A DEMATEL Approach to Evaluate the Enablers for Effective Implementation of Ecodesign in Sustainable Product Development: A Case of MSMEs

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Abstract Increasing pressure of producing environmentally friendly products and services has forced companies to adopt ecodesign practices in their production process, especially in micro, small and medium enterprises (MSMEs). These practices help the designers to mitigate the environmental issues such as climate change and depleting natural resources by designing sustainable products. There are certain enablers that need to be realized by companies for effective implementation of eco-friendly practices. The main focus of this research is to identify and evaluate the key enablers for sustainable product development. A Decision Making Trial and Evaluation Laboratory (DEMATEL) approach is used in this study to evaluate the identified enablers. A case study based on an Indian manufacturing MSME is carried out to present the real-life applicability of the proposed study. The findings of this study show that training of designers to use various available ecodesign methods and tools is the most important enabler that can have a significant effect in the implementation of ecodesign practices for sustainable product development.

Keywords Ecodesign · Sustainable development · MSMEs · Enablers · DEMATEL

1 Introduction

Currently, the world is facing various environmental issues such as increasing amount of greenhouse gases in the atmosphere, melting glaciers, increasing occurrences of flood and drought and continuously depleting natural resources. One of the main reasons which is responsible for these issues is the current irresponsible production and consumption patterns. The current pattern of production and consumption may lead the world toward an unavoidable collapse by the end of

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twenty-first century [1]. An active participation is required by all stakeholders of the society (i.e., government, industries and academia) to mitigate these issues and to achieve sustainable development. The term ‘sustainable development’ is a philosophy which says that we should consume our resources to fulfill our current need in such a way that the ability of our future generations to meet their need is not compromised. Ecodesign can be a potential approach to deal with these issues through a responsible production and consumption of various products and services. Ecodesign is defined as ‘an approach that considers the integration of environmental criteria in the development of products throughout the entire life cycle of products’ [2]. The Biofore Company defines ecodesign as ‘design and produce products responsibly to be safe and sustainable, and ensure that, whenever possible, the end of products’ life cycle is the birth of something new.’ It is encouraged to consider ecodesign principles in the development of a product in the earlier stage of the design, i.e., in conceptual design because almost 80% of environmental load of a product is determined in this stage [3–5].

Adopting eco-friendly practices is a challenge for micro, small and medium enterprises (MSMEs) because they have limited resources of finance and personnel [6]. Generally, MSMEs are considered as the backbone of the developing countries because they have a significant contribution to the growth of a developing nation. MSMEs are defined on the basis of various criteria such as a number of employees, investment in plant and equipment, sales turnover and production capacity [7]. In India, MSMEs are defined on the basis of investment in plant and machinery, as given in Table 1.

The objective of this research is to identify and evaluate various enablers to improve the implementation of ecodesign practices in sustainable product development in MSMEs using DEMATEL approach. The enablers are identified through a literature survey. A case study is conducted by applying the proposed idea in an Indian manufacturing MSME.

The remaining work is structured as follows: Sect. 2 provides a brief description of the enablers in ecodesign implementation which is identified through the literature search. The methodology of this work is explained in Sect. 3 which is followed by Sect. 4 in which a case study is carried out based on the proposed methodology in an Indian MSME and some managerial implications are provided based on the results of the case study. The conclusion of the study is provided in Sect. 5.

Table 1 Definitions of micro, small and medium enterprises (MSMEs) in India

Enterprises	Investment in plant and machinery/equipment	
	Manufacturing sector	Service sector
Micro	< INR 25 lakh	< INR 10 lakh
Small	> INR 25 lakh but < INR 5 crore	> INR 10 lakh but < INR 2 crore
Medium	> INR 5 crore but < INR 10 crore	> INR 2 crore but < INR 5 crore

2 Literature Review

A literature survey is carried out using the online sources such as Web of Science, Scopus and Google Scholar to find out the enablers for effective implementation of ecodesign in sustainable product development in MSMEs. Only those enablers which are mentioned in multiple studies are considered in this work. Variously identified enablers are presented in Table 2 with a short description and references.

Table 2 Enablers for effective implementation of ecodesign practices in sustainable product development in MSMEs

Code	Enablers	Short description	Refs.
E1	Support from top management	Strong and continuous support is required from the top management so that there is no lack of resources such as finance and personnel, especially in MSMEs	[8, 9]
E2	Using a life cycle approach to design products	Almost all products consume resources and cause emission during each phase of their life cycle beginning from raw material to the end of life. Therefore, the life cycle approach should be used to design products	[10]
E3	Training of designers	Training of the designers should be conducted through green activities such as seminars and workshops. It provides an opportunity for the designers to understand the environmental aspects of a product	[11, 12]
E4	Collaboration between design domains	Ecodesign is a multidisciplinary activity and requires collaboration not only among internal but also among external stakeholders	[13, 14]
E5	Building an information system to exchange data	There should be an information system in place so that the important data related to ecodesign of products can be exchanged between different departments of the firm	[15–17]
E6	Considering ecodesign strategies as essential practices	Most of the MSMEs focus only on earning profit and consider environmental issues as a short-term goal. This attitude should be changed and ecodesign strategies should be considered as essential practices for long term	[15, 18]
E7	Including an environmental expert in the product development team	Generally, MSMEs are reluctant to recruit personnel for a specific task. But, the inclusion of an environmental expert can improve the development of eco-friendly products	[19, 20]

(continued)

Table 2 (continued)

Code	Enablers	Short description	Refs.
E8	Considering ecodesign approaches in the initial design phase	Almost 80% of the environmental load of a product is determined in the conceptual design phase. Therefore, ecodesign approaches should be considered in the initial design phase	[3–5]
E9	Making the customers aware about environmental issues	The companies which are based on consumer products and services can make their customers aware of the environmental issues so that the products are used in an eco-friendly manner	[21, 22]
E10	Environmental certifications	Environmental certifications provide a way not only to adopt green practices but also to develop an environmentally friendly infrastructure	[23, 24]

3 Methodology

The methodology of this work is based on the DEMATEL approach. This approach was introduced by Battelle Memorial Institute of Geneva in 1976. This approach has been used in various multi-criteria decision problems to obtain the interrelationship among different factors [25, 26]. DEMATEL divides the factors into cause and effect groups and provides their interrelationship with the help of a causal diagram.

A flow diagram of the research methodology is shown in Fig. 1. Various steps involved in this study are as follows:

Step 1: In this step, various enablers for effective implementation of ecodesign are identified and finalized through an extensive literature survey and opinion of the experts.

Step 2: Form a direct assessment matrix using the judgment of each expert with the help of a linguistic scale. A score is provided to each factor with respect to the linguistic judgment of the experts. The scale is given as:

0—No influence; 1—Low influence; 2—Medium influence; 3—High influence

Step 3: Construct the average matrix after receiving the inputs of all experts. For each expert, a non-negative matrix of the order $n \times n$ is constructed as $X^k = \left[x_{ij}^k\right]$ where k is the number of experts with $1 \leq k \leq P$ and n indicates the number of factors. X^1, X^2, …, X^P.

Are the matrices obtained through P experts? The average matrix $A = \left[a_{ij}\right]$ can be established as:

$$a_{ij} = \frac{1}{P}\sum_{k=1}^{P} x_{ij}^k \tag{1}$$

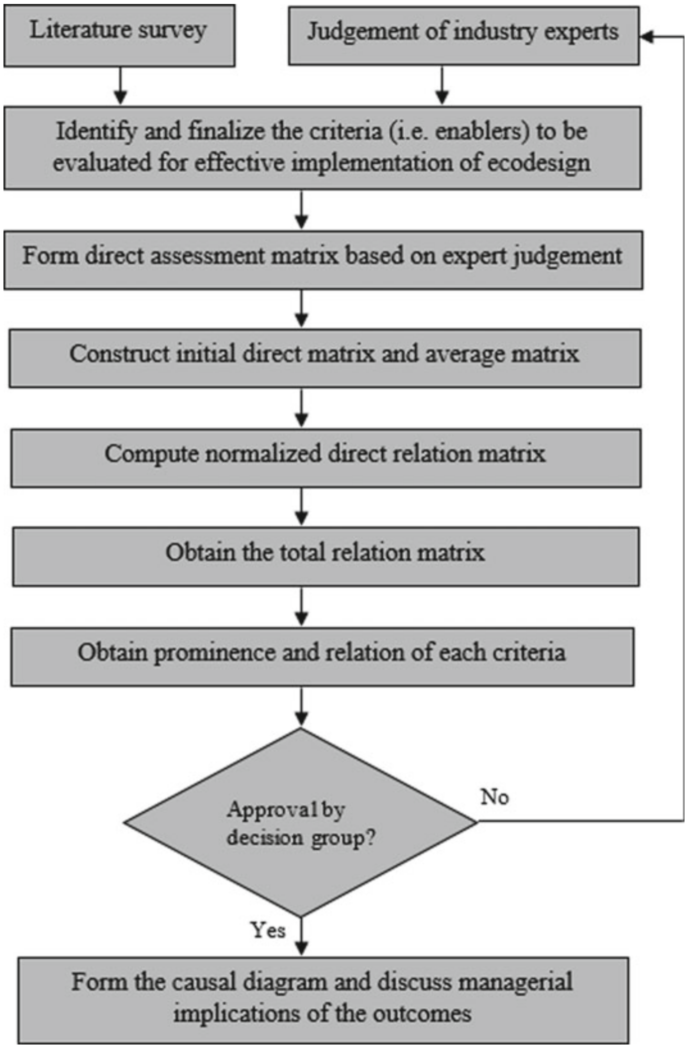

Fig. 1 Flow diagram of the research methodology

Step 4: Compute the normalized direct relation matrix D as $D = A \times B$, where B is given as

$$B = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}}. \tag{2}$$

Each element of matrix D lies within 0 and 1.

Step 5: Calculate total relation matrix T as $T = D\ (I - D)^{-1}$ where I represents identity matrix.

Step 6: Obtain prominence and relation for each factor which is represented by $(r + c)$ and $(r - c)$, respectively. Here, r and c denote the sum of rows and columns of total relation matrix for individual factors, respectively. If r_i be the sum of ith row of matrix T, then it shows the total effect of factor i on other factors. If c_j be the sum of jth column of matrix T, then it shows the total effect received by factor j from the other factors. The sum $(r + c)$ of a factor shows the degree of importance of that factor on the entire system. If $(r - c)$ of a factor is positive, then it is known as 'cause factor' and is known as a receiver if $(r - c)$ is negative.

4 Case Study and Managerial Implications

A case study based on the proposed methodology is carried out in an Indian manufacturing MSME situated in the northern part of India. This company manufactures automotive components such as rings, pistons and connecting rods. This company falls under the medium category of MSME and has an ISO 14001:2015 certification. The company is doing business from the last 40 years and has an eco-friendly state-of-the-art infrastructure spread over 20,000 m^2. The officials showed a keen interest to be a part of this study because of their commitment to adopt and improve the environmentally friendly practices in their production process.

Detailed information of the current study was shared with a team of five experts out of which two are environmental engineers, two senior designers and one production manager. Each of them has experience of at least 10 years with more than 3 years in the case company. All the 10 identified enablers for effective ecodesign implementation were discussed with the experts, and eight enablers (E1 − E8) were finalized. Two enablers (E9 and E10), i.e., 'Making the customers aware about environmental issues' and 'Environmental certifications' were removed because the company does not produce consumer goods and is already registered with ISO 14001:2015 certification. Each expert was asked to provide his linguistic judgment about the relative importance of each enabler on the basic of a linguistic scale as mentioned in Sect. 3. On the basis of the input provided by the experts, the initial direct matrix for each expert is constructed as follows:

$$X^1 = \begin{bmatrix} 0 & 1 & 0 & 3 & 2 & 2 & 2 & 2 \\ 0 & 0 & 1 & 2 & 1 & 2 & 2 & 0 \\ 1 & 2 & 0 & 2 & 1 & 3 & 2 & 3 \\ 3 & 1 & 0 & 0 & 1 & 0 & 2 & 2 \\ 2 & 2 & 3 & 0 & 0 & 1 & 1 & 2 \\ 2 & 2 & 3 & 2 & 2 & 0 & 2 & 3 \\ 2 & 1 & 2 & 3 & 1 & 2 & 0 & 1 \\ 2 & 1 & 1 & 0 & 2 & 1 & 2 & 0 \end{bmatrix} \quad X^2 = \begin{bmatrix} 0 & 0 & 1 & 2 & 2 & 1 & 2 & 0 \\ 1 & 0 & 2 & 3 & 3 & 1 & 2 & 1 \\ 0 & 1 & 0 & 2 & 3 & 3 & 1 & 2 \\ 1 & 3 & 1 & 0 & 1 & 1 & 3 & 1 \\ 3 & 0 & 2 & 1 & 0 & 0 & 1 & 0 \\ 2 & 1 & 3 & 1 & 1 & 0 & 1 & 2 \\ 3 & 2 & 1 & 1 & 1 & 2 & 0 & 3 \\ 1 & 1 & 3 & 1 & 1 & 2 & 0 & 0 \end{bmatrix}$$

$$X^3 = \begin{bmatrix} 0 & 2 & 1 & 1 & 1 & 0 & 2 & 1 \\ 1 & 0 & 2 & 3 & 1 & 1 & 1 & 1 \\ 1 & 3 & 0 & 1 & 1 & 2 & 2 & 1 \\ 1 & 2 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 2 & 2 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 2 & 1 & 1 & 0 & 2 & 1 \\ 1 & 2 & 2 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 2 & 2 & 0 \end{bmatrix} \quad X^4 = \begin{bmatrix} 0 & 1 & 2 & 2 & 1 & 1 & 1 & 1 \\ 2 & 0 & 3 & 2 & 2 & 0 & 1 & 2 \\ 2 & 3 & 0 & 1 & 3 & 3 & 1 & 2 \\ 3 & 3 & 2 & 0 & 2 & 2 & 1 & 0 \\ 1 & 1 & 3 & 2 & 0 & 2 & 2 & 1 \\ 1 & 1 & 3 & 0 & 0 & 0 & 1 & 3 \\ 2 & 1 & 1 & 3 & 2 & 1 & 0 & 2 \\ 0 & 2 & 3 & 2 & 2 & 3 & 1 & 0 \end{bmatrix}$$

$$X^5 = \begin{bmatrix} 0 & 2 & 1 & 1 & 2 & 2 & 1 & 2 \\ 1 & 0 & 3 & 3 & 1 & 1 & 0 & 1 \\ 1 & 2 & 0 & 0 & 3 & 3 & 1 & 2 \\ 1 & 3 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 2 & 2 & 1 & 0 & 1 & 1 & 2 \\ 0 & 2 & 3 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 3 & 1 & 1 & 3 & 2 & 0 \end{bmatrix}$$

The average matrix A is constructed using Eq. (1) and normalized matrix D using Eq. (2) as follows:

$$A = \begin{bmatrix} 0.0 & 1.2 & 1.0 & 1.8 & 1.6 & 1.2 & 1.6 & 1.2 \\ 1.0 & 0.0 & 2.2 & 2.6 & 1.6 & 1.0 & 1.2 & 1.0 \\ 1.0 & 2.2 & 0.0 & 1.2 & 2.2 & 2.8 & 1.4 & 2.0 \\ 1.8 & 2.4 & 1.0 & 0.0 & 1.0 & 1.0 & 1.6 & 1.0 \\ 1.6 & 1.4 & 2.4 & 1.0 & 0.0 & 1.0 & 1 & 1.2 \\ 1.2 & 1.2 & 2.8 & 1.0 & 1.0 & 0.0 & 1.4 & 2.0 \\ 1.8 & 1.4 & 1.4 & 1.8 & 1.0 & 1.2 & 0.0 & 1.6 \\ 1.0 & 1.0 & 2.2 & 1.0 & 1.4 & 2.2 & 1.4 & 0.0 \end{bmatrix}$$

$$D = A \times \frac{1}{\max\limits_{1 \le i \le 8} \sum_{j=1}^{8} a_{ij}}$$

$$= \begin{bmatrix} 0.00 & 0.09 & 0.08 & 0.14 & 0.12 & 0.09 & 0.12 & 0.09 \\ 0.08 & 0.00 & 0.17 & 0.20 & 0.12 & 0.08 & 0.09 & 0.08 \\ 0.08 & 0.17 & 0.00 & 0.09 & 0.17 & 0.22 & 0.11 & 0.15 \\ 0.14 & 0.18 & 0.08 & 0.00 & 0.08 & 0.08 & 0.12 & 0.08 \\ 0.12 & 0.11 & 0.18 & 0.08 & 0.00 & 0.08 & 0.08 & 0.09 \\ 0.09 & 0.09 & 0.22 & 0.08 & 0.08 & 0.00 & 0.11 & 0.15 \\ 0.14 & 0.11 & 0.11 & 0.14 & 0.08 & 0.09 & 0.00 & 0.12 \\ 0.08 & 0.08 & 0.17 & 0.08 & 0.11 & 0.17 & 0.11 & 0.00 \end{bmatrix}$$

Finally, the total relation matrix T is computed as:

$$T = D(I - D)^{-1} = \begin{bmatrix} 0.36 & 0.50 & 0.56 & 0.53 & 0.49 & 0.49 & 0.48 & 0.46 \\ 0.49 & 0.48 & 0.70 & 0.62 & 0.54 & 0.54 & 0.50 & 0.51 \\ 0.56 & 0.70 & 0.67 & 0.62 & 0.66 & 0.74 & 0.59 & 0.65 \\ 0.50 & 0.59 & 0.58 & 0.43 & 0.48 & 0.50 & 0.49 & 0.47 \\ 0.48 & 0.53 & 0.67 & 0.49 & 0.40 & 0.51 & 0.46 & 0.48 \\ 0.50 & 0.56 & 0.76 & 0.53 & 0.52 & 0.49 & 0.53 & 0.58 \\ 0.52 & 0.55 & 0.63 & 0.56 & 0.49 & 0.53 & 0.40 & 0.52 \\ 0.48 & 0.54 & 0.70 & 0.52 & 0.53 & 0.61 & 0.51 & 0.43 \end{bmatrix}$$

Prominence and relation of the enablers calculated using matrix T are given in Table 3. Based on $(r + c)$ values, the degree of importance of the enablers in effective implementation of ecodesign practices is obtained in the order as E3 > E6 > E2 > E8 > E4 > E7 > E5 > E1. Training of designers (E3) comes out to be the most important enabler with a value of 10.46 followed by E6, i.e., considering ecodesign strategies as essential practices with 8.88. Support from the top management (E1) is the least important enabler with a value of 7.76. Considering ecodesign strategies as essential practices (E6), including an environmental expert in product development team (E7) and considering ecodesign approaches in the initial design phase (E8) together form the cause group as they are having positive values of $(r - c)$, whereas support from top management (E1), using life cycle approach to design products (E2), training of designers (E3), collaboration between design domains (E4) and building an information system to exchange data

Table 3 Prominence and relation of the enablers

Enablers	r	c	$r + c$	$r - c$
E1	3.87	3.89	7.76	−0.02
E2	4.38	4.45	8.83	−0.07
E3	5.19	5.27	10.46	−0.08
E4	4.04	4.30	8.34	−0.26
E5	4.02	4.11	8.13	−0.09
E6	4.47	4.41	8.88	0.06
E7	4.2	3.96	8.16	0.24
E8	4.32	4.10	8.42	0.22

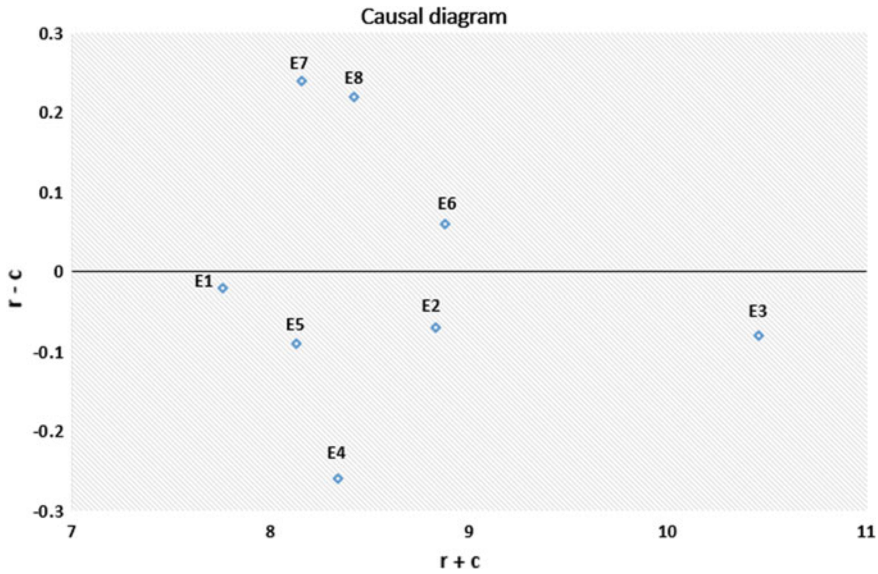

Fig. 2 Causal diagram

(E5) are the enablers that form effect group and fall under receivers category with negative values of $(r - c)$. Cause and effect groups are also shown with the help of a causal diagram in Fig. 2. Support from the top management (E1) is the most independent enabler among all because it neither affects nor gets affected by the other criteria. It happens because many individuals in the case company are self-motivated to learn about eco-friendly practices.

Some important managerial implications are suggested to the case company on the basis of results obtained through the DEMATEL approach. The case company should pay much attention to the causes (E6, E7, E8) in comparison with the receivers (E1, E2, E3, E4, E5). Considering ecodesign strategies as essential practices (E6) is not only the second most important enabler but also a cause factor. Therefore, the company needs to develop a culture in which environmentally friendly practices are treated as a necessity. Including an environmental expert in product development team (E7) is also crucial because it is a cause factor and does not get affected by the other factors. However, the appointment of an environmental expert in the product development team will further enhance two enablers, i.e., training of designers (E3) and collaboration between design domains (E4), i.e., collaboration between environmental and engineering design domains.

5 Conclusion

This study proposes a methodology based on the DEMATEL approach to evaluate the enablers for effective implementation of ecodesign practices in sustainable product development in MSMEs. The proposed methodology is applied in an Indian manufacturing MSME for evaluating the identified enablers. Results show that training of designers is the most important enabler. It provides an opportunity for the designers to learn about various challenges to develop environmentally friendly products and different ecodesign methods and tools to deal with these challenges. Support from the top management is the least important enabler among all identified enablers. Apart from that, the appointment of an environmental expert in the product development team is another essential enabler because an environmental expert can not only assist a designer about the requirement of an eco-friendly product but also act as a link between environmental and engineering design domains.

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