, (4) determine the value of the optimization function of each alternative, (5) determine the highest-ranking level of the alternatives based on the value of the optimization function.

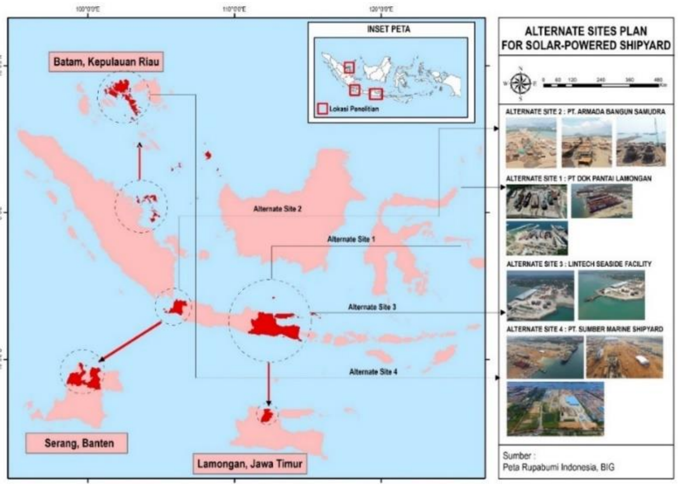

Fig. 2: Alternate Sites Plan for Solar-Powered Shipyard.

2.4.5 DEMATEL - OCRA Method

OCRA is comparable to a max-min normalization procedure applied to a straightforward machine average[11,49,50]. The fundamental concept behind the OCRA method is to conduct autonomous assessments of alternatives based on advantageous and disadvantageous criteria and subsequently merge these two sets of ratings to derive operational competitiveness ratings[50]. Several stages comprise the primary procedure for implementing the OCRA method. (1) construct the decision matrix, (2) calculate the competitiveness rating of the alternatives for the cost parameter, (3) calculate the linear competitiveness rating of each alternative for the cost parameter, (4) calculate the competitiveness rating of the alternatives for the beneficial parameter, (5) calculate the linear competitiveness rating of each alternative for the beneficial parameter, (6) rank the alternatives based on the total competitiveness rating for each alternative.

2.4.6 DEMATEL - WASPAS Method

The weighted aggregated sum product assessment (WASPAS) model, developed by Zavadskas et al., has been widely implemented in various real-world scenarios. It is a more precise combination of the weighted sum model (WSM) and the weighted sum model (WPM)[9,51–54]. The following are the stages comprising the WASPAS method. (1) Create a decision matrix, (2) Identification of the normalized matrix, (3) Calculating matrix normalization values and DEMATEL weights, (4) calculate the preference value of each alternative, (5) Arranging substitutes: The best option is identified by looking up the most significant value, which is then ranked.

2.5 Evaluation of the Various MCDM Ranking Methods

Different decision ranking methods produce ranks with varying levels of similarity for alternatives in a decision matrix. To investigate the potential of the suggested MCDM approach in mitigating uncertainty and improving apparent performance, a sensitivity analysis of ranking stability based on different ranking methodologies was conducted. Sensitivity analysis is often performed in complex decision environments by comparing a model's output with other well-structured approaches to evaluate the robustness and reliability of the alternatives' ranking scores[7,55]. A strong correlation coefficient between ranking scores can provide useful confirmation and agreement, serving as a global method for comparing decision outcomes during practical implementations.

Based on earlier research[6], sensitivity analysis was conducted using the results from applying the various MCDM approaches. The rankings obtained from the different methods were compared and statistically analyzed through Spearman's rank correlation tests. The Spearman rank correlation coefficient, a non-parametric method, was used to measure the strength and direction of the association between ranked variables. In evaluating MCDM methods, this coefficient helps assess the consistency and reliability of the rankings produced by different methods. High correlation coefficients indicate strong agreement, suggesting the rankings are robust and consistent across different methods. Conversely, low correlation coefficients may indicate significant discrepancies, highlighting potential differences in how each method evaluates and ranks the alternatives. Including the Spearman rank correlation coefficient in the robustness test provides valuable insights into the reliability of the decision-making process and ensures that the chosen methods produce stable and dependable results.

Table 1. Site Parameters for Solar Powered Shipyard Industry.

Code	Site Parameters	Characteristics	Details or Value / Scale					References
p1	The angles of Slope (%)	Benefit	(0-8)/Flat/5	(8-15)/Ramp/4	(15-25)/Rather Steep/3	(25-45)/Steep/2	(>45)/Very Steep/1	56–60)
p2	The ground type	Benefit	Gley, Palnosol, Alluvial, Gray Hydromorphic / Sensitive / 5	Rather Latosol / Sensitive / 4	Mediterranean, non-marshy brown forest soil / Less Sensitive / 3	Laterite, Grumusol, Andosol, Podsol, Podzolic / Sensitive / 2	Lithosol, Organosol, Regosol, Renzina / Very Sensitive/ 1	56–60)
p3	The amount of rain(mm/Year)	Benefit	0 – 1500 / 5	1500 – 2000 / 4	2000 – 2500 / 3	2500 – 3000 / 2	>3000 / 1	56–58)
p4	Flood vulnerability (m)	Benefit	Low / <1 / 3	Medium / 1 – 3 / 2	High / >3 / 1	-	-	56–58)
p5	Landslide hazard possibility (cm/year)	Benefit	Low / <0,9 / 3	Medium / 0,9 – 1,8 / 2	High / >1,8 > 1	-	-	56–58)
p6	Use of land	Benefit	Zone of industrial designation / 2	Protected Areas or Designated Areas for Sustainable Food Agriculture / 1	-	-	-	56–58)
p7	Lands area (Ha)	Benefit (non-scale)	Main Industry / >50 / -	Small and Medium / 5 – 50 / -	Industry Not Presented / <5 / -	-	-	56–58)
p8	The accessibility of land transport	Benefit	Main arterial thoroughfare / 4	Road for Primary Collection / 3	Primary community thoroughfare / 2	Village Streets / 1	-	56–58)
p9	The distance to the train station	Benefit	<5 / 4	5 – 10 / 3	10 – 50 / 2	None /1	-	56–58)
p10	Toll road availability	Benefit	<5 / 4	5 – 10 / 3	10 – 50 / 2	None /1	-	56–58)
p11	The distance to the harbour (km)	Cost (non-scale)	-	-	-	-	-	56–58)
p12	The distance to airports (km)	Cost (non-scale)	-	-	-	-	-	56–58)
p13	Provision of an area dock	Benefit	A designated area jetty exists. / 3	A regional jetty development is occurring / 2	Absence of jetty construction in the area / 1	-	-	56–58)
p14	Existence of sources of raw water	Benefit	Alternative surface water site / 4	Company for Regional Drinking Water / 3	Reprocessing of industrial wastewater for reuse / 2	Provisions sourced from external organizations or local governing bodies / 1	-	56–58)

<table>
<tr><th>Code</th><th>Site Parameters</th><th>Characteristics</th><th colspan="8">Details or Value / Scale</th><th>References</th></tr>
<tr><td>p15</td><td>The accessibility of a wastewater plant</td><td>Benefit</td><td>A regional sewage treatment facility is present / 4</td><td colspan="2">Temporary Storage Building (TPS) / 3</td><td colspan="2">Temporary Storage Site (TPS) / 2</td><td colspan="2">There is no Waste Temporary Storage Site (TPS) / 1</td><td>-</td><td>56–58)</td></tr>
<tr><td>p16</td><td>Provision of regional electricity lines (kV)</td><td>Benefit</td><td>Extra High Voltage Air Line (SUTET) / 200 – 500 / 3</td><td colspan="2">High Voltage Air Line (SUTET) / 30 – 150 / 2</td><td colspan="2">No Transmission line yet / 0 / 1</td><td colspan="2">-</td><td>-</td><td>56–58)</td></tr>
<tr><td>p17</td><td>Sea Level Specification/Ship Weight (DWT)</td><td>Benefit</td><td>80.000 – 150.000 / 8</td><td>50.000 – 80.000 / 7</td><td>30.000 – 50.000 / 6</td><td>15.000 – 30.000 / 5</td><td>8.000 – 15.000 / 4</td><td>3.000 – 8.000 / 3</td><td>1.000 – 3.000 / 2</td><td>to 000 / 1</td><td>58,61)</td></tr>
<tr><td>p18</td><td>Water wave height (m)</td><td>Cost (non-scale)</td><td>Calm (Rippled) / 0 – 0,1 / -</td><td colspan="2">Smooth (Wavelets) / 0,1 – 0,5 / -</td><td colspan="2">Slight / 0,5 – 1,25 / -</td><td colspan="2">Moderate / 1,25 – 2,5 / -</td><td>-</td><td>58,62)</td></tr>
<tr><td>p19</td><td>The accessibility of educational institutions for maritime education</td><td>Benefit</td><td>Superior / 5</td><td colspan="2">Excellent / 4</td><td colspan="2">Good / 3</td><td colspan="2">Not Accredited / 2</td><td>Not University / 1</td><td>58)</td></tr>
<tr><td>p20</td><td>The residential distance from industrial area (km)</td><td>Benefit</td><td><2 / 2</td><td colspan="2">≥2</td><td colspan="2">-</td><td colspan="2">-</td><td>-</td><td>56–58)</td></tr>
<tr><td>p21</td><td>Leading industry in the appropriateness parameters at the regional level</td><td>Benefit</td><td>Industry penetration with a prominent regional industry / 2</td><td colspan="2">Sectors excluded from the list of prominent industries in the region / 1</td><td colspan="2">-</td><td colspan="2">-</td><td>-</td><td>56–58)</td></tr>
<tr><td>p22</td><td>Distance of raw materials and ship parts</td><td>Cost</td><td>0 – 100 / 5</td><td colspan="2">100 – 200 /4</td><td colspan="2">200 – 300 /3</td><td colspan="2">300 – 500 /2</td><td>>500 / 1</td><td>58)</td></tr>
<tr><td>p23</td><td>The number of hours of sunlight</td><td>Benefit</td><td>>5 / 5</td><td colspan="2">4,5-5 / 4</td><td colspan="2">4-4,5 /3</td><td colspan="2">3.56 – 4 /2</td><td>< 3,56 /1</td><td>2,63,64)</td></tr>
</table>

3. Results and Discussion

The decision planner identified four potential sites for a solar-powered shipyard, designated as alternative site 1 (A1), alternative site 2 (A2), alternative site 3 (A3), and alternative site 4 (A4). The decision-makers will then evaluate the 23 parameters set for each alternative location. The result is shown in Table 3. The Decision Matrix is the value the decision maker gives to each parameter for each candidate.

3.1 Evaluating DEMATEL's Weight

The DEMATEL process began by collecting expert assesment on each of the 23 criteria. The expert's panel consisted of 5 individuals: 4 professionals working at Indonesia's national innovation research agency with distinct expertise and 1 policy maker working at the Ministry of Investment/Investment Coordinating Board. The 4 experts included an environmental expert, a maritime expert, a shipyard expert, and a shipping expert. For the current study, the experts were asked to decide on the importance of one parameter over another by comparing one parameter to another. The evaluations of the group members were considered equally important. Certain characteristics of the experts' profiles are presented in Table 2.

Table 2. Experts' characteristics.

Experts	Yrs Exp	Education	Job Title
Maritime expert	>25	Doctor of Marine Technology	Senior researcher at Indonesia's National Innovation Research Agency
Environmental expert	>12	PhD, Department of Environmental Science	Associate researcher at Indonesia's National Innovation Research Agency
Investment policy maker	>10	Magister of business administration	Planner associate expert Ministry of Investment / BKPM RI
Shipyard expert	>20	Doctor of Naval Architecture	Associate researcher at Indonesia's National Innovation Research Agency
Shipping expert	>25	Master's degree in shipping engineering	Senior researcher at Indonesia's National Innovation Research Agency

The influence value between parameters was assessed on a scale of 0 to 4 and then compared in pairs (pairwise comparison scaling as described in point 2.3). A score of 4 indicates the highest relationship, while zero indicates no influence. The opinions of the experts are combined and aggregated at a later stage. This serves as the starting matrix for subsequent DEMATEL processing.

Table 3. Matrices are of Evaluation.

	A1	A2	A3	A4
p1	4	3	3	3
p2	5	1	5	4
p3	5	5	5	5
p4	3	3	3	3
p5	3	3	3	3
p6	3	3	3	3
p7	2	2	2	2
p8	3	3	3	4
p9	2	3	2	1
p10	2	3	1	1
p11	3	3	3	3
p12	1	1	1	2
p13	3	3	3	3
p14	1	1	1	1
p15	3	2	2	2
p16	2	3	2	2
p17	7	4	4	5,3
p18	2	3	2	3
p19	5	4	5	3
p20	2	1	1	1
p21	2	2	2	2
p22	1	2	1	1
p23	4	4	4	5

The normalization is then carried out. The total relation matrix for the assumed criteria is obtained in the next phase. The sum of each row (called vector D) and each column (called vector R) is shown in Table 4. We can get the ($R + D$), and ($R - D$) columns to determine the weight of each decision criterion. This is how criteria weights were initially seen. Besides, the difference ($R - D$) notes that the related parameter is a causer that affects the other parameter when the value is positive. Whereas it is negative, the related parameter is a receiver; the other parameters are influencing parameters. According to our findings in Table 4, produced using the DEMATEL, the most preferred parameter is p16 (Provision of regional electricity lines with a score of $R + D$ is 3.29 and is 0.079). Meanwhile, there are important parameters that can be improved by other parameters with positive values for $R - D$: P1, P2, P3, P4, P5, P17, P18, P19, P23. Also, some parameters have important parameters that cannot be improved by other parameters with negative values for $R - D$: P6, P8, P9, P10, P11, P12, P13, P15, P20, P21, P22. Table 4 summarizes the effects exerted and received on the parameters and lists the parameter weights.

Table 4. Weights and Impacts of Parameters.

Parameters	$R+D$	$R-D$	Weights
p1	1,468	1,372	0,020
p2	1,248	0,859	0,017
p3	2,127	1,975	0,029
p4	2,218	0,986	0,031
p5	2,311	0,94	0,032
p6	5,043	-0,456	0,070
p7	1,848	-0,722	0,026
p8	4,364	-0,882	0,060
p9	3,399	-1,099	0,047
p10	3,546	-0,814	0,049
p11	4,284	-0,884	0,059
p12	3,382	-0,711	0,047
p13	3,461	-0,047	0,048
p14	2,879	-0,188	0,040
p15	3,262	-1,24	0,045
p16	3,29	0,079	0,045
p17	2,275	0,729	0,031
p18	2,409	0,98	0,033
p19	2,748	0,526	0,038
p20	5,4	-0,63	0,075
p21	6,005	-0,905	0,083
p22	4,439	-0,605	0,061
p23	0.927	0,736	0,013

3.2 Comparison of the Rankings Obtained Through the Different MCDM Method

This study applied six different integration-MCDM methods to solve the site selection problem in the electric-powered shipyard industry. Table 5 and Figure 3 present the results of the solar-powered shipyard site selection problem using the DEMATEL method for weighting, combined with CoCoSo, MOORA, TOPSIS, ARAS, OCRA, and WASPAS. The table shows the final performance values (Pi) and positions in the ranking (ri) for each alternative (A1, A2, A3, and A4) according to the six MCDM methods.

Table 5. Results of the solar-powered shipyard site selection problem according to the different MCDM methods, using the first scheme of weights (Pi = final performance value of alternative i; ri = position in the ranking).

		A1	A2	A3	A4
DEMATEL-CoCoSo	Pi ri	**2,88** **1**	2,42 2	1,45 4	1,7 3
DEMATEL-MOORA	Pi ri	**0,328** **1**	0,320 2	0,255 3	0,250 4
DEMATEL-TOPSIS	Pi ri	**0,490** **1**	0,487 2	0,346 4	0,362 3
DEMATEL-ARAS	Pi ri	**0,797** **1**	0,790 2	0,691 4	0,701 3
DEMATEL-OCRA	Pi ri	**0,385** **1**	0,320 2	0,028 3	0,00 4
DEMATEL-WASPAS	Pi ri	**0,804** **1**	0,794 2	0,705 3	0,699 4

Each alternative is evaluated and ranked based on these integrated methods, with the ranks ranging from 1 (most suitable) to 4 (least suitable). The weights used for each ranking method are the result of the DEMATEL weighting method. The ranking positions 1 for each of these six approaches are indicated in bold text in Table 5 to allow easier comparison of the results.

Figure 3 shows that alternative location A1 consistently ranked as the most suitable location with a rank of 1 across all methods. Alternative location A2 also consistently ranked as the second most suitable location with a rank of 2 across all methods. Meanwhile, alternative locations A3 and A4 display variability in their rankings, indicating differences in how the methods evaluate these alternatives. The subsequent observations may be made following the discussion of the comparative study that has been proposed:

i. The two alternative locations of the electric shipyard industry (i.e. A1 and A2) were observed to have the same ranking (Rank 1 and 2, respectively) with all the proposed methodologies.
ii. The first alternative location, followed by the second one, can be considered optimal sites for the electric shipbuilding industry.
iii. All integration methods produce the same rank 1 and 2. Comparatively speaking, the obtained ranks using all integration methods seem very reliable. This implies that there is not much difference in the results determined by the approach chosen. For understandability, computability, interpretability, and traceability, simpler approaches can always be suggested; nonetheless, comparative evaluation ensures the robustness of the results. Consistency, noncontradiction, and close values indicate that all integration methods can be relied upon in practice, and the results of the site selection decision are reliable.
iv. The rankings of A3 and A4 show variability, suggesting that these locations are more sensitive to the different evaluation criteria and weightings of the MCDM methods.
v. Using multiple MCDM methods, integrated with DEMATEL for weighting, provides a robust analysis by highlighting how different methods can influence the final rankings, thus ensuring a more objective and

reliable decision-making process.

vi. A strong correlation is seen between DEMATEL-MOORA and DEMATEL-OCRA, as well as DEMATEL-WASPAS, as these three methods show similar results in ranking the selected alternatives. In addition, a considerable correlation was also found between DEMATEL - CoCoSo and DEMATEL - TOPSIS as well as DEMATEL - ARAS. The results of six MCDM integration methods are compared with each other. Due to the bivariate nature of the ranking correlation coefficient approach, only two methods were grouped simultaneously to test the correlation. This analysis aims to identify correlations between the proposed methods. Evaluation analysis is carried out using statistical tools. SPSS is used to determine the Spearman rank correlation coefficient (r) and the $p-value$ to test the level of acceptance of significance with a value less than 0.05[65]. Table 6 shows the correlation of the resulting rankings and the $p-value$ from the evaluation analysis. It is visible that DEMATEL–CoCoSo, DEMATEL-TOPSIS, and DEMATEL- ARAS show strong correlations with each other, and significance with $p-value$ is less than 0.05. On the other hand, DEMATEL–MOORA, DEMATEL-OCRA, and DEMATEL-WASPAS showed strong correlations and significant $p-value$ less than 0.05. However, DEMATEL–CoCoSo, DEMATEL- TOPSIS and DEMATEL- ARAS versus DEMATEL–MOORA, DEMATEL-OCRA and DEMATEL- WASPAS have lower correlations with non-significant $p-value >$ 0.005 ($r = 0.8$ and $p-value = 0.2$).

vii. For the approaches, DEMATEL-MOORA is the most straightforward algorithm. It must only add and subtract the favourable (benefit) and unfavourable (cost) elements, respectively.

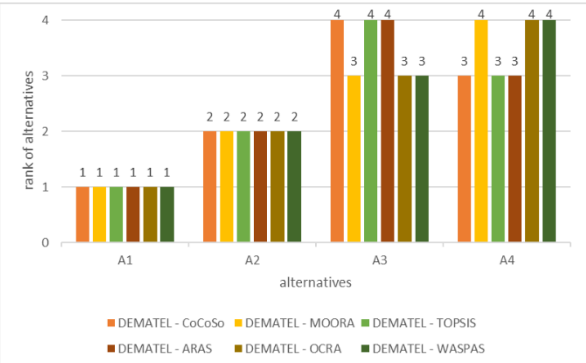

Fig. 3: Comparison of integration methods - MCDM and ranking.

Table 6. Rank correlation and p-value for the MCDM integration method.

MCDM Integration	r-value	p-value
DEMATEL–CoCoSo vs DEMATEL-MOORA	0,800	0,200
DEMATEL–CoCoSo vs DEMATEL-TOPSIS	1	0
DEMATEL–CoCoSo vs DEMATEL-ARAS	1	0
DEMATEL–CoCoSo vs DEMATEL-OCRA	0,800	0,200
DEMATEL–CoCoSo vs DEMATEL-WASPAS	0,800	0,200
DEMATEL-MOORA vs DEMATEL-TOPSIS	0,800	0,200
DEMATEL-MOORA vs DEMATEL-ARAS	0,800	0,200
DEMATEL-MOORA vs DEMATEL-OCRA	1	0
DEMATEL-MOORA vs DEMATEL-WASPAS	1	0
DEMATEL- TOPSIS vs DEMATEL-ARAS	1	0
DEMATEL- TOPSIS vs DEMATEL-OCRA	0,800	0,200
DEMATEL- TOPSIS vs DEMATEL-WASPAS	0,800	0,200
DEMATEL- ARAS vs DEMATEL-OCRA	0,800	0,200
DEMATEL- ARAS vs DEMATEL-WASPAS	0,800	0,200
DEMATEL-OCRA vs DEMATEL-WASPAS	1	0

4. Conclusion

Over the past few decades, various MCDM techniques have been employed to determine optimal locations in sectors such as shipyards and electrification. However, few researchers have compared the outcomes of multiple MCDM methodologies in the same case study. To effectively use MCDM in practical decision-making, evaluating how different MCDM approaches influence the final decision is essential, helping to identify the best strategy for solar-powered shipyard site selection.

Therefore, the real case study of the shipyard site problem was applied to this research using DEMATEL as a weighting approach integrated with six MCDM ranking methods (CoCoSo, MOORA, TOPSIS, ARAS, OCRA, and WASPAS). Each method considered the same parameters, alternative locations, and weights for the indicators. This research utilized comprehensive parameters from several aspects to solve the solar-powered shipyard site selection problem. Based on the DEMATEL score analysis, p16 (Provision of regional electricity lines) was the most preferred parameter.

A sensitivity analysis was also conducted between the ranking methods to evaluate the robustness. The results showed that the two alternative locations of the electric shipyard industry (i.e., PT Dok Pantai Lamongan and PT Armada Bangun Samudra) were observed to have the same ranking (Rank 1 and 2, respectively) with all the proposed methodologies. Despite the differences in the methods used, consistency and close values indicate that all integration methods can be relied upon in practice, making the site selection decision reliable

Moreover, the sensitivity analysis using Spearman rank correlation showed a strong correlation between DEMATEL-MOORA, DEMATEL-OCRA, and DEMATEL-WASPAS, as these three methods provided similar results in ranking the selected alternatives. A considerable correlation was also found between DEMATEL-CoCoSo, DEMATEL-TOPSIS, and DEMATEL-ARAS. For the integration method, DEMATEL-MOORA is the most straightforward algorithm, requiring only the addition and subtraction of favourable (benefit) and unfavourable (cost) elements, respectively.

For further research, it would be more interesting to explore additional environmental condition parameters and their historical data using remote sensing with satellite imagery.

Acknowledgements

All the organizations and individuals who have made contributions toward the publication of this research paper are warmly acknowledged. We extend our sincere gratitude to PT. Armada Bangun Samudera, PT. Dok Pantai Lamongan, and PT. Sumber Marine Shipyard, PT. Lintech Seaside Facility for their invaluable support and provision of the necessary resources that enabled us to accomplish this undertaking. Additionally, we express our gratitude to the Banten and Lamongan Regional Governments for their invaluable counsel and assistance during this research. The Ministry of Investment/BKPM, also known as the Indonesian Investment Coordinating Board, and the National Research and Innovation Agency contributed financially to this investigation. Their assistance was indispensable in enabling us to complete this endeavour successfully.

Nomenclature

Variables

D	Sum of Matrix Rows
R	Sum of Matrix Columns
ri	Position in the ranking
Pi	Final performance value of alternative *i*
r	Correlations Coefficient

Abbreviations

IMO	International Maritime Organization
DWT	Deadweight Tonnage
MCDM	Multi-Criteria Decision-Making
SAW	Simple Additive Weighting
WPM	Weighted Product Model
AHP	Analytic Hierarchy Process
TOPSIS	Technique for Others Preference by Similarity to Ideal Solution
ELECTRE III	ELimination Et Choix Traduisant la REalite III
DEMATEL	Decision-Making Trial and Evaluation Laboratory
MOORA	Multi-Objective Optimization on the basis of Ratio Analysis
CoCoSo	Combined Compromise Solution
OCRA	Operational Competitiveness Rating
WASPAS	Weighted Aggregated Sum Product Assessment
ARAS	Additive Ratio Assessment
EWP	Exponentially Weighted Product
WSM	Weighted Sum Model
SPSS	Statistical Package for the Social Sciences

References

1) I.K. Rohman, I. Asaad, I. Budiani, and I. Fikri. Shipping's Energy Transition: Strategic Opportunities in Indonesia. 2022. Retrieved from https://www.u-mas.co.uk/wp-content/uploads/2022/08/UMAS-GMF-2022-Shippings-Energy-Transition_Strategic-Opportunities-in-Indonesia.pdf
2) Sudiyono, and B. Antoko, "Perancangan dan pembuatan kapal wisata dengan motor generator listrik tenaga surya sebagai energi alternatif penggerak propeler," Jurnal Teknik Mesin Universitas Kristen Petra, (2008), doi:10.9744/jtm.10.1.pp. 52-62.

3) A. Ramadhan, E. Diniardi, and & M. Sony. "Analisis Desain Sistem Pembangkit Listrik Tenaga Surya Kapasitas 50 WP", (2016) Teknik. 37. 59. doi: 10.14710/teknik.v37i2.9011.
4) E.K. Zavadskas, Z. Turskis, J. Antucheviciene, and A. Zakarevicius, "Optimization of weighted aggregated sum product assessment," Elektronika Ir Elektrotechnika, (2012). DOI: 10.5755/j01.eee.122.6.1810
5) Transportation Policy Agency. Government Agency Performance Report (LKIP) of the Transportation Policy Agency for 2022. Jakarta, 2022. Retrieved from https://ppid.dephub.go.id/fileupload/informasi-berkala/20230714121354.LAKIP_Badan_Kebijakan_Transportasi_Tahun_2022.pdf
6) E. Vassoney, A. Mammoliti Mochet, E. Desiderio, G. Negro, M.G. Pilloni, and C. Comoglio, "Comparing multi-criteria decision-making methods for the assessment of flow release scenarios from small hydropower plants in the alpine area," Front Environ Sci, 9 (2021). doi:10.3389/fenvs.2021.635100.
7) M. Yazdani, P. Zarate, E.K. Zavadskas, and Z. Turskis, "A combined compromise solution (cocoso) method for multi-criteria decision-making problems," Management Decision, 57 (9) 2501–2519 (2019). doi:10.1108/MD-05-2017-0458.
8) M. Yazdani, Z. Wen, H. Liao, A. Banaitis, and Z. Turskis, "A grey combined compromise solution (cocoso-g) method for supplier selection in construction management," Journal of Civil Engineering and Management, 25 (8) 858–874 (2019). doi:10.3846/jcem.2019.11309
9) E.K. Zavadskas, Z. Turskis, J. Antucheviciene, dan A. Zakarevicius. Optimization of Weighted Aggregated Sum Product Assessment. Elektronika ir Elektrotechnika, 2012. https://doi.org/10.5755/j01.eee.122.6.1810
10) E. Ilbahar, C. Kahraman, and S. Cebi, "Evaluation of sustainable energy planning scenarios with a new approach based on fcm, waspas and impact effort matrix," Environ Dev Sustain, 25 (10) 11931–11955 (2023). doi:10.1007/s10668-022-02560-8
11) C. Parkan, "Operational Competitiveness Ratings of Production Units," 1994. doi: 10.1002/mde.4090150303
12) E.K. Zavadskas, and Z. Turskis, "A new additive ratio assessment (aras) method in multicriteria decisionmaking," Technological and Economic Development of Economy, 16 (2) 159–172 (2010). doi:10.3846/tede.2010.10.
13) A.C. Gök-Kısa, P. Çeli k, and İ. Peker, "Performance evaluation of privatized ports by entropy based topsis and aras approach," Benchmarking, 29 (1) 118–135 (2022). doi:10.1108/BIJ-10-2020-0554.
14) L. Balezentiene, and A. Kusta, "Reducing greenhouse gas emissions in grassland ecosystems of the central lithuania: multi-criteria evaluation on a basis of the aras method," The Scientific World Journal, 2012 (2012). doi:10.1100/2012/908384.
15) H. Wang, and H. Wang, "Sustainable circular supplier selection in the power battery industry using a linguistic t-spherical fuzzy magdm model based on the improved aras method," Sustainability (Switzerland), 14 (13) (2022). doi:10.3390/su14137816.
16) H. Alpdoğan, "OECD ülkelerinde sürdürülebilir kalkınma politikalarının aras metodu ile performans analizi," Business & Management Studies: An International Journal, 11 (3) 1079–1103 (2023). doi:10.15295/bmij.v11i3.2285.
17) M. Madić, D. Petković, and M. Radovanović, "Selection of non-conventional machining processes using the ocra method," Serbian Journal of Management, 10 (1) 61–73 (2015). doi:10.5937/sjm10-6802.
18) M. Ozcalici, and M. Bumin, "An integrated multicriteria decision making model with self-organizing maps for the assessment of the performance of publicly traded banks in borsa istanbul," Applied Soft Computing Journal, 90 (2020). doi:10.1016/j.asoc.2020.106166.
19) M. Ozcalici, "ASSET allocation with multi-criteria decision making techniques," Decision Making: Applications in Management and Engineering, 5 (2) 78–119 (2022). doi:10.31181/dmame0305102022o.
20) A. Kazaz, İ. Erbaş, I. Erbas, and R. Simsek, "A regional perspective for work accidents: evaluating the amount of work accidents on a city basis by the help of multi-criteria decisionmaking methods a regional perspective for work accidents: evaluating the amount of work accidents on a city basis by the help of multi-criteria decision-making methods," (2021). doi:10.31462/jcemi.2021.01037051.
21) Ö.F. Görçün, "Efficiency analysis of black sea container seaports: application of an integrated mcdm approach," Maritime Policy and Management, 1–28 (2020). doi:10.1080/03088839.2020.1783467.
22) H.C. Liu, M. Yang, M. Zhou, and G. Tian, "An integrated multi-criteria decision making approach to location planning of electric vehicle charging stations," IEEE Transactions on Intelligent Transportation Systems, 20 (1) 362–373 (2019). doi:10.1109/TITS.2018.2815680.
23) E. Skupien, "The use of the dematel method to analyze factors influencing the usage of inland waterway transport," TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation, 17 (4) 799–804 (2023). doi:10.12716/1001.17.04.05.
24) O. Derse, "CO2 capture, utilization, and storage (ccus) storage site selection using dematel-based grey relational analysis and evaluation of carbon emissions with the arima method," Environmental Science and

Pollution Research, 30 (6) 14353–14364 (2023). doi:10.1007/s11356-022-23108-3.
25) E. Fontela, "Structural Analysis of the World Problematique:(Methods)," (1974).
26) A. Gabus, and E.J.B.G.R.C. Fontela, "World problems, an invitation to further thought within the framework of DEMATEL," (1972). url=https://api.semanticscholar.org/CorpusID:148882619
27) Sukisno, and M.L. Singgih, "Location Selection Analysis for New Shipyard Using Integration of DEMATEL and ANP: A Case Study (PT IKI)," in: IOP Conf Ser Mater Sci Eng, Institute of Physics Publishing, (2019). doi:10.1088/1757-899X/598/1/012109.
28) H.I. Caner, and C.C. Aydin, "Shipyard site selection by raster calculation method and ahp in gis environment, i skenderun, turkey," Mar Policy, 127 (2021). doi:10.1016/j.marpol.2021.104439.
29) J. Sharma, A. Bhardwaj, and R. Singh Walia, "Factors Assessment for Encumbering the Implementation of Sustainability Based Lean Six Sigma Practices in Food Supply Chain," (2023). Doi: 10.5109/6781097
30) S. Agarwal, M. Tyagi, and R.K. Garg, "Circular Economy Reinforcement to Diminish GHG Emissions: A grey DEMATEL Approach," (2023). Doi: 10.5109/6781099
31) W. Song, Z. Xu, and H.C. Liu, "Developing sustainable supplier selection criteria for solar airconditioner manufacturer: an integrated approach," Renewable and Sustainable Energy Reviews, 79 1461–1471 (2017). doi:10.1016/j.rser.2017.05.081
32) D. Sumrit, and P. Anuntavoranich, "Using DEMATEL Method to Analyze the Causal Relations on Technological Innovation Capability Evaluation Factors in Thai Technology-Based Firms," (2013). url: http://TuEngr.com/V04/081-103.pdf
33) V.K. Pathak, D. Garg, and A. Agarwal, "Analysis of last mile delivery performance barriers by the dematel approach," Evergreen, 10(3) 1495–1507 (2023). doi:10.5109/7151698
34) G. Büyüközkan, and S. Güleryüz, "An integrated dematel-anp approach for renewable energy resources selection in turkey," Int J Prod Econ, 182 435–448 (2016). doi:10.1016/j.ijpe.2016.09.015.
35) H. Shakeri, and M. Khalilzadeh, "Analysis of factors affecting project communications with a hybrid dematel-ism approach (a case study in iran)," Heliyon, 6 (8) (2020). doi:10.1016/j.heliyon.2020.e04430.
36) G.M. Sullivan, and A.R. Artino, "Analyzing and interpreting data from likert-type scales," J Grad Med Educ, 5 (4) 541–542 (2013). doi:10.4300/jgme-5-4 18.
37) Jeff Sauro. *A Practical Guide to Measuring Usability: 72 Answers to the Most Common Questions About Quantifying the Usability of Websites and Software*. Measuring Usability LLC, 2010. ISBN: 978-1453806562.
38) P.P. Das, and S. Chakraborty, "SWARA-cocoso method-based parametric optimization of green dry milling processes," Journal of Engineering and Applied Science, 69 (1) (2022). doi:10.1186/s44147 022-00087-3.
39) V. Kumar, K. Kalita, P. Chatterjee, E.K. Zavadskas, and S. Chakraborty, "A swara-cocoso-based approach for spray painting robot selection," Informatica (Netherlands), 33 (1) 35–54 (2022). doi:10.15388/21 INFOR466.
40) P.W. Lee, and Z. Yang, "Multi-Criteria Decision Making in Maritime Studies and Logistics," Springer, (2018). http://www.springer.com/series/6161. https://themys.sid.uncu.edu.ar/rpalma/UCB/Bibliografia/galeradas/GAL_MaritimeStudiesLogistics_App.pdf
41) P.L. Singh, and B.S. Sikarwar, "Parametric performance of condensation factors for extracting potable water from atmosphere," Evergreen, 8(3) 586–592 (2021). doi:10.5109/4491650.
42) A. Baležentis dan T. Baležentis. *An Innovative Multi-Criteria Supplier Selection Based on Two-Tuple MULTIMOORA and Hybrid Data*. Lithuania, 2011. https://www.researchgate.net/publication/297518336_An_innovative_multi-criteria_supplier_selection_based_on_two-tuple_MULTIMOORA_and_hybrid_data
43) V. Gupta, and A. Jayant, "A novel hybrid mcdm approach followed by fuzzy dematel-anp-topsis to evaluate low carbon suppliers," Evergreen, 8(3) 544 555 (2021). doi:10.5109/4491640.
44) D. Niu. *Studies on TOPSIS Arithmetic with DEMATEL Weights Scheme*. International Conference on Mechatronic Sciences, Electric Engineering and Computer (MEC), 2013. https://www.semanticscholar.org/paper/Studies-on-TOPSIS-arithmetic-with-DEMATEL-weights-Niu/493b57925dd080fd6bfd72447046c42ed913245c
45) E. GÖÇMEN POLAT, "Distribution centre location selection for disaster logistics with integrated goal programming-ahp based topsis method at the city level," Afet ve Risk Dergisi, 5 (1) 282–296 (2022). doi:10.35341/afet.1071343.
46) H. Wang, and H. Wang, "Sustainable circular supplier selection in the power battery industry using a linguistic t-spherical fuzzy magdm model based on the improved aras method," Sustainability (Switzerland), 14 doi:10.3390/su14137816.
47) E.K. Zavadskas, and Z. Turskis, "A new additive ratio assessment (aras) method in multicriteria decision making," Technological and Economic Development of Economy, 16 doi:10.3846/tede.2010.10. (2)
48) N. Liu, and Z. Xu, "An overview of aras method: theory development, application extension, and future challenge," International Journal of Intelligent

Systems, 36 (7) doi:10.1002/int.22425.
49) A.R. Mishra, P. Rani, F. Cavallaro, I.M. Hezam, and J. Lakshmi, "An integrated intuitionistic fuzzy closeness coefficient-based ocra method for sustainable urban transportation options selection," Axioms, 12 (2) (2023). doi:10.3390/axioms12020144.
50) M. Madić, D. Petković, and M. Radovanović, "Selection of non-conventional machining processes using the ocra method," Serbian Journal of Management, 10 doi:10.5937/sjm10-6802. (1) 61–73 (2015).
51) A.R. Mishra, and P. Rani, "Multi-criteria healthcare waste disposal location selection based on fermatean fuzzy waspas method," Complex and Intelligent Systems, 7 (5) 2469–2484 doi:10.1007/s40747-021-00407-9.
52) A.P. Darko, and D. Liang, "Probabilistic linguistic waspas method for patients' prioritization by developing prioritized maclaurin symmetric mean aggregation operators," Applied Intelligence, 52 (8) 9537–9555 (2022). doi:10.1007/s10489-021-02807 3.
53) C. Sukumaran, M. Ramachandran, C. Sivaji, and M. Selvam, "Ranking of product in e-store using waspas method," REST Journal on Banking, Accounting and Business, 1 (1) 1–9 (2022). doi:10.46632/jbab/1/1/1.
54) Turskis, Z., Zavadskas, E. K., Antuchevičienė, J., & Kosareva, N. (2015). A hybrid model based on Fuzzy AHP and Fuzzy WASPAS for construction site selection. *International Journal of Computers, Communications & Control*, 10(6), 873–888. https://doi.org/10.15837/ijccc.2015.6.2078
55) Demir, G., & Arslan, R. (2022). Sensitivity analysis in multi-criterion decision-making problems. *Ankara Hacı Bayram Veli University Journal of the Faculty of Economics and Administrative Sciences*, 24(3), 1025–1056. https://doi.org/10.26745/ahbvuibfd.1103531
56) Republic of Indonesia. (2014). *Law of the Republic of Indonesia Number 3 of 2014 concerning Industry.* Jakarta: State Gazette of the Republic of Indonesia of 2014 Number 4. Retrieved from https://peraturan.bpk.go.id/Download/27824/UU%20Nomor%2003%20Tahun%202014.pdf
57) Regulation of the Minister of Industry of the Republic of Indonesia. *Technical Criteria for Industrial Designated Areas, Regulation of the Minister of Industry of the Republic of Indonesia No. 30 of 2020*. Jakarta, 2020. https://peraturan.bpk.go.id/Details/167011/permenperin-no-30-tahun-2020
58) R.L. Storch, C.P. Hammon, H.M. Bunch, dan R.C. Moore. *Ship Production*. Edisi ke-2, 1995. The Society of Naval Architects and Marine Engineers. ISBN: 978-0939773572. https://www.sname.org/ship-production
59) Minister of Agriculture of the Republic of Indonesia. *Criteria and Procedures for Designating Production Forests, Decree of the Minister of Agriculture No. 683/Kpts/Um/8/1981*. Jakarta, 1981. Retrieved from https://cdkmalang.dishut.jatimprov.go.id/wp-content/uploads/2021/10/kriteria-hlhp-keppresmentan.pdf
60) Minister of Agriculture of the Republic of Indonesia. *Criteria and Procedures for Designating Protected Forests, Decree of the Minister of Agriculture No. 837/Kpts/Um/11/1980*. Jakarta, 1980. Retrieved from https://cdkmalang.dishut.jatimprov.go.id/wp-content/uploads/2021/10/kriteria-hlhp-keppresmentan.pdf
61) The Overseas Coastal Area Development Institute of Japan. *Technical Standards and Commentaries for Port and Harbour Facilities in Japan*. Japan, 2002. Retrieved from https://ocdi.or.jp/tec_st/tec_pdf/tech_00H.pdf
62) World Meteorological Organization. *Manual on Codes International Codes Volume I.1 Annex II to the WMO Technical Regulations Part A – Alphanumeric Codes 306*. 2019. https://www.caspcom.com/files/306_Manual_on_codes_volI.1_en.pdf
63) World Meteorological Organization. *Guide to Meteorological Instruments and Methods of Observation*. Edisi ketujuh, 2008. https://www.weather.gov/media/epz/mesonet/CWOP-WMO8.pdf
64) P. Pan, Y. Sun, C. Yuan, X. Yan, and X. Tang, "Research progress on ship power systems integrated with new energy sources: a review," Renewable and Sustainable Energy Reviews, doi:10.1016/j.rser.2021.111048.
65) D.L. Mohr, W.J. Wilson, and R.J. Freund, "Nonparametric Methods," in: Statistical Methods, Elsevier, (2022): pp. 651–683. doi:10.1016/b978-012-823043-5.00014-x.