

Interpretive structural modeling for technology-related barriers to energy efficiency improvement in Indonesia steel industry

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Abstract. This paper investigates the existence of the barriers in Indonesia steel industry, namely: existing technologies were still considered efficient, new technologies not available, new technology not adequate or inappropriate at the site, the energy efficient technology not compatible with other elements of the plant, the uncertainty about future technology standards, lack of technical skills, technology installation period was too long, and poor information quality regarding access to new energy efficient technology. Five practitioners from the national steel industry were retrieved to identify and analyze critical elements and the causal interrelationships among the technology-related barriers. Finally, using the approach of interpretive structural modelling, the barriers were clustered in accordance with their driving power and dependence power. Lack of reliable information access about new technologies is the only barriers at the bottom level of the hierarchy, implying higher driving power. It is also observed that the availability of new technologies, existing technology still efficient, and the uncertainty about future technology standardization have a weak dependent on the other constructs but strongly driver. The four remaining constructs are identified as dependent obstacles. It means that these barriers are the automatic followers of other impediments. The result of this model will assist managers to understand the relative importance and the interdependencies among the barriers. It can guide them to resolve these barriers.

1 Introduction

The iron and steel industry is one of the highly energy-intensive industrial sectors. The energy consumption in Indonesia's steel industry depletes about 20-35 % of total production costs. As a consequence, energy use efficiency is the important measure to reduce energy intensity that eventually results declining production costs. Although some national industries have focused on rectifying energy efficiency by implementation of energy efficient technologies, but the result had not significantly decreased the energy use rate [1]. It can denote that there are still a number of difficulties which impedes implementation of improved energy efficiency. These difficulties show the existence of barriers to energy use efficiency, in particular related to technology.

Nevertheless, the implementation of improved energy efficiency measures becomes an imperative for manufacturing industries, a number of barriers still exist which prevents industry involvement in reducing energy use [2]. To obtain and understand the suitable policies and the know-how of energy-efficient technologies and practices adopted in the firm may be possible with thorough understanding and reforming studies of these hindrances [3]. Therefore, it is still needed to find new and more effective methods to evaluate the importance of

barriers to the firm's decision-making process for adopting energy saving technologies.

Furthermore, there is a trend to explore how each hindrance interconnected. In other words, it is still significantly needed to develop a barrier model involving the relationship between barrier. For these reasons above, this research has conducted to identify and analyze the interaction of the technology-related barriers to energy efficiency improvement from energy use in the Indonesia steel industry using interpretive structural modeling (ISM) approach.

2 Technology-related Barriers

According to [4] said that “*A barrier is a postulated mechanism that inhibits in technologies that are both energy efficient and (apparently) economically efficient.*”

Whereas in accordance with [5], the technical risk is related to technological barriers in energy efficiency implementation lead to production failure and product quality losses.

Limited in skilled technical workforce can impede the improved energy efficiency because staffs only focus on daily production target [6].

The same situation have been mentioned by [7] that lack of technical skill and expertise or skilled man power are barriers to energy efficiency improvement. Beside

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these obstacles, [7] reveals that lack of qualified information access to new technologies may bring out a barrier.

3 Methodology

The focus of this research is to understand the mutual relationship of technology-related barriers to energy efficiency using ISM approach and identify these barriers which influence the other barriers and are influenced by others. Interpretive structural modeling (ISM) is a well-established methodology for identifying and summarizing relationships among specific variables, which define a problem [8].

Formerly, the technology-related barriers which relevant to energy use issue were identified based on literature review. Five practitioners from five steel industries were consulted to identify the relationships among related elements. The practitioners' opinions were taken separately using a questionnaire to avoid possible influence among their answers. Further, the questionnaire results were combined and analyzed by three academics to achieve a final matrix.

3.1 Structural Self-Interaction Matrix (SSIM)

The eight barriers identified previously are arranged in rows and columns for developing the barrier matrix. A contextual relationship is symbolized with four symbols that denote the direction of the relationship between the barriers (*i* and *j*) [9]:

- V: Barrier *i* will influence/cause Barrier *j*;
- A: Barrier *j* will be influenced/caused by Barrier *i*;
- X: Barriers *i* and *j* will influence each other; and
- O: Barriers *i* and *j* are unrelated.

On the basis of pairwise relationships between barrier issues, the SSIM is developed, as shown in Table 1.

Table 1. Structural Self-Interaction Matrix

Technology-related barriers	8	7	6	5	4	3	2	1
1. Availability of new energy efficient technologies	O	X	O	O	O	V	V	
2. New technologies not adequate or compatible at the site	A	A	A	O	O	A		
3. Lack of know-how in integration of new and existing technology	A	A	O	X	X			
4. The installation period of new technologies was too long	O	O	O	A				
5. Lack of skilled technical staff for new technology implementation	O	A	A					
6. Lack of reliable information access to new technologies	O	V						
7. Existing technology still efficient	O							

8. The uncertainty about future technology standardization	
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3.2 Reachability Matrix (RM)

An initial reachability matrix is then developed in the next step. This matrix (Table 2) is constructed from the SSIM by converting into binary numbers, "1" and "0". In this regard, rules for transformation are given.

1. If the (*i, j*) entry in the SSIM is V, then substitute in the (*i, j*) entry in the reachability metrics becomes 1 and the (*j, i*) entry as 0.
2. If the (*i, j*) entry in the SSIM is A, then substitute in the (*i, j*) entry in the reachability metrics becomes 0 and (*j, i*) entry as 1.
3. If the (*i, j*) entry in the SSIM is X then substitute in the (*i, j*) entry in the reachability metrics becomes 1 and (*j, i*) entry as 1.
4. If the (*i, j*) entry in the SSIM is O then substitute in the (*i, j*) entry in the reachability metrics becomes 0 and (*j, i*) entry as 0.

Table 2. Initial Reachability Matrix

Technology-related barriers	8	7	6	5	4	3	2	1
1. Availability of new energy efficient technologies	0	1	0	0	0	1	1	1
2. New technologies not adequate or compatible at the site	0	0	0	0	0	0	1	0
3. Lack of know-how in integration of new and existing technology	0	0	0	1	1	1	1	0
4. The installation period of new technologies was too long	0	0	0	0	1	1	0	0
5. Lack of skilled technical staff for new technology implementation	0	0	0	1	1	1	0	0
6. Lack of reliable information access to new technologies	0	1	1	1	0	0	1	0
7. Existing technology still efficient	0	1	0	1	0	1	1	1
8. The uncertainty about future technology standardization	1	0	0	0	0	1	1	0

The initial reachability matrix is examined for incorporating the transitivity concept and making modifications (if any). This concept states that if a barrier *i* is related to *j* and if the barrier *j* is related to a third barrier *k*, then *i* is necessarily related to *k*. Thus, a final reachability matrix is achieved, as shown in Table 3.

Table 3. Final Reachability Matrix

Technology-related barriers	8	7	6	5	4	3	2	1
1. Availability of new energy efficient technologies	0	1	0	1	1	1	1	1
1. New technologies not adequate or compatible at the site	0	0	0	0	0	0	1	0
2. Lack of know-how in integration of new and existing technology	0	0	0	1	1	1	1	0
3. The installation period of new technologies was too long	0	0	0	1	1	1	1	0
4. Lack of skilled technical staff for new technology implementation	0	0	0	1	1	1	1	0
5. Lack of reliable information access to new technologies	0	1	1	1	1	1	1	1
6. Existing technology still efficient	0	1	0	1	1	1	1	1

7.The uncertainty about future technology standardization	1	0	0	1	1	1	1	0
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3.3 Level partitions and Canonical Matrix

The reachability and antecedent set for each barrier is obtained from the final reachability matrix. The reachability set consists of the barrier itself and the other barriers, which it may reach. Whereas, the antecedent set consists of the barrier elements itself and the other barrier elements, which may reach it. The intersection for the reachability and antecedent sets is derived for all the barriers. The barriers are considered as a top-level barrier in the ISM hierarchy for which these sets are the same. To obtain the next level, the top-level barrier is separated out from the other remaining barriers. The whole process of partitioning is continued until the levels of all barriers are determined (Table 4-7).

Table 4. Partition of RM Interaction – Iteration 1

Barriers #	Reachability set	Antecedent set	Intersection set	Level
1	1,2,3,4,5,7	1,6,7	1,7	
2	2	1,2,3,4,5,6,7,8	2	I
3	2,3,4,5	1,2,3,4,5,6,7	3,4,5	
4	2,3,4,5	1,2,3,4,5,6,7	3,4,5	
5	2,3,4,5	1,2,3,4,5,6,7	3,4,5	
6	1,2,3,4,5,6,7	6	6	
7	1,2,3,4,5,7	1,6,7	1,7	
8	2,3,4,5,8	8	8	

Table 5. Partition of RM Interaction – Iteration 2

Barriers #	Reachability set	Antecedent set	Intersection set	Level
1	1,3,4,5,7	1,6,7	1,7	
3	3,4,5	1,3,4,5,6,7,8	3,4,5	II
4	3,4,5	1,3,4,5,6,7,8	3,4,5	II
5	3,4,5	1,3,4,5,6,7,8	3,4,5	II
6	1,3,4,5,6,7	6	6	
7	1,3,4,5,7	1,6,7	1,7	
8	3,4,5,8	8	8	

Table 6. Partition of RM Interaction – Iteration 3

Barriers #	Reachability set	Antecedent set	Intersection set	Level
1	1,7	1,6,7	1,7	III
6	1,6,7	6	6	
7	1,7	1,6,7	1,7	III
8	8	8	8	III

Table 7. Partition of RM Interaction – Iteration 4

Barriers #	Reachability set	Antecedent set	Intersection set	Level
6	6	6	6	IV

The final reachability matrix is converted into a canonical format by clustering barriers in the same level across the rows and columns of the matrix, as shown in Table 8. In this table, the driver power is the total number

of first in the row and the dependence power is the total number of first in the column

Table 8. Canonical matrix

Barrier #	6	8	7	1	5	4	3	2	Driver power	Ranks
2	0	0	0	0	0	0	0	1	1	5
3	0	0	0	0	1	1	1	1	4	4
4	0	0	0	0	1	1	1	1	4	4
5	0	0	0	0	1	1	1	1	4	4
1	0	0	1	1	1	1	1	1	6	2
7	0	0	1	1	1	1	1	1	6	2
8	0	1	0	0	1	1	1	1	5	3
6	1	0	1	1	1	1	1	1	7	1
Dependence	8	7	7	7	3	3	1	1		
Ranks	1	2	2	2	3	3	4	4		

3.4 ISM-based model formation

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4 Result and discussion

In MICMAC (Matrice d’Impacts Croises-Multiplication Applique’ an Classment or Cross-Impact Matrix-Multiplication Applied to a Classification) analysis, the barriers will be classified into four groups, namely autonomous, dependent, linkage and independent [10]. The driver-dependence power diagram is built.

It can be seen that there are no autonomous variables (see Figure 2). The absence of these barriers in the present research shows that all the considered barriers influence the energy efficiency improvement which related to energy efficient technology adoption. New technologies not adequate or compatible at the site (barrier 2), lack of know-how in integration of new and existing technology (barrier 3), the installation period of new technology was too long (barrier 4) and lack of skilled technical staff for new technology implementation (barrier 5) are in the category of dependent obstacles. These barriers have little driving power, but strong dependence. These barriers show the unfavorable outcome to the management. The handling of these barriers depends on overcoming other obstacles formerly.

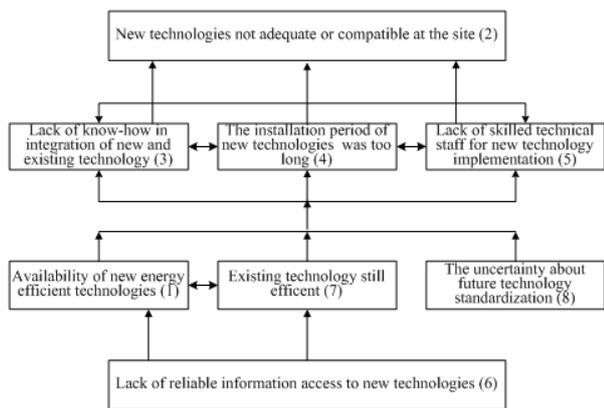


Fig. 1. Final of the Relationships among Technology-related Barriers

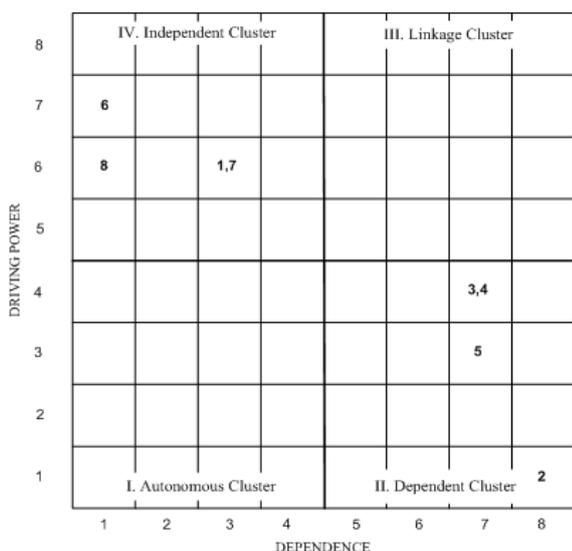


Fig. 2. Driving Power and Dependence Diagram

There is no barrier found in linkage cluster that has a strong driving power as well as strong dependence. It can be inferred that all the barriers of this study are stable. The driver-dependence power diagram indicates that barriers such as availability of new energy efficient technologies (barrier 1), lack of reliable information access to new technologies (barrier 6), existing technology still efficient (barrier 7), and the uncertainty about future technology standardization (barrier 8) are in the fourth cluster. This category includes independent barriers that have weak dependence, but strong driving power. They may be treated as the root cause of barriers or the major barriers.

5 Conclusion

Four issues have been identified as the driver or key variables and four as the dependent variable. No issue is seen as a linkage and autonomous barrier. Lack of reliable information access to new technologies is at the bottom level of the structural model which implies as the most important level of the hierarchy. Managers should focus on resolving this barrier that has high driving power. Thus, the management has the capability to tackle other barriers.

ISM model will help managers to understand the relationship among the barriers. The MICMAC analysis allows meaningful insights about the relative importance and the interdependencies among the barriers. This can help the top management to handle these barriers. The ISM model has not been statistically tested and validated. Thus, in the future research, it is needed to use another approach to test the validity and reliability of the model.

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