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Determining the objective weight of green manufacturing indicators: a case study of the Indonesian manufacturing company

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Abstract

With the growing of environmental issues, manufacturing companies are compelled to improve their performance to reduce resource consumption and environmental pollution. Accordingly, company's performance should be measured according to the green manufacturing indicators. The importance of the indicators must be determined properly aligned with the company's goals and profiles. This study aims to determine the weight of green manufacturing indicators which becomes the critical input for green performance evaluation. Different weighting methods including entropy and CRiteria Importance Through Inter-criteria Correlation (CRITIC), are integrated using Decision-Making Trial and Evaluation Laboratory (DEA) to determine the final weight. A case study of the Indonesian manufacturing company is presented to illustrate the application of the proposed method. The result indicates that process technology, compliance of environmental quality standards, and operational standards are considered critical in green manufacturing.

Keywords: Green manufacturing; green performance indicators; entropy weight; CRITIC; DEA

1. Introduction

Due to the decline in the availability of natural resources, the cost of energy and resources is significantly increasing [1] while companies should maintain their competitiveness. In addition, the current global issue deals with environmental protection to prevent pollution and harmful waste from production. Therefore, green manufacturing has

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received massive attention from companies all around the world as the main focus of performance measurement and evaluation. Companies have focused on the development of green manufacturing performance to reduce the impact on the environment and increase resource efficiency [2].

Green manufacturing encompasses three main focus areas: green energy, products, and processes [3]. However, the implementation of green manufacturing can vary depending on the development actions that integrate product and process design throughout the product life cycle. As a result, the evaluation of green manufacturing performance may include different indicators. Green manufacturing performance indicators involve the 4R's (reduce, reuse, recycle, and remanufacturing), conservation, waste management, water supply, environmental protection, regulatory compliance, pollution control, and a variety of related issues [4].

The importance of indicators plays a significant role in the evaluation of green manufacturing performance, which in turn can be used as a consideration to measure whether the performance target is achieved or not. Green manufacturing has been widely studied in the literature, including determining the importance of green manufacturing indicators. A multi-criteria decision making (MCDM) approach, including Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Decision-Making Trial and Evaluation Laboratory (DEMATEL), and AHP (Analytical Hierarchy Process), has been employed to determine the importance of the indicator in the context of green manufacturing performance evaluation. Luo, Jie [5] examined the ranking of Chinese SMEs green manufacturing drivers using fuzzy TOPSIS. Bhowmik and Jagadish [6] evaluated the attributes for product development in a green manufacturing environment using AHP.. Yadegaridehkordi, Hourmand [4] employed fuzzy DEMATEL to determine the priority of sustainability indicators, which are taken into account in assessing green building manufacturing.

MCDM approaches generally involve an evaluation process that relies on decision-makers' opinions or judgments. Under a decision maker's judgment, determining the importance of green manufacturing indicators tends to involve vagueness and impreciseness, which can lead to subjectivity. The aforementioned studies, in majority, rely on the decision-maker's judgment to determine subjectively important weight. Therefore, this study aims to determine the importance of green manufacturing indicators based on the objective value of information. We adopted entropy and CRITIC to determine a different objective weight. The final weight is obtained based on a novel procedure that integrates the different objective weights using DEA.

2. Literature review

Yadegaridehkordi, Hourmand [4] determined the importance of sustainability indicators for assessing green building manufacturing in Malaysia by considering the Green Building Index (GBI) by using fuzzy DEMATEL. Tupenaite, Lill [7] created a sustainability measurement tool for new housing facilities, outlining major sustainability factors, with the Baltic States as the focus. "Energy and atmosphere considerations" were determined to be the most important indicators by using fuzzy AHP. Shad, Khorrami [8] proposed an evaluation method for green structures in Iran. To account for all the crucial elements, they took into account eight criteria and 61 associated sub criteria. They discovered that "water efficiency" was the most significant element in that context by applying AHP. Khalil, Kamaruzzaman [9] developed the Building Performance Risk Rating Tool (BPRT), which has a focus on the users' health and safety. According to the weight calculated by using AHP, structural stability, fire prevention facilities, electrical services, and emergency exits were found to be the most crucial indicators. In order to construct a model for small-sized urban areas in British Columbia, Haider, Hewage [10] took into account LEED, BREEAM, and CASBEE as sustainability indicators. The fuzziness in the expert opinion in assessing sustainability indicators was then covered by fuzzy AHP. Bansal, Biswas [11] used the fuzzy methodology to evaluate the green building construction process.

3. Methods

A two-phase weighting process is introduced to determine the objective weight. In the first phase, the objective weight is calculated using entropy and CRITIC methods based on the value of information. Then, the final objective weights are derived using the CCR-DEA model. A two-phase methodology is depicted in Fig. 1.

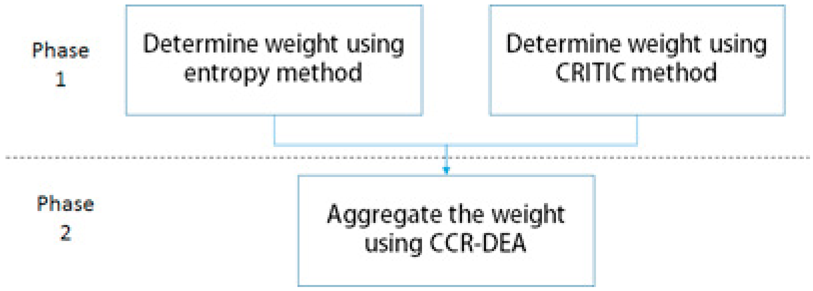

Fig. 1. A two phase weighting process

The methods employed in the two-phase weighting process are described in the following.

3.2 Entropy weight

Entropy is a measure of how much uncertainty a discrete probability distribution can reflect, and it is generally accepted that a broad distribution may represent more uncertainty than one that is tightly packed. According to the entropy method, criteria with performance ratings that are significantly different from one another are more significant for the problem because they have a greater impact on ranking results Jahan, Mustapha [12]. In other words, if all candidate alternatives have equal performance ratings for a criterion, then that criterion is less significant. Using Eqs. (1), (2), and (3), the weights of the criteria are calculated.

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad i = 1, \dots, m; j = 1, \dots, n \tag{1}$$

$$E_j = -\frac{\left(\sum_{i=1}^{m} p_{ij} \ln p_{ij}\right)}{\ln m} \qquad j = 1, \dots, n \tag{2}$$

$$w_j = \frac{1-E_j}{\sum_{i=1}^{n}(1-E_k)} \qquad j = 1, \dots, n \tag{3}$$

3.3 Criteria importance through inter-criteria correlation (CRITIC)

A method for weighting the value of criteria through cross-criteria correlation (CRITIC), which was developed based on the SD methodology suggested by Diakoulaki, Mavrotas [13]. Eqs. (4) and (5) are used to standardize the criterion before calculating the correlation using Eq. (6). The relationship between two variables is frequently determined using correlation. Weights are calculated using Eqs. (7) and (8).

$$r_{ij} = \frac{x_{ij}-x_{ij}^{min}}{x_{ij}^{max}-x_{ij}^{min}} \qquad i = 1, \dots, m; j = 1, \dots, n \text{ for benefit criteria} \tag{4}$$

$$r_{ij} = \frac{x_{ij}^{max} - x_{ij}}{x_{ij}^{max} - x_{ij}^{min}} \quad i = 1, \dots, m; j = 1, \dots, n \text{ for cost criteria} \tag{5}$$

$$\rho_{jk} = \frac{\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)(r_{ik} - \bar{r}_k)}{\sqrt{\sum_{i=1}^{m}(r_{ij} - \bar{r}_j)^2}} \quad j, k = 1, \dots, n \tag{6}$$

$$w_j = \frac{c_j}{\sum_{k=1}^{n} c_k} \quad k = 1, \dots, n \tag{7}$$

$$c_j = \sigma_j \sum_{k=1}^{n}(1 - \rho_{jk}) \quad j = 1, \dots, n \tag{8}$$

3.4 DEA

Since it offers a superior method of organizing and analyzing data that allows efficiency to evolve over time and doesn't require any previous assumptions on the specification of the best practice frontier, DEA is a leading methodology for performance analysis in many areas [14]. In this study, DEA is based on the ‘efficiency’ analysis of the objective weight of green manufacturing sub-indicators. The weights are evaluated based on outputs and inputs. The objective weight efficiency is defined as the ratio of the weighted sum of its outputs (i.e., the weight derived based on correlation) to the weighted sum of its inputs (i.e., the weight derived from its entropy).

We assume that there *n* DMU_j (j = 1, 2, ..., n) representing the sub-indicators of green manufacturing. Each DMU_j has m different inputs x_{ij} and s different outputs y_{rj}. Let the observed input and output vectors of DMU_j be $X_j = (x_{1j}, x_{2j}, \dots, x_{mj})^T > 0, j = 1,2, \dots, n$ and $Y_j = (y_{1j}, y_{2j}, \dots, y_{sj})^T > 0$, respectively. The relative efficiency of DMU_j is calculated as

$$E_j = \frac{\sum_{r=1}^{s} u_r y_{kj}}{\sum_{i=1}^{m} v_i x_{ij}} = \frac{U^T Y_j}{V^T X_j}, \quad j = 1, 2, \dots, n \tag{9}$$

where $V = (v_1, v_2, \dots, v_m)^T$ and $U = (u, u_2, \dots, u_s)^T$ are input and output weight vectors, respectively.

The CCR model can be written as

$$\text{Max } \frac{U^T Y_0}{V^T X_0} \tag{10}$$

$$\text{s.t. } \frac{U^T Y_j}{V^T X_j} \le 1, \quad j = 1, 2, \dots, n \tag{11}$$

$$U^T \ge 0, V^T \ge 0 \tag{12}$$

In the CCR model, each DMU computes its own optimal weights and achieve its best efficiency.

4. Result and discussion

4.1 Case study

In this section, a novel procedure is applied to determine the final objective weight of green manufacturing sub-indicators for an Indonesian garment company. Green manufacturing performance assessment criteria are important as a consideration to sustain the company's capabilities to achieve an efficient and effective production system. ABC Company is being compelled to take on challenges related to corporate wellness and environmental issues as environmental circumstances receive more attention on a worldwide scale. The weight of the green manufacturing assessment indicators must therefore be decided. There are three indicators and fourteen sub-indicators identified for green manufacturing performance assessment (shown in Table 1) which are adopted from the legislation of the Industrial Research and Development Agency, Ministry of Industry of Indonesia.

Table 1. Green manufacturing indicators and sub-indicators

Indicators	Sub-Indicators	Code
Production	Production Efficiency Program	C1
	Input Materials	C2
	Energy	C3
	Water	C4
	Process Technology	C5
	Human Resources	C6
	Work Environment in the Production Plant	C7
Waste/Emission	Greenhouse Emission Reduction Program	C8
	Compliance of Environmental Quality Standards	C9
	Waste/Emissions Management Facility	C10
Management System	Operational Standards	C11
	Corporate Social Responsibility	C12
	Production and environmental management recognition	C13
	Employee Health	C14

Table 2 shows the score of green manufacturing performance from the annual assessment report in last three years. According to the value of information summarized in Table 2, the objective weight of sub-indicators are derived using the proposed procedure.

Table 2. The score of green manufacturing performance

Sub-Indicators	Time Frame		
	1	2	3
C1	6	8	7
C2	13	10	14
C3	4	6	5
C4	11	9	12
C5	16	13	12
C6	5	6	8
C7	3	4	5
C8	2	4	5
C9	5	8	6
C10	5	9	8
C11	8	7	8
C12	8	6	5
C13	2	4	3
C14	4	6	5

4.2 Weight of green manufacturing sub-indicators

The weight of green manufacturing sub-indicators is calculated using entropy and CRITIC methods. The results are shown in Table 3 and 4.

Table 3. The weight of green manufacturing: entropy method

Indicators	**Sub-Indicators**	**Local Weight**	**Global Weight (w_j)**
Production	C1	0.145	0.101
(weight = 0.7)	C2	0.136	0.095
	C3	0.149	0.104
	C4	0.138	0.096
	C5	0.134	0.094
	C6	0.147	0.103
	C7	0.152	0.106
Waste/Emission	C8	0.353	0.071
(weight = 0.2)	C9	0.324	0.065
	C10	0.324	0.065
Management System	C11	0.238	0.024
(weight = 0.1)	C12	0.238	0.024
	C13	0.273	0.027
	C14	0.251	0.025

Table 4. The weight of green manufacturing: CRTITIC method

Indicators	**Sub-Indicators**	**Local Weight**	**Global Weight (w_j)**
Production	C1	0.163	0.114
(weight = 0.7)	C2	0.134	0.093
	C3	0.140	0.098
	C4	0.126	0.088
	C5	0.216	0.151
	C6	0.122	0.086
	C7	0.098	0.069
Waste/Emission	C8	0.428	0.086
(weight = 0.2)	C9	0.394	0.079
	C10	0.179	0.036
Management System	C11	0.318	0.032
(weight = 0.1)	C12	0.255	0.025
	C13	0.214	0.021
	C14	0.214	0.021

In order to derive the final objective weight, we first set the decision-making units (DMUs), which are represented by sub-indicators C1 up to C14. The global weights (w_j) calculated by using entropy and CRITIC are respectively considered inputs and outputs. The CCR-DEA model is constructed to obtain an optimal solution to maximize the efficiency of all DMUs. The efficiency of all DMUs is summarized in Table 5.

Table 5. DMUs' efficiency score

DMUs	Inputs (X_j)	Outputs (Y_j)	Efficiency
C1	0.101	0.114	0.703
C2	0.095	0.093	0.609
C3	0.104	0.098	0.587
C4	0.096	0.088	0.571
C5	0.094	0.151	1
C6	0.103	0.086	0.52
C7	0.106	0.069	0.405
C8	0.071	0.086	0.754
C9	0.065	0.079	0.757
C10	0.065	0.036	0.345
C11	0.024	0.032	0.83
C12	0.024	0.025	0.648
C13	0.027	0.021	0.484
C14	0.025	0.021	0.523

After the efficiency score for each DMU is computed, the final objective weight (W_j) for sub-indicators is calculated by using normalization. The normalized efficiency scores of the DMUs are summarized in Table 6.

Table 6. The final weight of green manufacturing sub-indicators

Normalized Eficiency	C1	C2	C3	C4	C5	C6	C7
W_j	0.080	0.070	0.067	0.065	0.114	0.060	0.046
Normalized Eficiency	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
W_j	0.086	0.087	0.039	0.095	0.074	0.055	0.060

4.3 Analysis of Green Manufacturing Indicators' Ranking

We analyze the ranking of sub-indicators calculated by using entropy and CRITIC methods. For each method results in different weight and ranking of sub-indicators. The differences rise depending on the choice of the decision matrix normalization method [15]. Furthermore, the relative difference in the weights for a particular case for some criteria can reach up to 50% and even higher [15]. Figure 2 depicts the ranking from both methods. According to Figure 2, the most critical sub-indicators resulted from entropy method subsequently are work environment in the production plant (C7), energy (C3), and human resources (C6). While, process technology (C5), production efficiency Program (C1), and energy (C3) becomes the critical sub-indicators according to the weight determined by using CRITIC method.

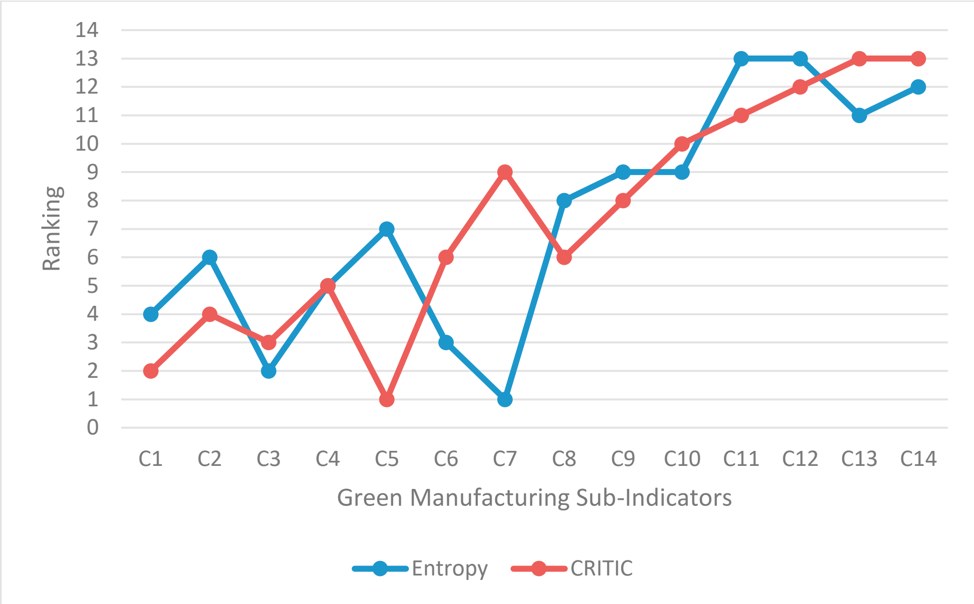

Figure 2. Ranking of Green Manufacturing Sub-Indicators

This section also provides analysis on key parameters that have an impact on the final ranking of green manufacturing sub-indicators. We perform analysis on the inputs and outputs to understand their impact on the final ranking of sub-indicators. We set the inputs and outputs according to two scenarios. In the first scenario, we set the input of the CCR-DEA model based on the weight derived from the entropy method and set the weight derived from the CRITIC method as the output. It is vice versa for the second scenario. The results of the analysis are summarized in Table 7.

Table 7. The ranking of green manufacturing sub-indicators for different scenarios of input and output

	Input = Entropy Weight Output = CRITIC Weight		Input = CRITIC Weight Output = Entropy Weight	
Sub-Indicators	W_j	**Ranking**	W_j	**Ranking**
C1	0.080	5	0.059	10
C2	0.070	7	0.068	8
C3	0.067	8	0.071	7
C4	0.065	9	0.072	6
C5	0.114	1	0.041	14
C6	0.060	11	0.080	4
C7	0.046	13	0.102	2
C8	0.086	4	0.055	11
C9	0.087	3	0.055	12
C10	0.039	14	0.120	1
C11	0.095	2	0.050	13
C12	0.074	6	0.064	9
C13	0.055	12	0.085	3
C14	0.060	10	0.079	5

According to the analysis of the impact of the change in inputs and outputs, the ranking of sub-indicators is extremely different. These changes were found since the inputs and outputs follow the reciprocal analytical formula as a ratio. A decision-maker can consider both objective weights, either inputs or outputs. Nevertheless, the two different objective weights can be traded off by aggregating them into an average weight.

5. Conclusion

This study proposed a model for determining the objective weight of green manufacturing indicators based on the value of information in green manufacturing performance evaluation. Different weighting methods, including entropy and CRITIC, have been employed to determine the weight of green manufacturing indicators. The final objective weights are derived by using CCR-DEA. Considering entropy weight as an input, the three most critical sub-indicators, respectively, involve process technology, operational standards, and compliance with environmental quality standards. This study has limitations because it only incorporates the objective value of information from the evaluation of green manufacturing performance in the past. The future work can be extended by considering not only objective weight but also subjective weight, which is judged based on the decision-makers' perspectives.

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We declare that there are no conflicts of interest to disclose.

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