Fostering systematic eco-innovation in an industrial symbiosis environment using DEMATEL

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Abstract: In today's rapidly changing and evolving world, industrial symbiosis acts as an important strategy for the development of any organisation. Industrial symbiosis helps different organisations to pool their resources, discuss their problems, their merits-demerits and also to share their profit. This study was conducted with the objective of understanding the key parameters to enhance the organisational performance in an industrial symbiotic setup. This study collected information from the sugar mill industry, and paper mill and cement industries in Tamil Nadu, India. Decision making trial and evaluation laboratory (DEMATEL) method was used to visualise the impact of different attributes on the company. On the basis of DEMATEL approach solid waste management was identified as a critical area and the organisations need to focus on solid waste management to improve the efficiency in terms of eco-innovation and industrial symbiosis.

Keywords: multiple attribute decision making; DEMATEL; criteria interaction; visualise; sustainability; eco-innovation; industrial symbiosis.

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1 Introduction

Industrial symbiosis (IS) is mainly an agreement or partnership between two or more industries in which the by product of one company acts as the raw material for the other company. It helps companies to decrease the raw material cost and at the same time saves the cost of waste disposal. This idea also helps in waste reduction and reduces environmental pollution. In IS industries should try to locate their plants in such a manner so that the waste product from one plant can be used as the raw material to next plant which ultimately helps in reduction of transportation cost. So this approach is widely used nowadays in order to properly utilise the waste from industries (Puente et al., 2015). International Synergies Limited governs IS at the national scale in the UK. Due to lack of research in this field there is need for operational attributes into a measure structure. This is a new concept so if the companies start following it then they will be in profit both in long term as well as in short term. Industries are not aware about the importance of supply chains and how to uses them (Su et al., 2013). Simboli et al. (2014) indicate that in IS, companies and government should try to help each other and to compensate each others' faults and uses and share their profits. This involves the implementation of tools and methodologies used in national industrial symbiosis programme (NISP). Leigh and Li (2015) proposed valuable insight to develop such a supply chain so that it is cost effective and environmentally friendly and works in such a manner that waste from one company can reach to another company at a time that it can be used effectively. Dong et al. (2017) highlight the relationship among different industries, categories, and different types of waste and show different methods to utilise them effectively. Wu et al. (2017) mainly tries to show different types of redundancies of IS network and they also try to establish stability and reliability on IS. Puente et al. (2015) describe the properties that enhance to highest network when the waste product from one industry or process becomes an income resource for other industries or processes. None of the studies is planned with comprehensive orderly feedback characteristics for eco-innovations or give a clear view on how to enhance IS. Fraccascia et al. (2017) mainly develop technical exchange efficiency in IS and also discuss how to analyse the efficiency. Bacudio et al. (2016) indicated a quantitive approach through which barriers to implementing IS can be analysed. This paper recognises the parameters that improve eco-innovation in the implementation of IS. Due to poor resource management and improper network connection a large volume of resources get wasted every year (Zhe et al., 2016). Thus the objectives formulated for this study are:

- To create proper awareness among firms so that IS is followed and to show its positive result.
- To utilise eco-innovation as an opportunity for developing techniques, and to plan strategy for sustainable growth.

Various analytical and quantitative methods with proper measures are vital. This paper aims to use decision making trial and evaluation laboratory technique (DEMATEL) to find relation between various components within a business organisation. DEMATEL is selected because it considers the entire set of factors instead of particular factors only, and it can establish relationships among different criteria even in complex problems by showing interdependence among unpredictable attributes. The section deals with the eco-innovation and IS of industries. Section 3 deals with the methodology used in the evaluation of aspects and criteria. Section 4 deals with the proposed procedure of criteria assessment. Next section deals with results, showing cause and effect between the criteria and other aspects.

2 Literature review

This section shows the basis of eco-innovation in IS and explains the relation among the stated attributes for evaluation.

2.1 Eco-innovation

Eco-innovation is defined as the development of new innovative ideas, products and methods which will help in sustainable development (Horbach, 2008). Eco-innovation includes pollution prevention systems, renewable energy technologies, eco-design products (Veeramanikandan et al., 2017), waste management equipment, and also the utilisation of biological materials (Kemp, 2010). Soares (2012) indicated that eco-innovation is opportunity of developing techniques and planning strategies for sustainable growth. The fulfilment of eco-innovation is assessed in terms of the environment, profitability, feasibility, and sustainability (Dong et al., 2014). Hansen et al. (2009) defines it as a contribution to sustainable developments, development that combines social, environmental and economic dimensions in truly sustainability-oriented innovation. Dong et al. (2014) defines that eco-innovation includes improved operational processes, more efficient products and organisational practices so that it helps in the development but at the same time does no harm to the environment. The term eco-innovation means the integration of environmental parameters along with the development (Karakaya et al., 2014). Kemp and Pearson (2007) indicate that compared to alternatives, eco-innovation is better for organisations and firms and results in prevention of environmental risk. Eco-innovation has a favourable effect on economic performance and natural environment (Kammerer, 2009). Nowadays, owing to rapid development and industrialisation our ecosystem is also changing rapidly, so innovation should be done to adjust to the changing ecosystem and to protect it (Alegre and Chiva, 2008). Eco-innovation connects the system of innovation and donates to the regeneration of the entire system by taking into consideration both economic and ecological applications (Carrillo-Hermosilla et al., 2010). Eco-innovation must satisfy consumers' demand, with less price, interest and regulatory changes simultaneously (Horbach, 2008). In many industries, eco-innovation is taken under consideration through economic considerations like cost reduction (Barsoumian et al., 2011)). Saxena and Khandelwal (2012) indicated that eco-innovation and IS seek to gain a competitive advantage which also leads to conformation to sustainable growth. The integration of sustainability and innovation related aspects will enhance the yield of an organisation by reducing risks, reducing costs, increasing brand value and reputation, increasing sales and profit margins, and building innovation capabilities (Schaltegger, 2011). Doran and Ryan (2014) dictates that focused firms which are specialised in a uniform kind of activity are better than multitasking firms in eco-innovation. Eco-innovation enhances green supply chain management by supporting the advancement of environmental orientation. Leonidou and Leonidou (2011) shows that industrialists emphasise collaboration with research institutes, which in turn attracts the attention of market for green product. This shows that market has inclination towards eco-product and eco-innovation. Cecere et al. (2014) tries to show the technical path to be used in order to make eco-innovation successful. Soota (2017) proposed and applied QFD and ANP based method to achieve eco-innvation in production development. The above review highlights the various methods, aspects and needs of eco-innovation in products (Soota, 2017; Veeramanikandan et al., 2017), processes (Biju et al., 2017) and systems (Jeng and Lin, 2017).

2.2 Industrial symbiosis

The main aim of IS is efficient and proper use of resources to their maximum extent (Zhe et al., 2016). Bansal and McKnight (2009), indicated that companies have to make extensive research in order to recognise among other companies those that will be directly related to them, IS partners find the different ways and solutions in order to make links with each other and try to overcome the different barriers they will face in supply chain network. IS development mainly depends upon the proper supply chain in a closed loop (Leigh and Li, 2015). IS emphasises that there should be proper awareness created among different firms within industries or between industries to effectively use each others' waste material that will in turn reduce waste and help in environment protection (Chertow, 2000). IS provides the most suitable methodology for sustainable development (Dong et al., 2013). IS provides an alternative method which increases sustainability (i.e., lower resource consumption and lower carbon emissions) through symbiosis networks that results in more efficient energy and material uses (Leigh and Li, 2015). During IS development, proper analysis should be done regarding costs and benefits associated with it, how it is going to change the economy of the industry (Bocken et al., 2014). IS mainly deals with the development of innovative ideas and strategies in order to make proper use of waste from industries through different supply chain networks and scientific innovations (Puente et al., 2015). IS accentuates coordination among different firms in enterprises for the advancement of eco-activities that are good with ecological and financial standards (Chertow, 2000). Irrespective of all these, the benefits of IS also influence the three most important parameters of maintainability (monetary, social and ecological), which in turn encourage the immergence of IS in the eco development. Lombardi and Laybourn (2012) consider IS as one of the most important innovations in which different industries take part in order to know about each others' ability, products, waste products and how these end products can be properly utilised among each other and in turn also be helpful for nature. By concentrating on innovation and learning sharing systems, IS enhances the productivity of materials and also helps in proper utilisation of waste resources and protection of nature (Lombardi and Laybourn, 2012). IS involves a suitable harmony and balance between individual procedures at the firm level and an aggregate technique for the proper supply of the by-products of one company to be used as raw material of other company (Romero and Ruiz, 2014). IS helps in growing links amongst different industries which initially did not communicate with each other and also helps to save money. This may help to build a strong relationship among different countries across the world so that they can unleash each others' positive points and help each other to emerge developed (Bansal and McKnight, 2009; Costa and Ferrao, 2010). Subsequently, it happens only through mutual cooperation, trust and help among different industries. In any case, it is understood that IS helps in the progress of different industries by using their end products efficiently which in turn leads to peace and prosperity in the society (Puente et al., 2015). Moreover, IS involves the proper supply chain network in order to properly coordinate the transportation of products from industry to other within proper time (Mattila et al., 2010). IS helps not only in proper utilisation of waste but also in effective utilisation of energy, carbon dioxide and different types of gases, water discharge, logistics, capacity and expertise (Bichraoui et al., 2013). The main aim of IS is to fully use raw material, to have maximum monetary gain but at the same time do not harm the environment (Jayswal et al., 2011). In this manner, IS is an innovative concept but because of lack of supply chain and coordination among the industries, the waste product and energies from one company cannot reach other companies where it could be used as raw material, so a plan has to be made in order to deal with the problem and develop a model that must be investigated (Ren et al., 2016). Song et al. (2017) tries to emphasise the problem faced by the company during implementation of IS and then to explore and discuss the feasibility for big data approach and how to use it effectively. Halstenber et al. (2017) involves business in IS, and different online platforms are developed to make symbiosis easy and effective. Wu et al. (2016) highlights the drivers and mechanisms for the evolution of IS and to show the environmental benefit of IS.

3 Aspects and criteria

All the criteria and aspects are listed in Table 1. All the aspects or criteria are chosen with the view in mind of environment protection. Table1 shows five different aspects and 25 different criteria (five different criteria under each aspect). Aspects chosen are economically viable for industries. Eco-innovations and IS are the major factors which are taken under consideration while considering these aspects and criteria. Descriptions of each criteria and aspects are given below.

Table 1 The direct and indirect effects of the criteria under each aspect

Aspects	*Criteria*	*Descriptions*
AS1 environment benefits	Recycle of waste resources (Huesemann, 2003; Brown and Buranakarn, 2003)	IS and eco-innovation aim to use waste from a company as the raw material required for production of a new product, hence recycling the waste in an economical and eco-friendly way.
	Design for the environment (EPA, 2013)	Design for the environment includes both product design and supply chain process design, in which, design for a more environmentally friendly product considers the creation of recoverable parts of a product that are durable, repeatedly usable, and environmentally recoverable in disposal at its design and development stage as well as emphasises the importance of product, process and supply chain design to their life cycle impact on the environment.
	Solid waste management (Swedberg, 2014)	Waste from a company as raw material, hence reducing the generated and the requirement of management to dispose of that waste generated.
	Utilisation of raw materials (Wolf, 2010)	IS and eco-innovation intends to use the minimum amount of raw materials for the production process, hence reducing the waste of raw materials and increasing the efficiency of the production.
	Energy recycling (Wong, 2011)	Energy recovery is a process of utilising energy that would normally be wasted, usually by converting it into other forms and storing it for its use in future.

Table 1 The direct and indirect effects of the criteria under each aspect (continued)

Aspects	*Criteria*	*Descriptions*
AS2 Policy benefits	Existing regulation	Existing regulations provides us the relevant contents of information regarding current policies which in turn demands of greener development, also it issues strict norms and guidelines to the polluters which is required.
	Expected regulation	Firms faces a big amount of cost if they produce considering environmental factors, so they may be reluctant to follow some possible regulations.
	Government grants (Sarkar, 2013)	Cost of eco-innovation to the firm also leads to big investment initially, so grants or help from government in funding green activities like elimination of injurious substances, acceptance of eco-friendly product by customer or by providing help to research projects.
	Stakeholder (Post, 2002).	Stakeholders' perception, which equals one if the firm eco-innovated in response to consumer demand is governed by several factors like compability among existing values and new innovation, customer's need and past experiences.
	Voluntary agreement (Jong, 2015.)	Firm take voluntary steps or agreements for environmental beneficiary practices within their sector.
AS3 management	Market structure management (Fooks et al., 2016)	The interconnected characteristics of a market such as number and relative strength of buyers and sellers and degree of collusion among them.
	Enterprise management	Enterprise management in broad terms is the field of organisational development that supports organisations in managing integrally and adapting themselves to the changes of a transformation.
	Waste management (Davidson, 2011)	Use waste from a company as raw material, hence reducing the generated and the requirement of management to dispose of that waste generated
	Information sharing	Information sharing is considered an important approach to increasing organisational efficiency and performance. With advances in information and communication technology, sharing information across organisations has become more feasible.
	Human resource management (Silverthorn, 2009; Collings and Wood, 2009)	Human resource management (HRM or HR) is the management of human resources. It is designed to maximise employee performance in service of an employer's strategic objectives

Table 1 The direct and indirect effects of the criteria under each aspect (continued)

Aspects	*Criteria*	*Descriptions*
AS4 economic values	Growth rate	Growth rates refer to the percentage change of a specific variable within a specific time period, given a certain context.
	Impact of R&D on GDP (Meyer and Peter, 2005)	Innovation drives economic growth. But what fuels innovation? At the heart of it, research and development (R&D) activities allow scientists and researchers to develop new knowledge, techniques, and technologies.
	Capital investment (Garavan et al., 200)	Capital investment refers to funds invested in a firm or enterprise for the purpose of furthering its business objectives.
	Revenue generated (Carcello, 2008)	Revenue is the income that a business has from its normal business activities, usually from the sale of goods and services to customers.
	Price and quality control (Masaaki,1997)	This criterion deals with the construction of a theoretical framework which allows a manufacturer to examine the trade-offs between pricing and quality control issues.
AS5 customer feedback	Customer satisfaction (Gupta et al., 2005)	Customer satisfaction is a marketing term that measures how products or services supplied by a company meet or surpass a customer's expectation.
	Serviceability	Degree to which the servicing of an item can be accomplished with given resources and within a specified timeframe.
	Reverse logistics (Rengel et al., 2002)	Reverse logistics is for all operations related to the reuse of products and materials. It is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal.
	Quality control and assurance (Garvin, 1988)	A system of maintaining standards in manufactured products by testing a sample of the output against the specification.
	Customer acquisition (Saylor, 2004)	Put simply, customer acquisition refers to gaining new consumers. Acquiring new customers involves persuading consumers to purchase a company's products and/or services.

4 Methodology

DEMATEL method was developed in order to tackle complicated problems and to make graphical representation between the factors causing problems, to properly analyse the method to overcome complex problems. It is considered as one of the best visual representations of cause and effect which helps the technicians to overcome the problems (Tzeng et al., 2007). This method mainly focuses to recognise the main factors which effect the performance and structure them in proper frame and then to find an innovative way to overcome the problem (Yang and Weinberg, 2008) or to fetch the connection and dependency among elements (Lin and Tzeng, 2009). In light of Yu and Tseng (2006), Liou et al. (2007), Tzeng et al. (2007), Yang and Weinberg (2008), Wu and Lee (2007) and Shieh et al. (2010), the system of DEMATEL strategy is presented in Figure 1.

Step 1 Experts' opinion is taken into consideration and average *Z* matrix is constructed

In first step a group of *x* experts were asked different questions and *y* factors are developed according to the answer. Each expert was asked to analyse the relationship and impact among different parameters. The impact uptill which the expert conclusion factor an affects on factor b is designated as C_{ab}. The ranking or score is ranged from 0,1, 2, 3 and 4 which indicates the meaning of 'no effect', 'low effect', 'medium effect', 'high effect', 'very high effect' respectively. For every expert, $y * y$ non-negative matrix is developed as $C^o = [C^o_{ab}]$, where o is the experts' number taking part in evaluation process with $1 \le o \le x$. Thus, $C^1, C^2, C^3 \ldots, C^x$ are the matrices from *x* experts.

The average matrix $Z = [Z_{ab}]$ is developed in order to show the judgment of all the experts using equation (1) (Tzeng et al., 2007).

$$Z_{ab} = \frac{1}{x}\sum_{a=1}^{x} C^o_{ab} \tag{1}$$

Step 2 Matrix *E* that is normalised initial direct-relation is calculated

The following process is followed where, $E = [e_{ab}]$, and value of elements lies between [0, 1]. Equation (2)–(5) is used (Yang and Weinberg, 2008; Lin, 2013).

$$E = \lambda * Z \tag{2}$$

Or

$$[e_{ab}]_{y*y} = \lambda [Z_{ab}]_{y*y} \tag{3}$$

where

$$\lambda = \min\left[\frac{1}{\max 1 \le a \le y \sum_{b=1}^{y} |Z_{ab}|}, \frac{1}{\max 1 \le a \le y \sum_{a=1}^{b} |Z_{ab}|}\right] \tag{4}$$

Markov chain theory states that E^a is the powers of matrix *E*, e.g., $E^2, E^3 \ldots E^\infty$ guarantee the final solutions to the matrix inversion as shown below (Tzeng et al., 2007).

$$\lim_{a \to \infty} E^a = [0]_{b \times b} \tag{5}$$

Step 3 Total relation matrix *P* is derived

Equation (6) is utilised properly in order to obtain the total influence matrix *P*, in which, *I* is an $y * y$ identity matrix. The element of p_{ab} denotes the indirect effects that factor '*a*' had on factor '*b*', then the total relationship between each pair is shown by the matrix *P* (Wu and Lee, 2007).

$$P = \lim_{a \to \infty} \left(E + E^2 + ... + E^a \right) = \sum_{a=1}^{\infty} E^x \tag{6}$$

where

$$\begin{aligned} \sum_{a=1}^{\infty} E^x &= E + E^2 + ... + E^m \\ &= E(I-E)^{-1}(I-E)\left(I + E^1 + E^2 + ... + E^{a-1}\right) \\ &= E(I-E)^{-1}\left(I - E^a\right) \\ &= E(I-E)^{-1} \end{aligned} \tag{7}$$

Step 4 Sums of rows and sum of columns of matrix P is calculated

In the total-influence matrix P, the sum of rows and the sum of columns are represented by vectors r and c, respectively [equations (8) and (9). (Lin and Tzeng, 2009)

$$R = [r_x]_{b \times l} = \left(\sum_{y=1}^{b} p_{ab} \right)_{b \times l} \tag{8}$$

$$C = [c_y]'_{l \times b} = \left[\sum_{y=1}^{b} p_{ab} \right]'_{l \times b} \tag{9}$$

where transposition matrix is denoted as $[C_y]'$.

Let r_x as the sum of x^{th} row in matrix P. The r_x value shows the effect produced by factor x on the other factors both directly or indirectly.

Let c_y be the sum of the y^{th} column in matrix P. The c_y value shows the total effect produced by the other factors either directly or indirectly on the factor y. If $y = x$, the value of $(r_x + c_x)$ represents the total effects both given and received by factor x. In contrast, the value of $(r_x - c_x)$ shows the net contribution by factor x on the system. Moreover, when $(r_x - c_x)$ was positive, factor I was a net cause. When $(r_x - c_x)$ was negative, factor was a net receiver (Tzeng et al., 2007; Liou et al., 2007; Yang and Weinberg, 2008; Lee et al., 2009).

Step 5 Set a threshold value (α)

The threshold value was computed by the average of the elements in matrix P, as computed by equation (10). This calculation is done in order to eliminate some of the defective elements in matrix ***P*** (Yang and Weinberg, 2008).

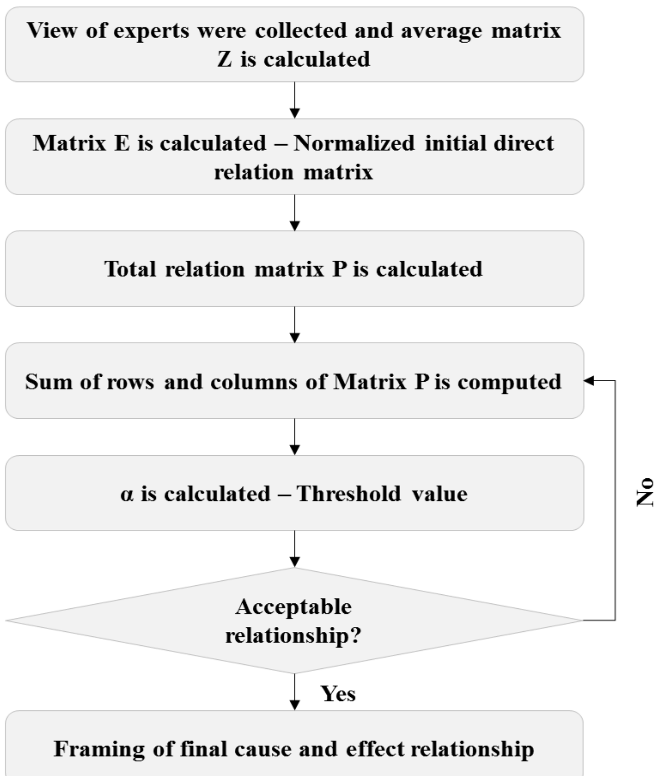
$$\alpha = \frac{\sum_{x=1}^{b} \sum_{y=1}^{b} [p_{xy}]}{N} \tag{10}$$

where N is the total number of elements in the matrix P.

Step 6 A cause and effect relationship diagram is developed

The cause and effect diagram is developed by plotting all coordinate sets of ($r_x + c_x$, $r_x - c_x$) to clearly understand the complex interrelationship and provide information to analyse that which is the most important factors and how its going to effect other factors (Shieh et al., 2010). Yang and Weinberg (2008) indicated that of that p_{xy} is more than that of threshold value α, as shown in cause and effect diagram.

Figure 1 DEMATEL method process flow



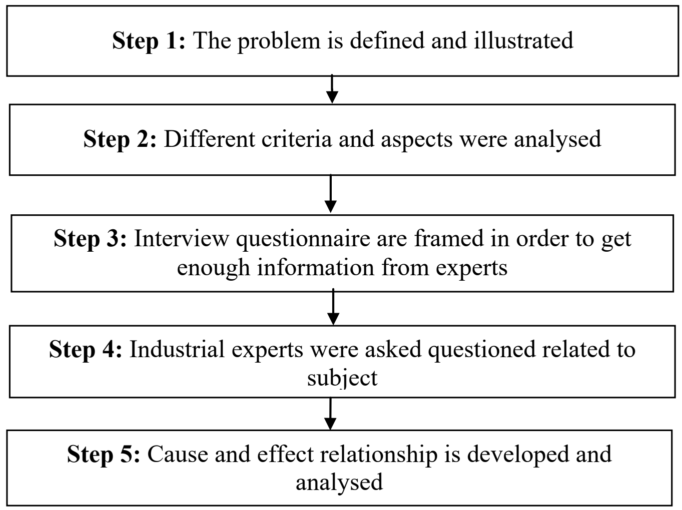
5 Research methodology

The context of the research and application of proposed method to the identified problem are discussed below.

5.1 Research context for IS and eco-innovation

This section is intended to clearly analyse the aspect and criteria as well as to determine the relationship between IS and eco-innovation factors. An overview of the proposed IS and eco-innovation evaluation framework is illustrated in Figure 2. The detailed explanations are given below.

Figure 2 Proposed flowchart of valuation of criteria



5.2 Procedure and the result

The process of IS and eco-innovation evaluation aspects and criteria is discussed in this section. The relationship between different criteria and aspects of IS and eco-innovation is also performed here. The methodologies used and the outcome at each stage will be presented in subsequent section.

5.2.1 The problem statement

Due to rapidly changing and developing world, IS and eco-innovation are considered as one of the major factors in industry in order to cope with competitiveness. Appropriate factors of IS and eco-innovation must be recognised. Hence, an evaluation of IS and eco-innovation helps managements to visualise weaknesses and strengths in terms of IS and eco-innovation. This study shows the relationship of cause and effect among the aspects and criteria and how to they are dependent on each other.

5.2.2 The stage of exploring IS and eco-innovation and measurement of aspects and criteria from literature reviews

Multi-dimensionalities of the IS and eco-innovation assessment factors were derived on the basis of extensive literature review. Based on the reviews, five aspects and five criteria were obtained.

5.2.3 Stage for the development of questionnaire

After obtaining the five aspects and five criteria of IS and eco-innovation, a questionnaire was designed. The questionnaire was reviewed and tested by a group of scholar experts who analysed the validity and importance of questions.

5.2.4 The stage of interviewing experts

Five experts were asked about the parameters we have considered. After the complete questionnaires were answered from the experts, DEMATEL analytical technique was used to show the causal relations and to identify and determine the significant context and criteria. The results of analyses are shown in the next section.

5.2.5 Stage of reviewing the causal relation and identifying the evaluation aspects and criteria

At this stage, DEMATEL method is used to show the complicated relationship and to determine the effect between the five aspects and five criteria determined by the experts in IS and eco-innovation. The computation is divided into two parts in order to get results based on perspectives and criteria. The procedure followed in DEMATEL and the final result obtained will be shown in later stages.

5.2.6 The stage of examining the causal relation and the assessment of aspects and criteria

On the basis of five aspects and 25 criteria stated above, this paper further explains the DEMATEL method to determine the multifaceted connection of aspects and criteria. The computation is divided into two different parts for calculation of aspects and criteria, respectively. The results of each stage are presented as follows. C^o showed the expert opinion for five aspects of expert x, where $C^o = [C^o_{ab}]$.

$$C^1 = \begin{bmatrix} 0 & 2 & 3 & 2 & 4 \\ 1 & 0 & 2 & 3 & 3 \\ 2 & 3 & 0 & 2 & 3 \\ 2 & 3 & 3 & 0 & 4 \\ 2 & 2 & 3 & 3 & 0 \end{bmatrix}, C^2 = \begin{bmatrix} 0 & 2 & 3 & 5 & 3 \\ 4 & 0 & 1 & 4 & 2 \\ 3 & 4 & 0 & 1 & 2 \\ 1 & 2 & 3 & 0 & 3 \\ 2 & 3 & 3 & 2 & 0 \end{bmatrix} C^3 = \begin{bmatrix} 0 & 3 & 4 & 5 & 4 \\ 2 & 0 & 5 & 1 & 3 \\ 1 & 4 & 0 & 2 & 4 \\ 4 & 4 & 3 & 0 & 2 \\ 3 & 3 & 2 & 1 & 0 \end{bmatrix}$$

$$C^4 = \begin{bmatrix} 0 & 4 & 4 & 3 & 4 \\ 3 & 0 & 3 & 2 & 4 \\ 3 & 2 & 0 & 4 & 3 \\ 2 & 4 & 1 & 0 & 3 \\ 3 & 1 & 2 & 3 & 0 \end{bmatrix} C^5 = \begin{bmatrix} 0 & 2 & 3 & 2 & 3 \\ 1 & 0 & 5 & 3 & 2 \\ 3 & 2 & 0 & 3 & 4 \\ 2 & 3 & 2 & 0 & 3 \\ 2 & 1 & 1 & 3 & 0 \end{bmatrix}$$

Step 1 Computation of the average matrix Z is constructed:

$$Z = \begin{bmatrix} 0 & 2.2 & 2.4 & 2.2 & 2.4 \\ 2.6 & 0 & 3 & 3.2 & 2.0 \\ 3.4 & 3.2 & 0 & 2.4 & 2.2 \\ 3.4 & 2.6 & 2.4 & 0 & 2.4 \\ 3.6 & 2.8 & 2.2 & 3 & 0 \end{bmatrix}$$

Step 2 Normalised initial direct-relation matrix E is calculated

$$E = \begin{bmatrix} 0 & 0.169 & 0.184 & 0.169 & 0.184 \\ 0.200 & 0 & 0.230 & 0.246 & 0.153 \\ 0.261 & 0.246 & 0 & 0.184 & 0.169 \\ 0.261 & 0.200 & 0.184 & 0 & 0.184 \\ 0.276 & 0.215 & 0.246 & 0.230 & 0 \end{bmatrix}$$

Step 3 Total relation matrix P is calculated

$$P = \begin{bmatrix} 0.872 & 0.892 & 0.913 & 0.890 & 0.801 \\ 1.157 & 0.849 & 1.047 & 1.045 & 0.868 \\ 1.222 & 1.068 & 0.882 & 1.024 & 0.897 \\ 1.195 & 1.011 & 1.012 & 0.843 & 0.887 \\ 1.344 & 1.142 & 1.175 & 1.149 & 0.835 \end{bmatrix}$$

Step 4 Sum of the rows and column of matrix T is calculated which is shown in Table 2.

Step 5 Computation of threshold value (α)

Threshold value is calculated by the equation (10).

$$\alpha = 25.0314 / 25$$

$$\alpha = 1.0013$$

Step 6 Relationship diagram – cause and effect

The value of p_{ab} from Table 1which is greater than threshold value (1.0013) is represented as p_{ab}* and then cause and effect diagram is constructed for five aspects as shown in Figure 3.

Figure 3 Visualisation of the causal relationship among aspects (see online version for colours)

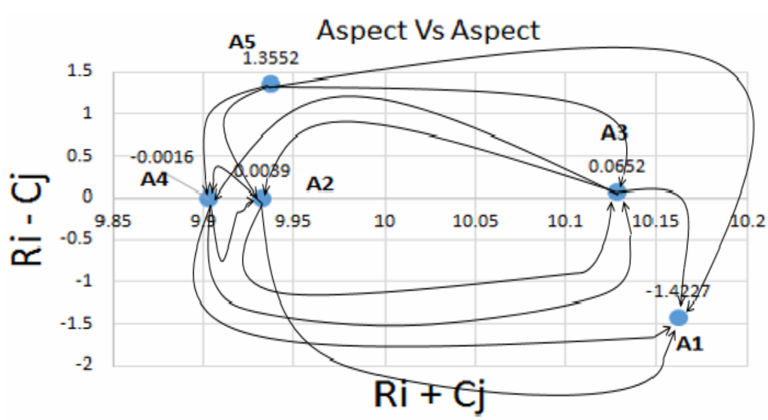


Table 2 The sum and difference of given and data among all aspects

	A1	*A2*	*A3*	*A4*	*A5*	*Ri*	*Cj*	*Ri + Cj*	*Ri – Cj*
A1	.8721	.8923	.9132	.8901	.8018	4.3696	5.7923	10.1619	–1.4227
A2	1.1577*	.8498	1.0473*	1.0450*	.8685	4.9681	4.9642	9.9323	0.0039
A3	1.2228*	1.0687*	.8826	1.0248*	.8979	5.0968	5.0316	10.1284	0.0652
A4	1.1951*	1.0115*	1.0129*	.8431	.8879	4.9506	4.9521	9.9027	–0.0016
A5	1.3446*	1.1420*	1.1756*	1.1492*	.8350	5.6463	4.2911	9.9375	1.3552

Note: The values marked with asterisk (*) in Table 2, denotes the values greater than the threshold value (α) which were greater than (1.0013).

Table 3 Effect of the criteria under each aspect

Criteria	*Ri + Cj*	*Ri – Cj*
Recycle of waste resources (C1)	21.7598	–1.5032
Design for environment (C2)	22.8518	0.4791
Solid waste management (C3)	23.0342	0.3255
Utilisation ratio of raw material (C4)	21.5919	2.4257
Energy recycling (C5)	22.2716	–1.727
Government policy (C6)	16.7006	–1.0203
Stakeholders' involvement (C7)	19.1419	0.2497
Voluntary agreement (C8)	19.754	0.3318
Existing policy (C9)	18.8672	–1.165
Expected policy (C10)	17.6411	1.6038
Market structure management (C11)	17.8056	–1.0843
Enterprise management (C12)	18.6939	0.4099
Waste management (C13)	16.5575	1.4349
Information sharing (C14)	19.4442	–0.2493
Human resource management (C15)	18.1189	0.5112
Growth rate (C16)	5.6396	0.3403
Impact of RandD in GDP (C17)	5.7981	0.6453
Capital investment (C18)	6.375	–1.2975
Revenue generated (C19)	5.9853	0.1384
Price and quantity Control (C20)	6.642	0.1735
Customer satisfaction (C21)	13.2955	0.4969
Serviceability (C22)	13.0577	–1.3326
Reverse logistics (C23)	12.157	0.457
Quality control and assurance (C24)	14.2114	–0.5789
Customer acquisition (C25)	13.3047	0.8675

The substantial criteria were determined under each aspect. In Table 3 effects of direct and indirect criteria are summarised. In Figure 4 to Figure 8 the casual relationship diagrams among criteria are shown.

Figure 4 Environmental benefits criteria's causes-effects diagram (see online version for colours)

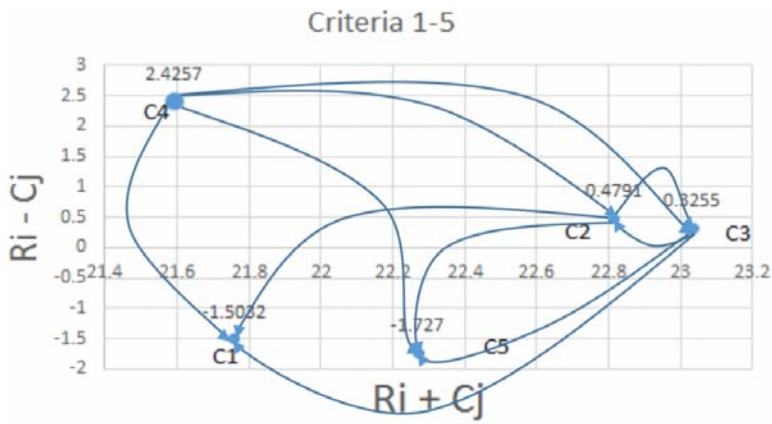


Figure 5 Policy benefits criteria's causes-effects diagram (see online version for colours)

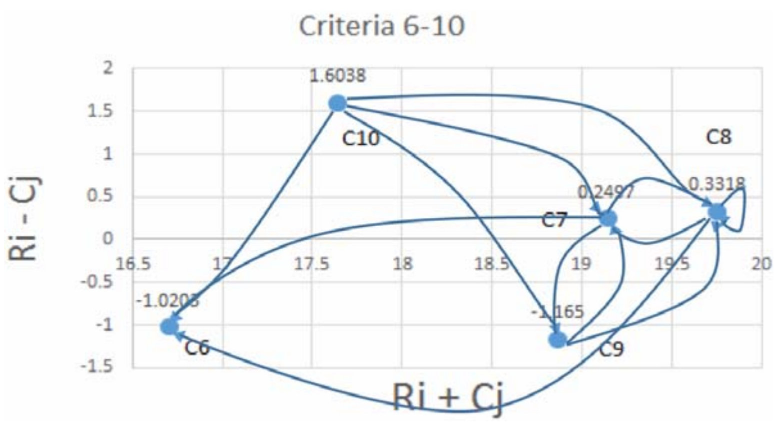


Figure 6 Management benefits criteria's causes-effects diagram (see online version for colours)

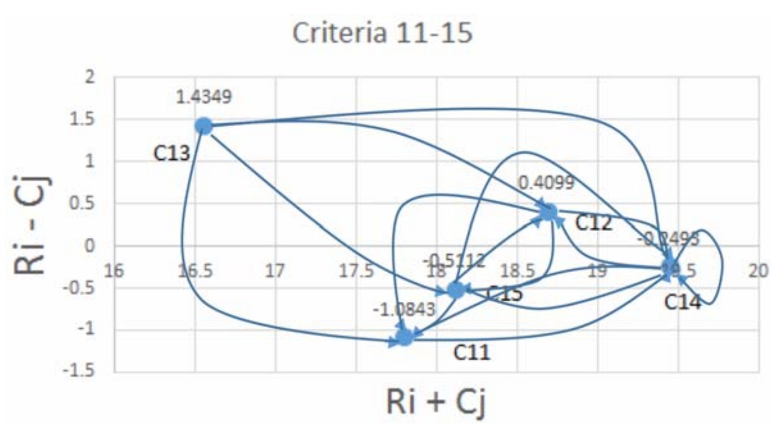


Figure 7 Economic values criteria's causes-effects diagram (see online version for colours)

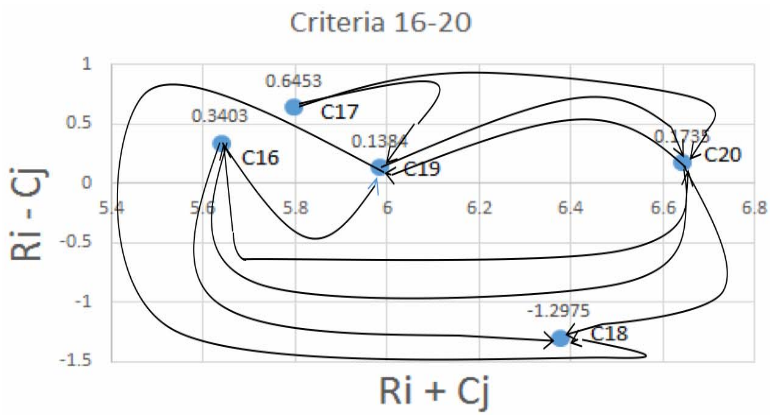
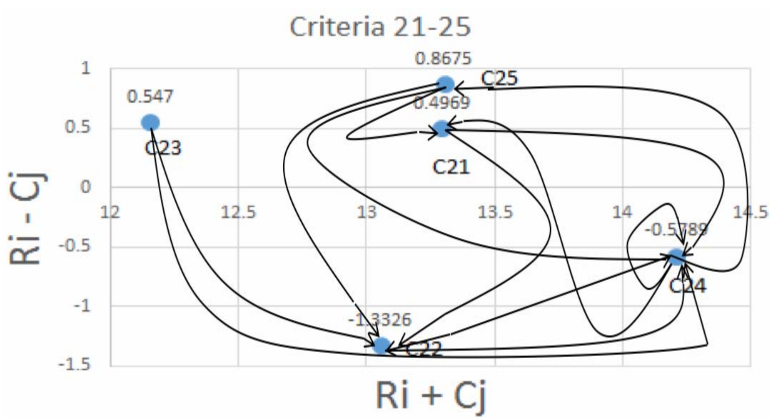


Figure 8 Customer feedbacks criteria's causes-effects diagram (see online version for colours)



6 Discussion and result

The results pertaining to aspects and criteria are discussed below.

6.1 Results on aspects

Importance of aspects is determined by (R + C) values. On the basis of Table 3, i.e., stated below solid waste management (C3) is the most important evaluation criterion with the largest (R + C) value = 23.034, whereas growth rate (C16) has the smallest value = 5.6396. On the basis of (R + C) values, the importance of aspect is prioritised, i.e., A1 > A3 > A5 > A2 > A4.

On the basis of (r – c) values, the five aspects are divided into cause and effect groups:

1 If value of (r – c) was coming positive, such aspects were categorised in cause group. On comparing the r – c value the highest positive (r – c) factors will be having

highest direct effect on the others. This study consists of, policy benefits (A2), management benefits (A3), and customer feedback (A5) are categorised in the cause group, which is having the (r – c) values of 0.0039, 0.0652, and 1.3552 respectively. A3 (management benefits) was having the highest effecting the others.

2 If value of (r – c) was negative, such aspects were categorised in the effect group. In this study, environment benefits (A1) and economic values (A4) were categorised in the effect group, with the (r – c) values of –1.4227 and –0.0016, respectively. And A1 (environment benefits) was the most affected by the other factors (A1), (A2), (A3), and (A5).

6.2 Results on criteria

Table 2 indicates that under environment benefits (A1), this study found that solid waste management (C3) and design for environment (C2) had highest (r + c) values of 23.0342and 22.8158 respectively. Whereas design for environment (C2), utilisation ratio of raw material (C4) and solid waste management (C3) have highest positive (r – c) values of 0.4791, 2.4257 and 0.3255 respectively and that's why they are in cause group. Recycle of waste resources (C1) and energy recycling (C5) have values of –1.5032 and –1.7270 (r – c) respectively that's why they are in effect group. From Figure 5, C4 was the most important criteria because it influenced directly on the other four criteria. Recycle of waste resources (C1), design for environment (C2), solid waste management (C3) and energy recycling (C5).

For the aspect of policy benefits (A2), voluntary agreement (C8), stakeholder involvement (C7), and existing policy (C9) were the three most critical criteria on the basis of higher (r + c) values 19.7540, 19.1419 and 18.8672, respectively. The expected policy (C10), Voluntary agreement (C8) and stakeholder involvement (C7) were having higher positive (r – c) values of 1.6038, 0.3318 and 0.2497, respectively and that's why they are very important criteria. For government policy (C6) and existing policy (C9) with the (r – c) value of –1.165 and –1.0203, respectively were in effect group. From Figure 6, expected policy (C10) is the most important criteria given effect on the other four criteria.

For the aspects of management benefits (A3) in Table 2, information sharing (C14), enterprise management (C12) and human resource management (C15) were the important level of the (r + c) values 19.4442, 18.6939 and 18.1189, respectively. However, on the basis of (r – c) value of 1.4349 and 0.4099 (Figure 7), waste management (C13) and enterprise management (C12) were a net cause. Waste management (C13) was most affected criteria.

According to aspect economic values (A4), price and quantity control (C20) and capital investment (C18) were the two important criteria with highest (r + c) values of 6.642 and 6.375, respectively. As shown in Figure 8, growth rate (C16), impact of RandD in GDP (C17), revenue generated (C19) and price and quantity control (C20) had the positive (r – c) value of 0.3403, 0.6453, 0.1384 and 0.1735 respectively. Growth rate (C16) was the directly affected criteria.

For the aspects of customer feedback (A5), criteria of quality control and assurance (C24) and customer acquisition (C25) had the important level of the (r + c) values 14.2114 and 13.3047, respectively. However, as Figure 9, customer acquisition (C25), reverse logistics (C23) and customer satisfaction (C21) were net cause with the (r – c) value of 0.8675, 0.547 and 0.4969 respectively, and most affected criteria were customer acquisition (C25) and quality control and assurance (C24).

7 Conclusions

This study applied DEMATEL method in order to find the relationship between aspects and criteria for the given manufacturing firm having five aspects and twenty criteria. The three important aspects in cause group that are policy benefits, management benefits, and customer feedback were given more importance and more research and innovative ways should be introduced in order to improve them.

In the whole process of arranging the value of criteria under the three fundamental aspects, it was found that the expected policy (C10), waste management (C13), customer acquisition (C25) and quality control and assurance (C24) were the most critical criteria. So for improving the business in terms of evaluations, industry should utilise more capitals in these fundamental aspects. If in case of industry having scarcity of capital or resources, industry should focus on waste management (C13) as one of the most important criteria in order to properly balance the expected policy and to get the most useful result in evaluation. The major limitation of the current study is the DEMATEL analysis has been done with minimum number of expert opinions. In near future, the study can be done by considering opinions of a wide population. It can be expanded further by conducting SEM analysis for statistically validating the relationships.

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Abbreviation

DEMATEL	Decision making trial and evaluation laboratory
IS	Industrial symbiosis
MADM	Multiple attributes decision making
Z	Average matrix
D	Normalised matrix
T	Total relation matrix
α	Threshold value