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Analyzing Environmental Continuous Improvement for Sustainable Supply Chain Management: Focusing on Its Performance and Information Disclosure

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Abstract: This study analyzes the relationship between the implementation and information disclosure of environmental continuous improvement (e-CI) in sustainable supply chain management. The analyzed data relates to e-CI delivered from 19 manufacturing industry types in Japan. A degenerated Charnes-Cooper-Rhodes model, a proposed model for data envelopment analysis, is also used for the analysis. The obtained result is a classification of types of manufacturing industries from the perspective of their capabilities in both e-CI implementation and information disclosure to systematically discover emphatic indicators of these two activities in each manufacturing industry type.

Keywords: manufacturing industry; supply chain management; environmental continuous improvement; information disclosure; data envelopment analysis

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1. Introduction

Recently, the necessity to realize a sustainable society has become increasingly important. Manufacturing companies have promoted the improvement of environmental performance to meet this requirement. In particular, relevant activities are widely practiced in supply chains because this function allows organizations to fulfill several environment-friendly goals such as zero emissions and exhaust control. Environmental continuous improvement (e-CI) differs from conventional continuous improvement (CI) in reducing cost, controlling service quality, and managing safety. In other words, the former more directly links to corporate social responsibility (CSR) than the latter. In addition, corporate image improves by disclosing the results of e-CI activity. Hence, it is necessary to not only positively execute e-CI, but also to disclose its results.

Data management is also very important to support these activities, especially for the globalized supply chain. Performance measurement systems [1] are widely used including materials management in the power industry [2] and product life cycle management in the aerospace industry [3] etc. Regarding a sustainable supply chain, there is literature to design the relevant key performance indicators [4,5] and to develop the methods to analyze them [6,7]. This paper focuses on managing the data of the above-mentioned two perspectives of e-CI for a sustainable supply chain.

The framework of the related literature review is illustrated in Figure 1. Two combinations of an activity and a result are involved in the process for e-CI information disclosure. The first is the combination of CI execution and improvement of indicators, which is performed within a company. The second is the combination of information disclosure and corporate image improvement, which is performed outside the company.

The relationship between indicator improvement and information disclosure is clarified by [8,9], who analyze the relationships between information disclosure and hazardous material and environmental indicators, respectively. Peter (1998) [10] analyzes the relationship between information disclosure and financial results, and Charles (2007) [11] analyzes the relationship between information disclosure and litigation. These investigations clarify the relationship between information disclosure and corporate image improvement. Moreover, Sulaiman (2004) [12] collects three factors and analyzes their relationship: an environmental indicator, information disclosure, and social performance.

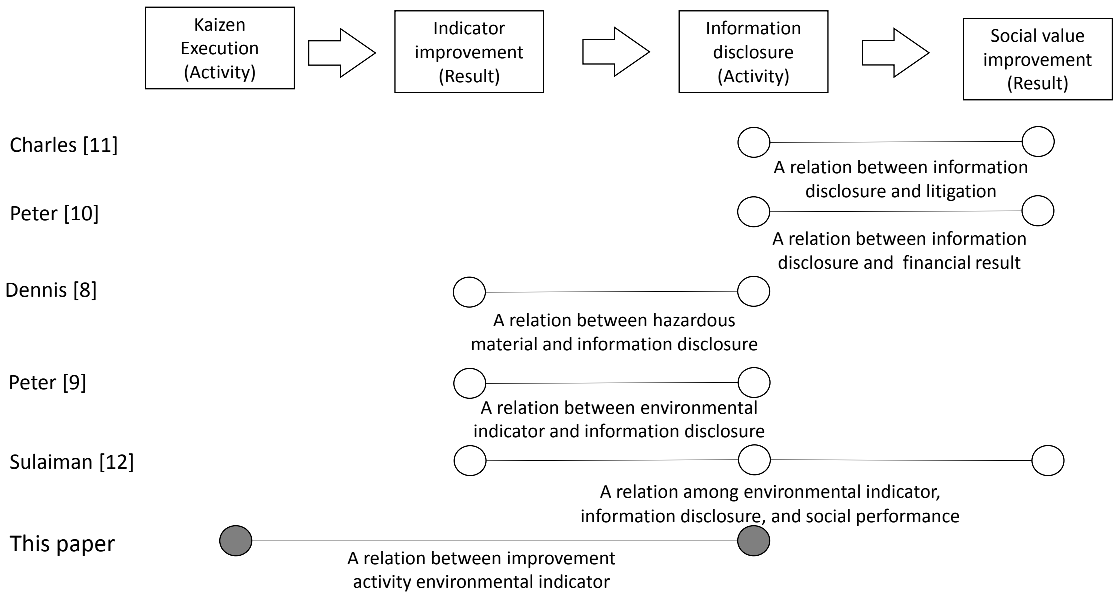

Figure 1. Process of information disclosure and its impact on environmental continuous improvement (e-CI) execution.

This study, under the aforementioned research stream, examines the association between CI execution and information disclosure in the supply chains of 19 manufacturing industry types in Japan. The analyzed data is delivered from a survey by Nikkei Research Inc., which is one of the group companies of Nikkei Sinbun-sya, a leading Japanese newspaper-publishing company. The analysis' methodology uses a degenerated Charnes-Cooper-Rhodes (CCR) model, a proposed model of data envelopment analysis (DEA).

This paper consists of five sections. The next section illustrates this study's research procedure based on the proposed e-CI framework. The framework involves two activities: the improvement of both supply chain capabilities and corporate image. The third section investigates each activity using fundamental statistics. The fourth section analyzes the relationship between the two activities and discusses the analysis' results. The final section concludes.

2. Research Procedure by e-CI Framework

Conventional CI, regarded as "Kaizen" in Western literature [13], primarily uses performance indicators to effectively manage a supply chain system, such as improving product quality, shortening production and delivery times, and reducing manufacturing costs. Further, the management of these performance indicators strengthens the supply chain's capability. Figure 2 illustrates the conventional CI evaluation system, a simple feedback loop for reviewing past steps. A CI project's result, in other words, is input in the evaluation system, and an evaluation result is returned for the next process.

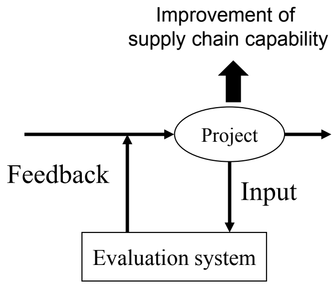

Figure 2. Conventional continuous improvement (CI) evaluation system.

Figure 3 displays the e-CI evaluation system, as another feedback loop is required to review past steps in addition to the conventional feedback loop. This involves evaluating the disclosure capability of a CI project's results. A management system considering environmental issues certainly improves corporate image, as this problem more closely relates to individuals' lives than other problems within a supply chain system. Hence, an important management strategy involves the disclosure of CI projects' results, and the evaluation system should include multi-evaluation systems that aim to simultaneously improve implementation capability and corporate image.

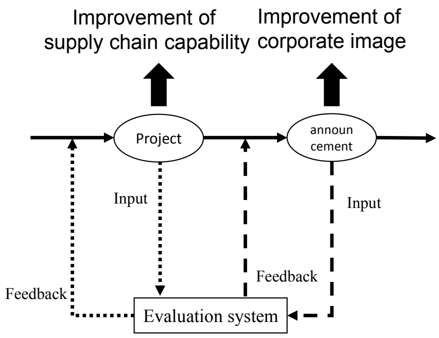

Figure 3. The e-CI evaluation system.

This study compares 19 types of manufacturing industries based on the above e-CI framework. The comparison analysis procedure consists of three steps, as displayed in Figure 4. First, the CI project's state of implementation is analyzed. The second step analyzes the state of disclosure of a project's results. Basic statistics are used for both steps, and the next section examines the two steps. The fourth section illustrates the analysis' third step, which involves analyzing the relationship between the two states described in the previous section. The analysis model in this step is proposed and quoted by the DEA.

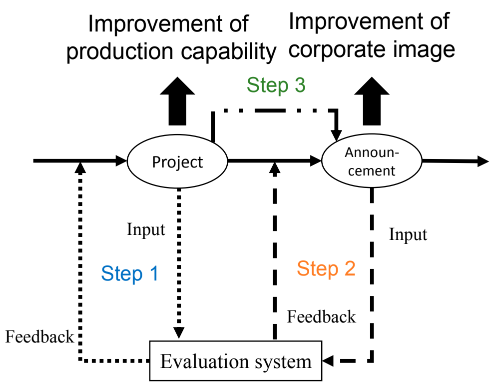

Figure 4. This study's research procedure, based on the e-CI framework.

3. Analysis of e-CI Implementation and Information Disclosure

Nikkei Inc. [14] have annually surveyed environmental management in Japanese industries. The 2014 survey investigated 735 firms, including those in both manufacturing and non-manufacturing industries; this study uses the results from 429 manufacturing companies. The surveyed companies are classified into the following 19 manufacturing industry types with the number of companies of each type indicated in parenthesis: 1. Foods (42); 2. Textiles and Apparel (15); 3. Pulp and Paper (7); 4. Chemicals (69); 5. Pharmaceutical (23); 6. Oil and Coal Products (4); 7. Rubber Products (10); 8. Ceramics (10); 9. Iron and Steel (9); 10. Metal Products and Nonferrous Metals (27); 11. Machinery (48); 12. Electric Appliances (86); 13. Shipbuilding (3); 14. Automobile and Automobile Parts (34); 15. Other Transportation Equipment (3); 16. Precision Instruments (17); 17. Printing (10); 18. Light Industries (9); and 19. Other Products (3). All companies answered 48 questions in the survey. This study especially uses the results from two questions; the first involves the state of e-CI projects' implementation, and the second involves the state of disclosure of the e-CI project's results. The analysis details from each question's result are described in the following section.

3.1. The State of Environmental Project Implementation (Step 1)

The first focus question was "Did your company implement the following seven environmental projects?" These environmental projects improve supply chain management (SCM) from an environmental performance perspective:

(*X1*) A modal shift of means of transportation;
(*X2*) A shift to a fuel-efficient or low-emissions vehicle;
(*X3*) The shortening of transportation distances and changes in transportation routes;
(*X4*) The improvement in the capability of packing and wrapping materials to improve loading efficiency;
(*X5*) A cooperative distribution;
(*X6*) Energy-saving driving to improve fuel consumption;
(*X7*) Other SCM activities.

Each project's implementation state is expressed in Formula (1):

$$I_{ij} = \frac{b_{ij}}{a_i} \times 100\,(i = 1, \ldots, 19, j = 1, \ldots, 7) \tag{1}$$

where I_{ij} is the ratio of the number of companies that implement project *Xj* to the number of companies in the type i manufacturing industry; b_{ij} is the number of companies that implement project *Xj* in the type i manufacturing industry; a_i is the number of companies in the type i manufacturing industry; i is the suffix of each manufacturing industry type; and j is the suffix for each project.

Table 1 illustrates the calculation result of I_{ij}. The environmental projects' implementation states are analyzed in Figures 5 and 6 based on this dataset.

Figure 5 displays each environmental project's state of implementation. Projects *X2*, *X3*, *X4*, and *X6* are advanced in their development, as their average values of I_{ij} are greater than 80.0. The average values of I_{ij} for projects *X1* and *X5* are less than 70.0. The two projects indicate a slight trend in the average values of I_{ij}, as they are more large-scale and have larger costs than the aforementioned four projects. The average value of I_{ij} for project *X7* is less than 40.0, and the average values of I_{ij} for projects *X1*, *X5*, and *X7* are less than those of projects *X2*, *X3*, *X4*, and *X6*. However, the range value of I_{ij} for projects *X1*, *X5*, and *X7* is greater than that of projects *X2*, *X3*, *X4*, and *X6*. This indicates that a difference in implementation states exists for projects *X1*, *X5*, and *X7* among the companies in one manufacturing type.

Table 1. The state of environmental project implementation (I_{ij}).

Type of Manufacturing Industry \ Environmental Project	*X1*	*X2*	*X3*	*X4*	*X5*	*X6*	*X7*
(1) Foods	88.1	81.0	100.0	88.1	90.5	90.5	40.5
(2) Textiles and Apparel	83.3	83.3	100.0	91.7	50.0	100.0	25.0
(3) Pulp and Paper	100.0	100.0	85.7	85.7	85.7	100.0	71.4
(4) Chemicals	85.3	75.0	94.1	86.8	64.7	80.9	32.4
(5) Pharmaceutical	36.4	86.4	63.6	63.6	59.1	86.4	27.3
(6) Oil and Coal Products	75.0	100.0	100.0	75.0	75.0	100.0	50.0
(7) Rubber Products	66.7	55.6	100.0	88.9	66.7	44.4	44.4
(8) Ceramics	55.6	100.0	88.9	88.9	33.3	100.0	44.4
(9) Iron and Steel	88.9	88.9	88.9	66.7	66.7	100	44.4
(10) Metal Products and Nonferrous Metals	65.4	73.1	80.8	88.5	57.7	84.6	42.3
(11) Machinery	66.0	91.5	85.1	87.2	48.9	95.7	31.9
(12) Electric Appliances	65.9	87.1	87.1	87.1	69.4	88.2	47.1
(13) Shipbuilding	50.0	100.0	100.0	50.0	0.0	50.0	0.0
(14) Automobile and Automobile Parts	70.6	82.4	94.1	94.1	82.4	94.1	52.9
(15) Other Transportation Equipment	100	66.7	66.7	66.7	33.3	33.3	0.0
(16) Precision Instruments	64.7	88.2	82.4	100	52.9	82.4	47.1
(17) Printing	30.0	80.0	80.0	80.0	50.0	90.0	10.0
(18) Light Industries	66.7	88.9	77.8	88.9	77.8	100	22.2
(19) Other Products	66.7	100.0	100.0	100.0	100.0	100.0	33.3

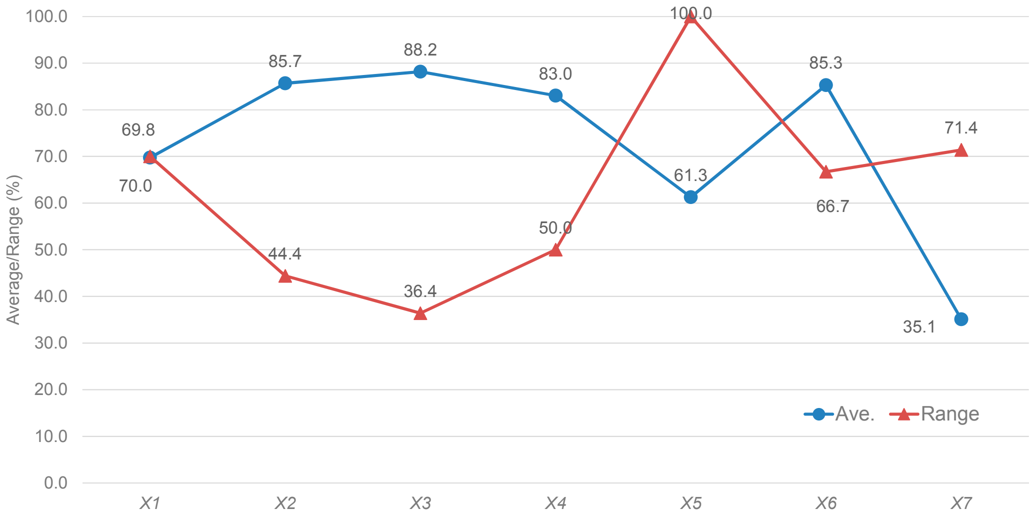

Figure 5. The state of implementation for each environmental project.

Figure 6 notes the implementation state for each manufacturing type. The average values of I_{ij} for (1) Foods; (3) Pulp and Paper; (6) Oil and Coal Products; (14) Automobile and Automobile Parts; and (19) Other Products are greater than 80.0. Specifically, it can be observed that most companies in (3) Pulp and Paper positively perform various environmental projects, as the range value for this industry is the lowest of all the manufacturing types. The average I_{ij} values for (13) Shipbuilding and (15) Other Transportation Equipment are approximately 50.0, and the range values of the two industries are 100.0. A similar set of contrasts of implementation states exist among the projects in each industry.

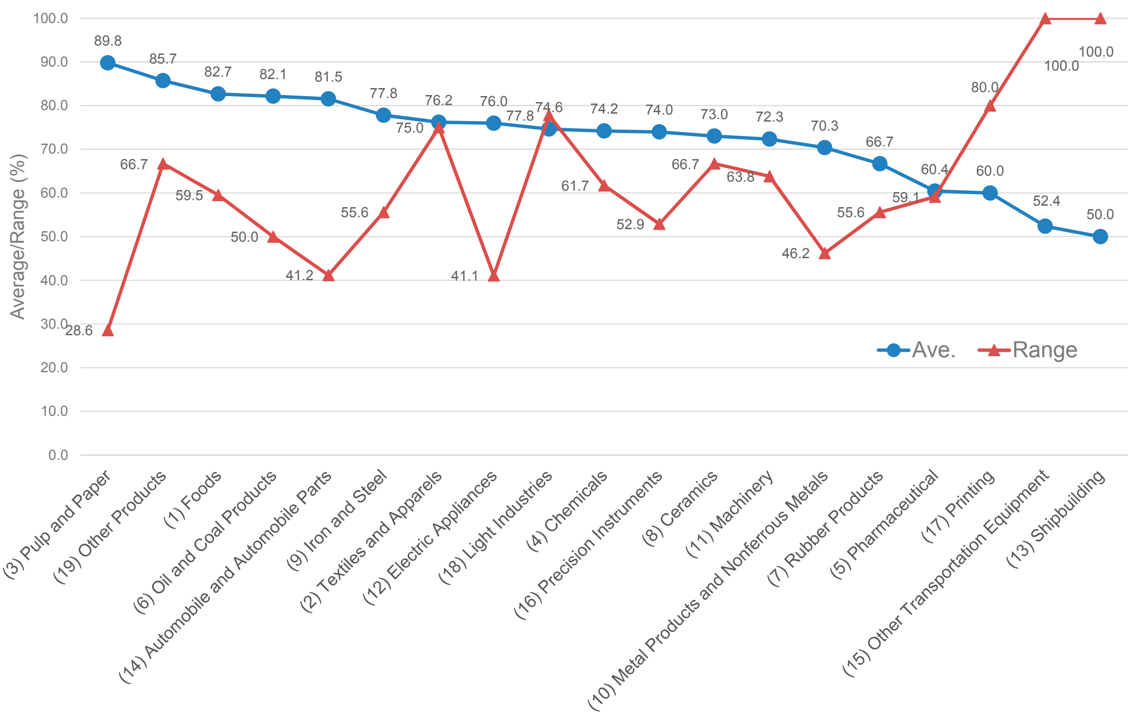

Figure 6. The implementation state for each manufacturing type (sorted based on average).

3.2. The State of Information Disclosure for Environmental Indicators (Step 2)

The second focus question was "Did your company disclose the following three environmental indicators?" The three environmental indicators involve greenhouse gas emissions in the full cycle of a supply chain:

(*Y1*) A distribution from materials/part companies to your factory;
(*Y2*) A distribution from your factory to retailers;
(*Y3*) A distribution to dispose of or recycle used products.

The level of disclosure is then established based on the following four levels in the original survey:

(Level 1) This company has already calculated and announced.
(Level 2) This company has already calculated and plans to announce in the future.
(Level 3) This company has already calculated and does not plan to announce in the future.
(Level 4) This company has no plans to calculate.

The disclosure state of the environmental indicators is expressed in Formula (2):

$$A_{ik} = \frac{\sum_{m=1}^{4} c_m d_{ikm}}{a'_{ik}} \times 100\,(i = 1, \ldots, 19, k = 1, \ldots, 3) \quad (2)$$

where A_{ik} is the ratio of the number of companies that disclose indicator Yk to the number of companies in the type i manufacturing industry; c_m is the weight of disclosure level m; d_{ikm} is the number of companies that disclose indicator Yk by disclosure level m in the type i manufacturing industry; a'_{ik} is the number of companies that disclose indicator Yk in the type i manufacturing industry; i is the suffix of each manufacturing industry type; k is the suffix of each indicator; m is the suffix of each environmental indicator's disclosure level.

Table 2 displays the disclosure state for each environmental indicator in each manufacturing type. The environmental indicators' state of disclosure is analyzed in Figures 7 and 8 based on this dataset.

Table 2. The state of disclosure for environmental indicators (A_{ik}).

Type of Manufacturing Industry \ Environmental Indicator	*Y1*	*Y2*	*Y3*
(1) Foods	63.8	85.9	58.8
(2) Textiles and Apparel	64.3	60.7	53.6
(3) Pulp and Paper	75.0	95.0	50.0
(4) Chemicals	65.2	78.4	53.6
(5) Pharmaceutical	72.5	72.7	46.4
(6) Oil and Coal Products	87.5	87.5	37.5
(7) Rubber Products	60.7	89.3	60.0
(8) Ceramics	60.7	75.0	39.3
(9) Iron and Steel	81.3	80.0	45.0
(10) Metal Products and Nonferrous Metals	64.3	78.6	51.9
(11) Machinery	66.2	77.9	50.7
(12) Electric Appliances	64.8	85.5	60.0
(13) Shipbuilding	50.0	100.0	50.0
(14) Automobile and Automobile Parts	72.4	84.5	69.3
(15) Other Transportation Equipment	0.0	75.0	0.0
(16) Precision Instruments	60.0	75.0	50.0
(17) Printing	70.0	70.0	55.0
(18) Light Industries	53.6	71.4	62.5
(19) Other Products	62.5	62.5	50.0

Figure 7 shows each environmental indicator's state of disclosure. The average values of A_{ik} for indicator *Y2* (79.2) are more than that of indicators *Y1* (62.9) and *Y3* (49.7). This continues for disclosure indicator *Y2* for some time because its logistics include a primary delivery system for finished products. The range value for indicator *Y1* (87.5) is the highest of all indicators and reveals that a difference exists among the states of disclosure for indicators in each industry. This indicator is for business to business (B to B) logistics, and it is difficult to inform end users regarding the state of its logistics. However, total supply chain management must involve improving and announcing its logistics capability. The distribution of indicator *Y3* is waste recovery logistics, a recent topic. Hence, relevant activities should increase in the future.

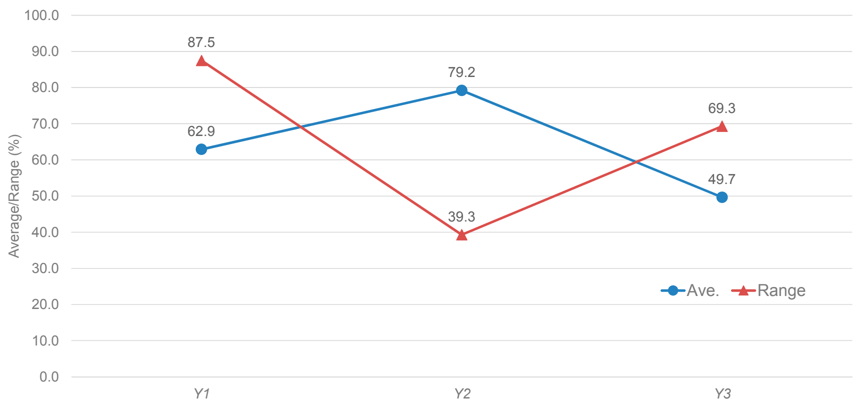

Figure 7. The state of disclosure for each environmental indicator.

Figure 8 illustrates the state of disclosure for each manufacturing type. The average value of A_{ik} for (14) Automobile and Automobile Parts (75.4) is the highest of all manufacturing types, and the range value of A_{ik} for the industry (15.2) is comparatively low. Namely, companies that belong to this industry positively disclose various indicators. Alternatively, the average value of A_{ik} for (15) Other Transportation Equipment (25.0) is the lowest of all manufacturing types, and the range value of A_{ik} for this type (75.0) is the highest of all manufacturing types. Table 2 reveals that no companies disclose indicators *Y1* and *Y3* in this type. The average values of A_{ik} for the 13 other industries, except for the aforementioned two industries, are approximately 60.0. Thus, disclosure capability can be improved.

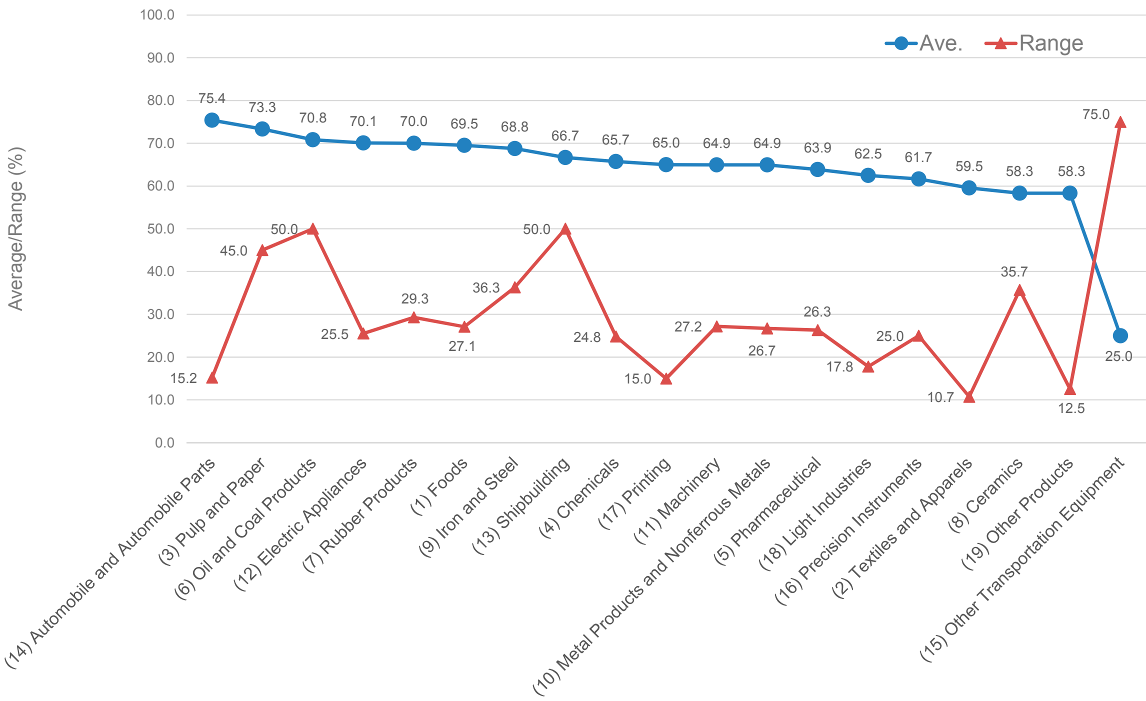

Figure 8. The state of disclosure for each manufacturing type (sorted based on average).

4. Comprehensive Analysis of e-CI (Step 3)

4.1. Conventional Model

Charnes et al. (1978) [15] originally introduced the DEA analytical model, which regards each enterprise, or "decision-making unit" (DMU), as a transformation function of input resources to output attainments. For example, sales revenue is typically considered as a relevant business output value and costs, such as total manufacturing costs, are considered an input value. A specific linear programming problem-solving set is performed based on this scheme to classify high- and low-efficiency units.

Many classes of DEA sub-models exist, depending on supposed assumptions [16–18]. The Charnes-Cooper-Rhodes (CCR) model [15] is the simplest among DEA models, and is represented mathematically by the following formula:

$$Max\ \frac{\sum_{s=1}^{t} u_s y_{sp_o}}{\sum_{q=1}^{r} v_q x_{qp_o}} \tag{3}$$

subject to

$$\frac{\sum_{s=1}^{t} u_s y_{sp}}{\sum_{q=1}^{r} v_q x_{qp}} \leq 1\,(p = 1, \ldots, m) \tag{4}$$

$$u_s \geq 0\,(s = 1, \ldots, t) \tag{5}$$

$$v_q \geq 0\,(q = 1, \ldots, r) \tag{6}$$

where p_o is the DMU which is to be evaluated; y_{sp} is a value of the output s of DMU p; x_{qp} is a value of the input q of DMU p; u_s is a weighting coefficient for output s; v_q is a weighting coefficient for input q; m is a number of DMU; t is a number of output; r is a number of input; p is a suffix of DMU; s is a suffix of output; and q is a suffix of input. The technological essence of this model involves obtaining the optimal weighting coefficient values for the target DMU's linear input and output functions, which enable it to accomplish the maximum ratio of the aforementioned defined functions. As the constraint introduced in Formula (4), this maximum value cannot exceed one, and each variable and coefficient are non-negative. Therefore, the target DMU's measured performance, namely the maximum ratio, falls between one and zero. The same calculation is described in Formulas (3)–(6), and is performed for all DMUs. The maximum ratios of all DMUs are then obtained as their position among the considered DMUs.

4.2. Proposed Model

The model is formulated using a DEA. Two kinds of models are used to evaluate not only an e-CI project's implementation state, but also the e-CI project result's disclosure state. This set of two models more clearly visualizes the relationship between the two states [19].

These models are mathematically represented by a degenerated CCR model. Further, the mathematical representation of the model used to calculate an efficiency value for the project implementation of each manufacturing type is provided as the following formula:

$$Max \sum_{j=1}^{7} Iu_j I_{ji_o} \tag{7}$$

subject to

$$\sum_{j=1}^{7} Iu_j I_{ji} \le 1\,(i = 1, \ldots, 19) \tag{8}$$

$$Iu_j \ge 0\,(j = 1, \ldots, 7) \tag{9}$$

where i_o is the type of manufacturing industry to be evaluated, I_{ji} is a value for the implementation state of project j in the i type manufacturing industry, Iu_j is the weighting coefficient for project j, i is a suffix of the manufacturing industry type, and j is the project suffix.

The technological essence of this model involves obtaining the optimal weighting coefficient values for a project's linear function of the target manufacturing industry type, which enables the maximum ratio of the aforementioned defined function. As the constraint introduced in Formula (8), this maximum value cannot exceed one, and each variable and coefficient are nonnegative. Therefore, the measured performance of the target manufacturing industry type, namely the maximum ratio, falls between one and zero. Namely, the actual dataset of I_{ji} uses Table 1 which consists of the data for seven environmental projects of 19 manufacturing industry types. Seven weighting coefficients (Iu_1, Iu_2, Iu_3, Iu_4, Iu_6, Iu_7) of the target manufacturing industry type are found by the liner programing with the proposed model.

The same calculations described in Formulas (7)–(9) are performed for all manufacturing industry types. The maximum ratios for all manufacturing industry types are then obtained as their position among the considered manufacturing industry types. Further, the model to calculate the efficiency value of the disclosure of the project result for each manufacturing type is mathematically represented by the following formula:

$$Max \sum_{k=1}^{3} Au_k A_{ki_o} \tag{10}$$

subject to

$$\sum_{k=1}^{3} Au_k A_{ki} \leq 1\,(i = \ 1, \ldots, \ 19) \tag{11}$$

$$Au_k \geq 0\,(k \ = 1, \ldots, \ 3) \tag{12}$$

where i_o is the type of manufacturing industry to be evaluated, A_{ki} is the value for the disclosure state of indicator k, Au_k is a weighting coefficient for indicator k, i is a suffix for the manufacturing industry type, and k is a suffix of the indicator.

The technological essence of this model involves obtaining the optimal weighting coefficient values of a linear indicator function for the target manufacturing industry type, which enables the maximum ratio of the aforementioned defined function. As the constraint introduced in Formula (11), this maximum value cannot exceed one, and each variable and coefficient are nonnegative. Therefore, measured performance of the target manufacturing industry type, namely the maximum ratio, falls between one and zero. Namely, the actual dataset of A_{ki} uses Table 2 which consists of the data for three environmental indicators of 19 manufacturing industry types. Three weighting coefficients (Au_1, Au_2, Au_3) of the target manufacturing industry type are found by the liner programing with the proposed model.

The same calculations described in Formulas (10)–(12) are performed for all manufacturing industry types. The maximum ratios of all manufacturing industry types are then obtained as their positions among the considered manufacturing industry types.

The two proposed models are utilized followed by the flowchart in Figure 9. The procedure consists of four portions; (1) calculating the two values of project implementation and information disclosure in the 19 manufacturing industry types with the two proposed models; (2) visualizing the relationship between the two states of the 19 manufacturing industry types by the distribution map of the calculation results; (3) classifying the 19 manufacturing industry types based on the combination of averages of the two values; and (4) discussing a future e-CI strategy of each manufacturing industry type by the result derived in Portion 3. The result of the analysis is explained in the following section.

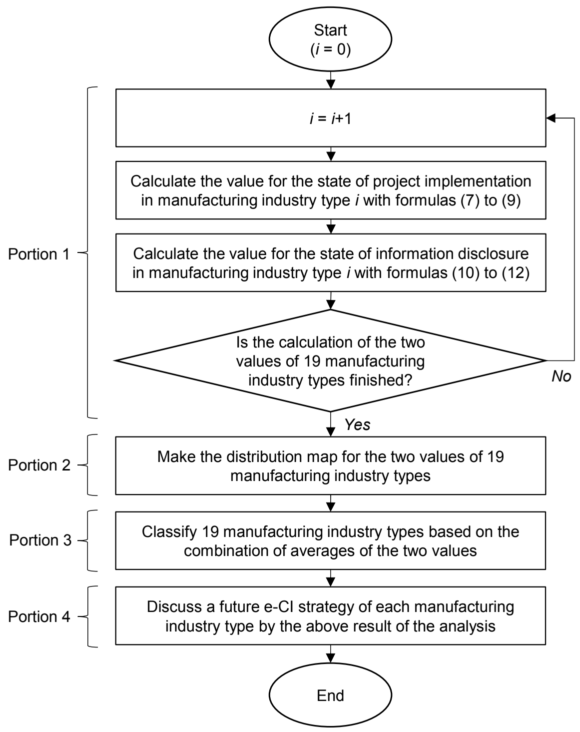

Figure 9. Flowchart for analyzing the e-CI of the manufacturing industry with the proposed models.

4.3. Calculation Result

A summary of the calculation results by the proposed model is illustrated in Tables 3–5.

Regarding the projects' implementation state, Table 3 reveals that the average of values from the 19 manufacturing industry types is 0.98, and the value range for the 19 manufacturing industry types is 0.14. Thirteen manufacturing industry types scored 1.00 for this value. Table 4 notes that in adopting a value to the fourth decimal place, 9 of the 13 types have implemented 1 special program, as follows:

- (3) Pulp and Paper and (15) Other Transportation Equipment -> *X1*
- (8) Ceramics and (13) Shipbuilding -> *X2*
- (7) Rubber Products -> *X3*
- (19) Other Products -> *X5*
- (2) Textiles and Apparel; (9) Iron and Steel; and (18) Light Industries -> *X6*

The characteristics of the four other manufacturing types are as follows: (1) Foods has strengths in projects *X1*, *X3*, and *X5*; (16) Precision Instruments has strengths in projects *X1*, *X4*, and *X7*; (6) Oil and Coal has strengths in projects *X1*, *X2*, and *X3*; (14) Automobile and Automobile Parts has strengths in projects *X3*, *X4*, *X5*, and *X7*.

Table 3. The value of projects' implementation state and project results' disclosure state.

Type of Manufacturing Industry	$\sum_{j=1}^{6} Iu_j^* I_{ji_o}$	$\sum_{k=1}^{3} Au_k^* A_{ki_o}$
(1) Foods	1.00	0.95
(2) Textiles and Apparel	1.00	0.85
(3) Pulp and Paper	1.00	1.00
(4) Chemicals	0.97	0.88
(5) Pharmaceutical	0.86	0.90
(6) Oil and Coal Products	1.00	1.00
(7) Rubber Products	1.00	0.98
(8) Ceramics	1.00	0.80
(9) Iron and Steel	1.00	0.97
(10) Metal Products and Nonferrous Metals	0.91	0.87
(11) Machinery	0.96	0.88
(12) Electric Appliances	0.93	0.96
(13) Shipbuilding	1.00	1.00
(14) Automobile and Automobile Parts	1.00	1.00
(15) Other Transportation Equipment	1.00	0.75
(16) Precision Instruments	1.00	0.83
(17) Printing	0.90	0.91
(18) Light Industries	1.00	0.90
(19) Other Products	1.00	0.82
Ave.	0.98	0.91
Range	0.14	0.25

Table 3 notes that regarding the project results' disclosure state, the average value for the 19 manufacturing industry types is 0.91, and their range is 0.25. Four manufacturing industry types score 1.00 for this value. Table 5 illustrates that all three indicators have been more positively announced in (14) Automobile and Automobile Parts than in the other three types; the (3) Pulp and Paper industry positively discloses indicators *Y1* and *Y2*; (6) Oil and Coal Products positively discloses indicator *Y1*; and (13) Shipbuilding positively discloses indicator *Y3*.

Table 4. A weighting coefficient for each project (Iu_{jio}).

Type of Manufacturing Industry	Iu^*_1 (X1)	Iu^*_2 (X2)	Iu^*_3 (X3)	Iu^*_4 (X4)	Iu^*_5 (X5)	Iu^*_6 (X6)	Iu^*_7 (X7)
(1) Foods	3.34×10^{-3}	0.00	2.54×10^{-4}	0.00	7.52×10^{-3}	0	0.00
(2) Textiles and Apparel	5.20×10^{-17}	0.00	0	2.17×10^{-18}	0.00	1.00×10^{-2}	0.00
(3) Pulp and Paper	1.00×10^{-2}	0.00	0	0.00	0.00	0.00	0.00
(4) Chemicals	3.75×10^{-3}	0.00	2.28×10^{-3}	5.00×10^{-3}	0.00	0.00	0.00
(5) Pharmaceutical	0.00	1.00×10^{-2}	0	0.00	0.00	0.00	0.00
(6) Oil and Coal Products	3.14×10^{-3}	2.16×10^{-3}	5.48×10^{-3}	0.00	0.00	0.00	0.00
(7) Rubber Products	0.00	0.00	1.00×10^{-2}	6.51×10^{-19}	0.00	0.00	4.34×10^{-18}
(8) Ceramics	0.00	1.00×10^{-2}	0.00	0.00	0.00	0.00	0.00
(9) Iron and Steel	5.20×10^{-17}	0.00	0.00	0.00	0.00	1.00×10^{-2}	0.00
(10) Metal Products and Nonferrous Metals	0.00	0.00	0.00	7.05×10^{-3}	0.00	2.07×10^{-3}	2.64×10^{-3}
(11) Machinery	5.20×10^{-17}	0.00	0.00	0.00	0.00	1.00×10^{-2}	0.00
(12) Electric Appliances	0.00	6.85×10^{-4}	6.20×10^{-3}	2.08×10^{-3}	0.00	0.00	3.11×10^{-3}
(13) Shipbuilding	0.00	1.00×10^{-2}	4.34×10^{-19}	0	0.00	0.00	0.00
(14) Automobile and Automobile Parts	0.00	0.00	6.66×10^{-3}	1.13×10^{-3}	1.10×10^{-3}	0.00	3.34×10^{-3}
(15) Other Transportation Equipment	1.00×10^{-2}	0.00	0.00	0.00	0.00	0.00	0.00
(16) Precision Instruments	2.92×10^{-3}	0.00	0.00	7.91×10^{-3}	0.00	0.00	4.23×10^{-4}
(17) Printing	0.00	0.00	0.00	0.00	0.00	1.00×10^{-2}	0.00
(18) Light Industries	4.21×10^{-17}	0.00	0.00	0.00	0.00	1.00×10^{-2}	0.00
(19) Other Products	0.00	0.00	0.00	0.00	1.00×10^{-2}	0.00	0.00

Table 5. A weighting coefficient for each indicator (Au_{kio}).

Type of Manufacturing Industry	Au^*_1 (Y1)	Au^*_2 (Y2)	Au^*_3 (Y3)
(1) Foods	1.44×10^{-3}	7.22×10^{-3}	4.12×10^{-3}
(2) Textiles and Apparel	9.50×10^{-3}	0.00	4.51×10^{-3}
(3) Pulp and Paper	1.82×10^{-3}	9.09×10^{-3}	0.00
(4) Chemicals	5.74×10^{-3}	4.34×10^{-3}	3.14×10^{-3}
(5) Pharmaceutical	9.50×10^{-3}	0.00	4.51×10^{-3}
(6) Oil and Coal Products	1.14×10^{-2}	0.00	0.00
(7) Rubber Products	0.00	7.13×10^{-3}	5.73×10^{-3}
(8) Ceramics	5.74×10^{-3}	4.34×10^{-3}	3.14×10^{-3}
(9) Iron and Steel	9.50×10^{-3}	0.00	4.51×10^{-3}
(10) Metal Products and Nonferrous Metals	1.44×10^{-3}	7.22×10^{-3}	4.12×10^{-3}
(11) Machinery	5.74×10^{-3}	4.34×10^{-3}	3.14×10^{-3}
(12) Electric Appliances	1.44×10^{-3}	7.22×10^{-3}	4.12×10^{-3}
(13) Shipbuilding	0.00	1.00×10^{-2}	0.00
(14) Automobile and Automobile Parts	1.44×10^{-3}	7.22×10^{-3}	4.12×10^{-3}
(15) Other Transportation Equipment	0.00	1.00×10^{-2}	0.00
(16) Precision Instruments	1.44×10^{-3}	7.22×10^{-3}	4.12×10^{-3}
(17) Printing	9.50×10^{-3}	0.00	4.51×10^{-3}
(18) Light Industries	0.00	0.00	1.44×10^{-2}
(19) Other Products	9.50×10^{-3}	0.00	4.51×10^{-3}

4.4. Classification of Manufacturing Types

The calculation results from the previous section are arranged in Figure 10. The graph's horizontal axis is the value for the projects' implementation state, and its vertical axis provides the value of the relevant indicators' disclosure state. The positioning of each manufacturing industry type can be clearly observed using a two-dimensional graph.

This graph absolutely indicates that the disclosure of project results could be improved compared with the rate of a project's implementation. Most manufacturing industry types scored 1.0 regarding the e-CI project's implementation state. The range of values among industry types is small due to the minimum value of 0.86 for the (5) Pharmaceutical industry. Four manufacturing industry types only scored 1.0 for the e-CI project results' disclosure state. The range of values among industries is 0.25, or approximately twice the other state's range.

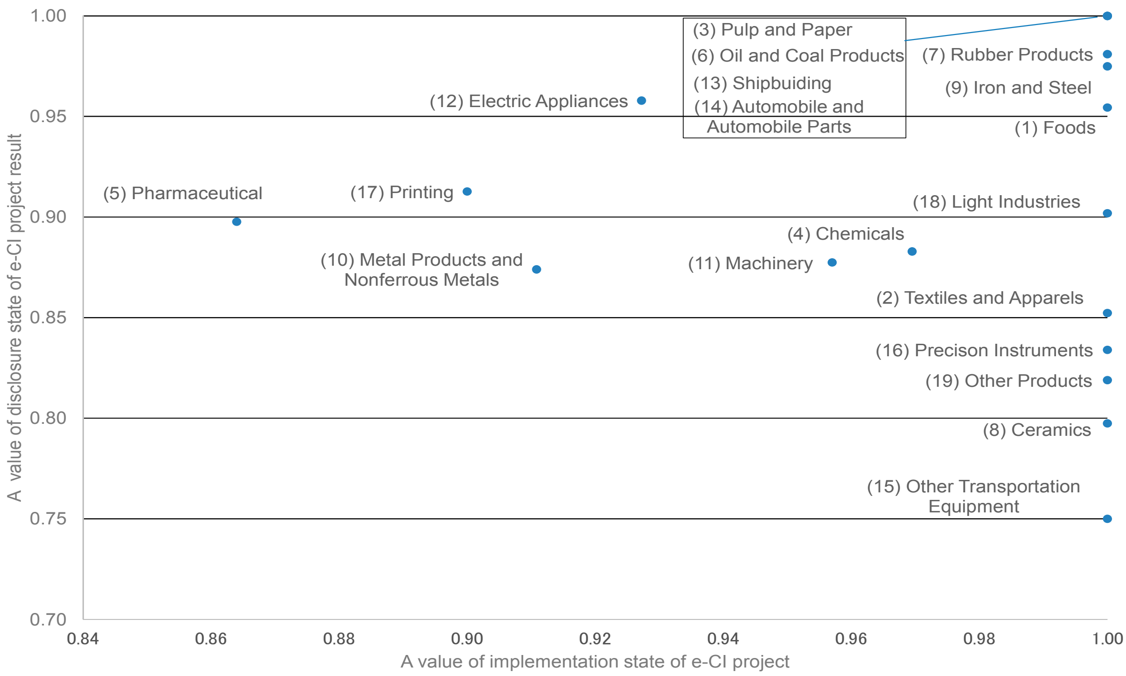

Figure 10. Implementation state of e-CI project and disclosure state of e-CI project result.

Further, 19 manufacturing industry types are classified based on the average of the 19 types' values for projects' implementation state (0.98 from Table 3) and the average of 19 types' values for project results' disclosure state (0.91 from Table 3). The four classification groups are illustrated as follows:

First group:	Above average values for the two states
Second group:	Above average value for implementation state
	Below average value for disclosure state
Third group:	Below average value for implementation state
	Above average value for disclosure state
Fourth group:	Below average values for the two states

Each industry's future e-CI strategy can be considered by comparing the futures of the industry types noted in Table 6. The industry types at the left of the table aim for multiple goals through multiple projects. For example, the (16) Precision Instruments industry belongs to the second group in the category, and should learn from the first group to proceed to the next e-CI level. Three focused industry projects, projects *X1*, *X2*, and *X3*, are especially similar to the focused projects in the (1) Foods industry.

Alternatively, when viewing the table horizontally, three differences are observed in how to proceed with e-CI in every category. For example, the (18) Light Industries, especially improved indicator *Y3* by project *X6*. Further, the (2) Textiles and Apparel industry improved indicators *Y1* and *Y3* by project *X6*. If the former industry will increase its managed indicator, it can possibly improve indicator *Y3* by strengthening project *X6*.

Table 6. Classification results of the 19 manufacturing industry types.

(a)	Three +			Two			One		
(b)	Three	Two	One	Three	Two	One	Three	Two	One
First Group	(1) Foods (14) Automobile and Automobile Parts		(6) Oil and Coal Products					(3) Pulp and Paper (7) Rubber Products (9) Iron and Steel	(13) Shipbuilding
Second Group	(16) Precision Instruments						(8) Ceramics	(2) Textiles and Apparel (19) Other Products	(15) Other Transportation Equipment (18) Light Industries
Third Group	(12) Electric Appliances							(5) Pharmaceutical (17) Printing	
Fourth Group	(4) Chemicals (10) Metal Products and Nonferrous Metals						(11) Machinery		

(**a**) Upper lines: A number for the project's weighting coefficients (Iu_{jio}), which have a value to the fourth decimal place; (**a**) Lower lines: A number for the indicator's weighting coefficients (Au_{kio}), which have a value to the fourth decimal place; (**b**): The four groups are based on the aforementioned implementation and e-CI disclosure states.

5. Conclusions

This study analyzes the environmental continuous improvement (e-CI) performance of 19 manufacturing industry types in Japan using a proposed DEA model. This study focuses on two capabilities: the implementation capability of e-CI, and the disclosure capability from its results. The results of the analyses tend to reveal that the former is clearly less than the latter, as the manufacturing industry's information disclosure is evolving. The proposed DEA model realizes a clear positioning for each industry type, visualized in the two-dimensional graph in Figure 10. This contributes to academia by supporting the expansion of the DEA model application.

An observation of effective manufacturing industry types reveals that the food and automobile industries positively execute the two capabilities among all manufacturing industry types. The food industry supports not only the improvement of existing transportation, but has also changed its transportation system by both a modal shift and cooperative distribution. The automobile industry has improved its packing and loading processes, in addition to the improvements undertaken in the food industry.

Moreover, this study's results are noted by the classification in Table 6. This shows that each type can systematically and strategically consider its next target industry and indicators. The analysis with the table in Section 4.4 is just one case for the benchmarking at the level of the industry-type. Additional analysis with the table is needed for practitioners of each industry-type. The potential also exists for some sort of disaggregation of the results for benchmarking within industry-type, because the analyzed data is the cumulative data of the frim-level.

This study is regarded as contributing to e-CI performance management by advancing sustainable supply chain management. The management process is divided into 4 sub-processes: (1) CI execution; (2) indicator improvement; (3) information disclosure; and (4) corporate image improvement. The combinations of the last three are a focus of past studies and the first two are analyzed in the present study as well. A comprehensive analysis of all processes could be considered in future studies. The two processes of focus in this study should also be continuously monitored to convey improvements in e-CI performance. Practitioners will recognize the e-CI situation in the manufacturing industry from the analysis of the results, and can consider strengthening e-CI performance and transferring relevant technology among industry types.

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