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Fuzzy approach to Eco-innovation for Enhancing Business Functions: A Case Study in China

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Abstract

Purpose: Although sustainability is a popular topic in the past decade, there is a lack of research to identify the driving factors for developing countries. The major objective of this study is to investigate the driving factors for achieving eco-innovation.

Design/methodology/approach: An in-depth case study is employed to address the objective outlined above. A Chinese company with more than 1200 employees was selected to address the research question.

Findings: By Fuzzy Decision Making Trial and Evaluation Laboratory (FDEMATEL) and Interpretive Structural Modelling (ISM) analysis, the driving factors for eco-innovation are identified, and the priority of different factors has also been extracted.

Originality/value: This is among the first studies to carry similar analysis regarding eco-innovation. More specifically, this is perhaps the first study to take this approach and to analyse this topic in a developing country.

Keywords: Eco-innovation; Business functions; Fuzzy decision making trial and evaluation laboratory; Interpretive structural modelling.

1. INTRODUCTION

Since the 1980s, an awareness of the Ecological Footprint, which is arguably mainly produced by human beings, has been receiving increased attention. This is because the issue has introduced a series of problems, including shortage of resources and ecological degradation that has stretched the health of the Earth to a worrying limit. The situation is complicated by the growing population. These evolutions force governments to explore policies and programs that support sustainable development. For example, the 2015 United Nations Climate Change Conference that was held in Paris led to the famous agreement to limit the effect of global warming by capping the increase in temperature by 2 degrees Celsius (°C).

One approach or school-of-thought that may contribute to this is eco-innovation, which has gradually become a focus of attention for government, academic and business. According to Rennings (2000), eco-innovation is the act of "developing new ideas, behaviours, products and processes that contribute to a reduction in environmental burdens or to ecologically specified sustainability targets". Developing the appropriate indicator is the key to the evaluation of the eco-innovation ability (or performance) of a company. Generally, we can define environmental performance from a micro or a macro perspective. Micro-level eco-innovation performance can be used to evaluate and compare a firm's operations to the others (Lazaro et al., 2008). Macro-level eco-innovation performance takes micro-level performance indicators into account and considers economic performance (Boons & Wagner, 2009).

Nevertheless, micro-level performance indicators alone are not sufficient at the company level. There is a need to integrate multi-indicators to measure eco-innovation performance. Zoboli (2006) suggested that R&D expenses, expenses on pollution control, production efficiency of natural materials, pollution intensity and reduction of pollutant emissions should be considered when measuring eco-innovation performance of a firm. Many studies have attempted to develop a system of multiple performance indicators on eco-innovation measures of the business practices in developed countries. However, the research in the developing countries is limited (Dong & Shi, 2010). Along with the economic development of those countries in recent years, the awareness of eco-innovation has been soaring (Ockwell et al., 2010). In order to better understand the eco-innovation status of developing countries in this study, a Fuzzy Decision Making Trial and Evaluation Laboratory (FDEMATEL) method is employed to extract causal indicators for evaluating the eco-innovation performance of a company. Specifically, the method incorporates a variety of business functions, namely, Production, Marketing, Research & Development (R&D), Human Resource Management (HRM), and Finance. Then, Interpretive Structural Modelling (ISM) technique is utilised to divide the identified factors into layers of index. To further contribute to the knowledge in this domain, the method is applied to a case company in a developing country. In the last few decades, the growth of China's economy is the more impressive among the developing countries in the world. Likewise, China's energy intensity level considerably exceeds the global average, and thus, eco-innovation plays an increasingly prominent role in the country's overall development plans (Cai & Zhou, 2014). As Tsui (2009) said: "over two decades, research in Chinese management has exploited existing questions, theories, constructs, and methods developed in the Western context. Lagging is exploratory studies to address questions relevant to Chinese firms and to develop theories that offer meaningful explanations of Chinese phenomena". Therefore, the case company of this study is located in China, and her business is agri-business in nature, which directly related to eco-innovation.

The rest of this paper is organised as follows: Literature is reviewed in the next section. Detailed discussion of the research method, i.e., the FDEMATEL, in this paper is provided in

Section 3. Section 4 presents the empirical results of a case study utilising the research method outlined in Section 3. Section 5 discusses the theoretical and managerial implications and conclusions.

2. LITERATURE REVIEW

In the introduction, a broad definition of eco-innovation is provided. In the literature, there are a couple of slightly adjusted versions. Kemp and Foxon (2007b) defined eco-innovation as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use compared to relevant alternatives". Reid and Miedzinski (2008) defined eco-innovation as the "creation of novel and competitively priced goods, processes, systems, services, and procedures that can satisfy human needs and bring quality of life to all people with a lifecycle-wide minimal use of natural resources (material including energy carriers, and surface area) per unit output, and a minimal release of toxic substances". Regardless of which definition should be applied, Hellstrom (2007) suggested that eco-innovation can be considered at firms' technological, social and institutional levels. For example, Cheng et al. (2014) explored the relationship between three types of eco-innovation, namely, process, product, organisational, and attempted to find the inter-relationships between them and their relative impact on business performance based on the resource-based view theory. Eco-innovation is an important driving force to support the sustainable development of companies (Kanda et al., 2015).

For many companies, eco-innovation is a new concept (Kemp & Arundel, 2009; Kemp, 2010) and may lead to varied levels of environmental improvement. Nevertheless, the literature on eco-innovation largely focuses on large and well-known companies (Bos-Brouwers, 2010). For example, Mylan et al. (2015) investigated the impact of eco-innovation in UK milk, beef and bread supermarket chains on their upstream members. Therefore, whether the knowledge can be applied in general is questionable. As a matter of fact, to apply eco-innovation well, the performance it can deliver should be studied first. Ekins (2010) presented a list of indicators of eco-innovation covering a wide area.

Eco-innovation performance is viewed as a composite indicator of environmental performance, economic performance and sustainable competitiveness (Margolis & Walsh, 2003). Not surprisingly, environmental performance is the core of eco-innovation among them, and it has been studied from different perspectives, for example, consumer green behaviours (Jansson et al., 2010). Environmental performance and competitiveness are significantly influenced by different types of eco-innovation with the most common one as organisational, then process, produce and finally end-of-pipe eco-innovation (Dong et al., 2014). For example, Huppes et al. (2008) discussed the ECODRIVE project that introduced different indicators in measuring a company's eco-innovation under different business functions.

Cai and Zhou (2014) developed a conceptual model and tested it on a large database of firms which came from various industries utilising a hierarchical regression analysis. This study reveals that eco-innovation is triggered by internal and external drivers. The effect, even if generated from the customer end, can propagate back to the upstream supply chain members. In this connection, the views from different business functions should be considered. Business functions are particularly important because they can reflect all aspects of the comprehensive function of the company. If it can evaluate the innovation ability of companies from a multi-business function perspective, companies can make better decisions from an environmental perspective. Although the emphasis studied is different, research and development (R&D), finance and human resource management (HRM) are the key business functions in the studies where eco-innovation is being considered. Przychodzen and Przychodzen (2015) explored four types of eco-innovation, which are product, process, market and supply sources. Przychodzen and Przychodzen (2015) also studied their influence on accounting-based measures and suggested that strong asset and financial capabilities are important for the development of eco-innovativeness. Polzin et al. (2016) found that certain finance mobilisation functions of institutional innovation intermediaries can partly overcome financial barriers to eco-innovation. Apart from the financial aspect, Ko et al. (2013) discussed the implications of developing a strategic marketing performance for green markets in Korea when building corporate images.

From the analysis above, there is a lack of theoretical framework that can be employed by companies to evaluate eco-innovation. In addition, a comprehensive performance evaluation that incorporates different business functions is still required. Nevertheless, there is no unique definition of what business functions should be included in a company or along a supply chain. It may be any activity along a supply chain such as purchasing, R&D or sales and marketing (Bowen et al., 2001; 2008; Seuring & Müller, 2008). In addition, other functions such as HRM, accounting, public relations, corporate finance and management control can also be involved (Shrivastava & Hart, 1995; Henri & Journeault, 2010). Schaltegger et al. (2014) investigated the differences between business functions involved in corporate sustainability management and observed that all functions can contribute to the eco-innovation of a company. Corporate functional strategy, including Product, Marketing, HRM, R&D, and Finance, aims to coordinate the operations among different functional units to minimise conflicts between them and to integrate the functional units well. In this connection, using corporate functional strategy to integrate different business functions is the theoretical basis for this study. The five business functions are included and further details will be given in Section 3. Following the above logic, a list of factors in relation to the five business functions can be identified.

The next question is how to make the evaluation from a list of factors to quantifiable indicator(s) for comparison or making decisions. The difficulty mainly links to the subjective evaluation particularly on the qualitative factors, and the multiple perspective of the objective function (e.g., Tseng, 2011a). The literature suggests many similar methods that point to the measurement of imprecise information and proposes fuzzy logic (or similar method) to handle the data. To enhance the quality of feasible alternatives, Baležentis and Zeng (2013) applied the interval-valued fuzzy numbers to assess uncertainty in multi-criteria decision making. Wu et al. (2015) integrated interval-valued triangular fuzzy number and grey relational analysis (GRA) method to evaluate Taiwan's high-tech electronics industry green supply chain. Horlings and Marsden (2011) also provided guidelines for eco-innovation through special dynamic organisation performance evaluation with GRA method. In addition, Wu et al. (2016a) used the fuzzy expert method (FDM) and grey Delphi method (GDM) to assess supply chain uncertainty and risk. However, Cornelis et al. (2006) revealed that several studies have debated that the presentation of linguistic expressions in the form of an ordinary fuzzy set is inadequately convincing and clear. Therefore, in this study, Interpretive Structural Modelling (ISM) is employed to supplement the traditional fuzzy-oriented methods.

ISM can help researchers and managers deeply understand the relationship among key issues (Saxena and Vrat, 1992). Warfield (1974) noted that the ISM theory is based on discrete mathematics, social sciences, graph theory, group decision-making and computer assistance. ISM can be used as a qualitative tool and a modelling technique to analyse the effect of one element (Wang et al., 2008) and deeply understand these relationships and their levels. It is not uncommon to come across difficulties when dealing with complex problems. The complexity is normally due to the large problem size that includes many parameters; hence, the interactions among these parameters are difficult to model. ISM is an example that aids in the identification of a structure within such a complex system (Attri et al., 2013). Thus, this study identifies the factors that can influence eco-innovation using fuzzy DEMATEL (FDEMATEL), and the factors will be layered using the ISM method. The proposed method was applied in a case study to evaluate the practical implications of the proposed framework.

3. RESEARCH METHOD

This study explores eco-innovation for business functions based on the proposed business functions and criteria. A case study in China is employed to help understand the critical factors to achieve eco-innovation. Development of these criteria is further discussed in Section 3.1. With this set of criteria, FDEMATEL and ISM are used to improve the accuracy of decision and the reliability of the study. The proposed analytic procedures are presented in Section 3.2 and Section 3.3.

3.1. Proposed Business Functions and Criteria

As shown in Table 1, there are five business functions proposed in this study. To understand the 43 criteria under these 5 functions, there is a need to understand why they are involved. First, Handfield et al. (2005) suggested that environmental quality of products is important to the environmental performance of a company and that companies should control the influence of product design to the environment along their supply chains. Supply chain activities are thus crucial to reduce environmental impacts of the final products (Darnall et al., 2008). In this connection, Product (A1) is an essential capability to reflect the company eco-innovation ability (Ekins, 2010; Triguero et al., 2013; Cheng et al., 2014). In order to assess companies eco-innovation behavior from the aspects of product， some studies have proposed possessing integral approach of green production (C1), generating added-value at farm level (C2), maintaining the companies' flexibility and adaptability to ecologies and places (C3), promoting green product to the community (C4), preventing harmful materials utilisation (C5) (Horlings & Marsden, 2011; Wu et al., 2015), improving health and safety with green purchasing (C6), adopting recycling approach to reduce agri-waste (C7) and complying with environmental standards (C8), raising service quality by launching green product (C9) (Lin et al., 2014; Wu et al., 2016; Wu et al., 2016).

The second business function is Marketing (A2). The basic principles of contemporary marketing is one of the foundations of the policies and procedures of companies, which emphasise the importance of adapting consumer and profits orientation by integrating marketing functions throughout the organisation's key operating areas (McKitterick, 1957). Most companies are keen to address information from marketing function in order to better promote new product development decision (Gupta et al., 1985). Marketing function (A2) thus plays an important role in eco-innovation (Scarpellini et al., 2016). Hence, previous studies have proposed exploring marketing through expanding intensity of market competition for promoting green products (C10), concerning consumer environmental requirements and preferences (C11), establishing special department responsible for marketing green products (C12), using local resources to develop agri-supply chain networks (C13), offering on-time agri-service (C14), market pull for green products (C15), practicing green purchasing concept to set up the price strategy (C16), launching sustainable packaging (C17), implementing E-commerce to enhance new market share (C18) and utilising green organisation to generate the market needs (C19) (Azzone & Noci, 1998; Tseng, 2011a; Horlings & Marsden, 2011; Wu et al., 2015; Wu et al., 2016).

Obviously, marketing function cannot be practised without people. Gupta and Singhal (1993) stated that "… people, not products, are an innovative company's major asset". HRM is understood to be critical to corporate entrepreneurship (Hayton, 2005). Wong et al. (2013) noted that HRM has a vital role to the performance of the company organisation. Therefore, HRM (A3) has an important influence on company innovation (Lewicka, 2013; Peters, 2014).

Mishra et al. (2014) discussed the need for green HRM initiatives as an innovative approach in public Companies. Florén et al. (2016) explore the relationship between HRM practices and entrepreneurial orientation. Several criteria address the HRM, namely, encouraging employee interaction in environmental practices, both formally and informally (C20), abilities to perform organizational adjustments (C21), environmental awareness of sales staffs (C22), facing on stakeholder pressure with positive attitude (C23), providing employee education and skills development (C24), stimulating employee aggressive participation (C25), accepting the proposed suggestions from employees (C26) and enhancing green activities within organization through internal competition (C27) (Azzone & Noci, 1998; Brunnermeier & Cohen, 2003; Tseng, 2011a; Wu et al., 2015; Wu et al., 2016; Wu et al., 2016).

The next identified business function is the R&D function (A4) regarding the performance of companies' eco-innovation. The level of technological capability acquired from R&D activities and the quality of knowledge management are important for production as well as diffusion of eco-innovation (Löschel, 2002; Popp et al., 2011). It is found that environmental policies and subsidies to R&D are the most important drivers of eco-innovation (Costantini et al., 2015). Therefore, in the measure of company eco-innovation, R&D function (A4) is one of the most important aspects. Related criteria are explored in some studies. Collaborating with research institutes, agencies and universities (C28), applying environmental patent (C29), setting up environmental R&D (C30), monitoring the pollution control and protection (C31), certifying eco-labeling (C32), applying eco-system to create added value for humans and nature (C33), adopting flexible and cleaner technology in R&D (C34), designing reverse logistics procedure (C35) and developing optimal inventory management (C36) (Tseng, 2011a; Horlings & Marsden, 2011; Wu et al., 2015; Wu et al., 2016; Wu et al., 2016).

As mentioned earlier, survival in the marketplace is crucial to companies. If a company cannot survive, it is meaningless to mention environmental performance. Existing literature has shown that the relationship of eco-innovative activities and financial performance are tightly coupled to each other (Semenova & Hassel, 2008; Heras-Saizarbitoria et al., 2011). The ability of companies to introduce eco-innovation is becoming more important and can influence financial gains (Jansson, 2011). In this connection, Finance function (A5) is an important factor of company performance (Cheng et al., 2014). Przychodzen & Przychodzen (2015) suggested that it is a pre-requisite for the development of eco-innovation. Several operations in eco-innovation may assist a corporate to attain the financial capability from accessing to exist subsidies and fiscal incentives (C37), gathering financial support from investors (C38), enabling recognize potential revenue in green production (C39), controlling capital efficiency (C40), generating annual growth in revenue (C41), decreasing cost of revenue (C42) and increasing profit margin (C43) (Lin et al., 2014; Wu et al., 2015; Wu et al., 2016).

The proposed evaluation aspects and criteria can be seen in Table 1.

Table 1: Proposed evaluation business functions and criteria.

Business Functions	Criteria	References
Product (A1)	Possessing integral approach of green production (C1) Generating added-value at farm level (C2) Maintaining the companies' flexibility and adaptability to ecologies and places (C3) Promoting green product to the community (C4) Preventing harmful materials utilisation (C5) Improving health and safety with green purchasing (C6) Adopting recycling approach to reduce agri-waste (C7) Complying with environmental standards (C8) Raising service quality by launching green product (C9)	Lin et al., 2014; Wu et al., 2016; Wu et al., 2016
Marketing (A2)	Expanding intensity of market competition for promoting green products (C10) Concerning consumer environmental requirements and preferences (C11) Establishing special department responsible for marketing green products (C12) Using local resources to develop agri-supply chain networks (C13) Offering on-time agri-service (C14) Market pull for green products (C15) Practicing green purchasing concept to set up the price strategy (C16) Launching sustainable packaging (C17) Implementing E-commerce to enhance new market share (C18) Utilising green organisation to generate the market needs (C19)	Azzone & Noci, 1998; Tseng, 2011a; Horlings & Marsden, 2011; Wu et al., 2015; Wu et al., 2016
HRM (A3)	Encouraging employee interaction in environmental practices, both formally and informally (C20) Abilities to perform organisational adjustments (C21) Environmental awareness of sales staffs (C22) Facing on stakeholder pressure with positive attitude (C23) Providing employee education and skills development (C24) Stimulating employee aggressive participation (C25) Accepting the proposed suggestions from employees (C26) Enhancing green activities within organisation through internal competition (C27)	Azzone & Noci, 1998; Brunnermeier & Cohen, 2003; Tseng, 2011a; Wu et al., 2015; Wu et al., 2016; Wu et al., 2016
R&D (A4)	Collaborating with research institutes, agencies and universities (C28) Applying environmental patent (C29) Setting up environmental R&D (C30) Monitoring the pollution control and protection (C31) Certifying eco-labelling (C32) Applying eco-system to create added-value for humans and nature (C33)	Tseng, 2011a; Horlings & Marsden, 2011; Wu et al., 2015; Wu et al., 2016; Wu et al., 2016

	Adopting flexible and cleaner technology in R&D (C34) Designing reverse logistics procedure (C35) Developing optimal inventory management (C36)	
Finance (A5)	Access to existing subsidies and fiscal incentives (C37) Gathering financial support from investors (C38) Enabling recognise potential revenue in green production (C39) Controlling capital efficiency (C40) Generating annual growth in revenue (C41) Decreasing cost of revenue (C42) Increasing profit margin (C43)	Lin et al., 2014; Wu et al., 2015; Wu et al., 2016

The 43 sub-criteria are identified from the literature. They are also discussed and confirmed with the experts in the case company, so that they are reliable in practice. The background of the case is discussed in Section 4.

3.2 FDEMATEL Method

The FDEMATEL method combines the operations of DEMATEL and fuzzy logic. This approach enables a visual analysis through a visual diagram. Hence, the FDEMATEL is a tool to assist in solving complicated system problems in various areas (Tseng, 2011b; Wu et al., 2015). FDEMATEL helps solve the uncertainty when analysing the causal relations among the factors (Luthra et al., 2016). Assume that initially there are sets of attributes $S = \{ S_i | i = 1, 2, \cdots, n \}$ and pairwise inter-relations. The linguistic scale is then implemented into the evaluation assessment, as displayed in Table 2.

Table 2: Linguistic scales for corresponding TFNs.

Scales	Linguistic preferences	Corresponding triangular fuzzy numbers
1	No influence/importance	(0, 0.1, 0.3)
2	Very low influence/importance	(0.1, 0.3, 0.5)
3	Low influence/importance	(0.3, 0.5, 0.7)
4	High influence/importance	(0.5, 0.7, 0.9)
5	Very high influence/importance	(0.7, 0.9, 1.0)

Suppose that there are *k* respondents, and the linguistic scale must be transferred to triangular fuzzy numbers $\overline{\mu}_{xy} = (\mu_{xy}^{ak}, \mu_{xy}^{bk}, \mu_{xy}^{ck})$, which represent the degree to which attribute *x* affects attribute *y* in the *k*th response. The defuzzification process requires triangular fuzzy numbers to be converted into crisp values (Lin et al., 2014). This study adopted Max-Min to normalise the triangular fuzzy numbers before obtaining the completed crisp values. The Max-Min normalisation process follows the equation below:

$$\tau\mu_{xy}^{ak} = (\mu_{xy}^{ak} - \min \mu_{xy}^{ak}) / \Delta_{\min}^{\max}$$

$$\tau\mu_{xy}^{bk} = (\mu_{xy}^{bk} - \min \mu_{xy}^{ak}) / \Delta_{\min}^{\max}$$

$$\tau\mu_{xy}^{ck} = (\mu_{xy}^{ck} - \min \mu_{xy}^{ak}) / \Delta_{\min}^{\max} \quad (1)$$

where $\Delta_{\min}^{\max} = (\max \mu_{xy}^{ck} - \min \mu_{xy}^{ak})$

Identifying the left (*l*) and right (*r*) normalised value, we have the following:

$$\tau l_{xy}^{k} = \tau\mu_{xy}^{bk} / (1 + \tau\mu_{xy}^{bk} - \tau\mu_{xy}^{ak})$$

$$\tau r_{xy}^{k} = \tau\mu_{xy}^{ck} / (1 + \tau\mu_{xy}^{ck} - \tau\mu_{xy}^{bk}) \quad (2)$$

Then, gathering the total normalised crisp values (τ_{xy}^{k}):

$$\tau_{xy}^{k} = [\tau l_{xy}^{k} \times (1 - \tau l_{xy}^{k}) + (\tau r_{xy}^{k})^2] / [1 - \tau r_{xy}^{k} + \tau l_{xy}^{k}] \quad (3)$$

Attaining the crisp values:

$$\sigma_{xy}^{k} = \min \mu_{xy}^{ak} + \tau_{xy}^{k} \times \Delta_{\min}^{\max} \quad (4)$$

The final step of the transformation is to aggregate the crisp values:

$$\sigma_{xy} = \sum_{1}^{k} \tau_{xy}^{k} / k \quad (5)$$

To arrange these crisp values in a pairwise comparison and express them as a direct relation matrix $F_{n\times n}^{d}$, the matrix can be rewritten as $F^{d} = [\sigma_{xy}]_{n\times n}$. Subsequently, the direct matrix F^{d} must be normalised into F^{n}, and the normalised matrix F^{n} can be obtained from the following equation:

$$F^{n} = \forall \times F^{d}, \quad (6)$$

where $\forall = 1 / \max_{1\le x\le n} \sum_{y=1}^{n} \sigma_{xy}, \quad x, y = 1, 2, \cdots, n$

Once the normalised matrix F^{n} is obtained, it must be correlated with the identity matrix to obtain the total relation matrix F^{t}, as in the following computation:

$$F^{t} = F^{n} \times (M - F^{n})^{-1}, \quad (7)$$

where *M* is the identity matrix

Finally, the sums of the rows and columns in the total relation matrix are used to acquire the vectors *D* and *R*, respectively. The computation of vectors is obtained using the following equations:

$$F^{t} = [\sigma_{xy}^{t}]_{n\times n}, \quad x, y = 1, 2, \cdots, n$$

$$D = [\sum_{x=1}^{n} \sigma_{xy}^{t}]_{n\times 1} = [\sigma_{x}^{t}]_{n\times 1}$$

$$R = [\sum_{y=1}^{n} \sigma_{xy}^{t}]_{1\times n} = [\sigma_{y}^{t}]_{1\times n} \quad (8)$$

Thus, the causal diagram is produced. The vertical axis, (*D* - *R*), represents the role of the attribute. If (*D* - *R*) is negative, the attribute is considered to be the effect, whereas if (*D* - *R*) is positive, the attribute is considered to be the cause. (*D* + *R*) is the horizontal axis and represents the importance of the attributes.

3.3 ISM

Through ISM modelling, the specific relationship and overall structure can be visualised in a diagram. The procedures to conduct ISM are summarised as follows:

a. Obtain a list of the criteria (and sub-criteria) considered for the problem. Define each criterion (and sub-criterion) as e_i, $i = 1, 2, \cdots, n$ (Lee et al., 2010).

b. Construct a relation matrix that shows the relationship between the criteria (and sub-criteria) (Lee et al., 2010). A relation matrix is prepared according to the opinion of the experts (Eswarlal et al., 2011). Data can be collected asking questions such as, "Does the variable e_i influence the variable e_j?" If the answer is "yes", then $r_{ij} = 1$; otherwise, $r_{ij} = 0$. The general structure of the relation matrix is illustrated below:

$$MATRIX \quad S: \begin{array}{c} \\ e_1 \\ e_2 \\ \vdots \\ e_n \end{array} \begin{array}{c} \begin{array}{cccc} e_1 & e_2 & \cdots & e_n \end{array} \\ \begin{bmatrix} 0 & \rho_{12} & \cdots & \rho_{1n} \\ \rho_{21} & 0 & \cdots & \rho_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{n1} & \rho_{n2} & \cdots & 0 \end{bmatrix} \end{array}$$

$i = 1, 2, \cdots, n; j = 1, 2, \cdots, n.$

where e_i is the *i*th element in the system, r_{ij} denotes the relationship between the *i*th and *j*th elements, and *S* is the relation matrix (Huang et al., 2005). Then, the reachability matrix can be calculated using Eqs. (9) and (10).

$$N = S + I \quad (9)$$

$$N^* = N^k = N^{K+1}, \quad k > 1 \quad (10)$$

where *I* is the unit matrix, *k* denotes the powers, and N^* is the final reachability matrix. The reachability set is then calculated and the priority is set based on Eqs. (11) and (12) as follows:

$$A(t_i) = \{t_j \mid m'_{ij} = 1\} \quad (11)$$

$$B(t_i) = \{t_j \mid m'_{ij} = 1\} \quad (12)$$

where m_{ij} denotes the value of the *i*th row and the *j*th column. Then, from Eq. (13), the levels and relationships between the elements can be determined and the structure of the elements' relationships can also be expressed using the graph (Shahbandarzadeh &

Ghorbanpour, 2011).

$$B(t_i) \cap A(t_i) = B(t_i) \tag{13}$$

4. Case Study and Results

4.1 Case background

To examine the effectiveness of the proposed method, it is applied to a case company. The case company, Company L, is a leading agricultural company in the Liaoning Province of China. Company L was established in 2010 with hundreds of million RMB capitals. There are ten independent subsidiary companies, with over 1200 employees. Her business spans across the whole supply chain in the industry, including supermarkets, distributions centres, and farms. Company L is committed to increase farmers' income and to improve farmers' quality of life. Company L builds the infrastructure for 123 agricultural companies in order to attempt to build an industry-wide chain, rather than just a supply chain. This initiative can integrate the resource of the business units involved and takes sustainability into consideration.

Company L is considered as best-in-class company in the industry by local government. Company L positively responds to national policy and pays attention to eco-innovation, aiming at quality first in production and to enhance eco-innovation behaviour. Nevertheless, a suitable evaluation of eco-innovation performance and a mechanism is still lacking. This may be even more serious for Chinese companies because the awareness of eco-innovation is lagging behind the developed countries. Several researchers have applied traditional statistical methods to evaluate such performance, but encountered difficulties in a complicated Chinese context. In this connection, this study combines the FDEMATEL and ISM methods associated with adequate inputs from experts to acquire a foundation for eco-innovation performance.

To collection data regarding the five business functions and the associated 43 sub-criteria, a survey was used to collect expert opinion from Company L. To verify that the survey is reliable and can is reflective practically, 12 employees from Company L were invited to participate in the data collection process. They are ranked as top management or managers of the company and her subsidiaries. To eliminate any potential issue with the survey questions, a working meeting was organising prior to the actual data collection phase. The meeting aimed to introduce the research and survey to the participants, and addressed any issues raised by them. The participants were contacted again a week after the meeting to fill in the questions. After the data were collected, the procedures outlined in Section 3.2 and 3.3 are followed in order to produce the results to be discussed in the next section.

4.2 Result analysis

4.2.1 FDEMATEL analysis

Following the procedures in Section 3.2, Table 3 presents the interactive evaluation of aspects based on the experts' judgement. These functions can be mapped into the causal diagram by adopting the coordinates [(*D*+ *R*), (*D* - *R*)], as displayed in Figure 1. The diagram reveals that A1 is the driving factor for eco-innovation. It is because of their (*D*-*R*) values are positive, whereas the (*D*+R) are negative. The physical meaning is that they are critical factors that can influence on the overall achievements of the organisation. In addition, A2, A4 and A5 are denotes the core attributes. This means they are essential factors for improvement even if their influence is less significant than A1. Finally, A3 represents voluntary attribute, which means its importance is not so significant to the organisation, despite its high influence. In other words, the priority of the factors involved should be in the following sequence: A1, A2/A4/A5, A3. Here, we consider A2, A4, and A5 are of similar importance because form Figure 1 there is no distinctive difference between them.

Table 3 Causal group for the five business functions.

	FDEMATEL			
	D	*R*	*D*+*R*	*D*-*R*
A1	10.538	9.814	20.352	0.724
A2	10.249	10.713	20.962	(0.464)
A3	9.069	7.743	16.812	1.326
A4	9.968	10.729	20.698	(0.761)
A5	9.582	10.407	19.988	(0.825)

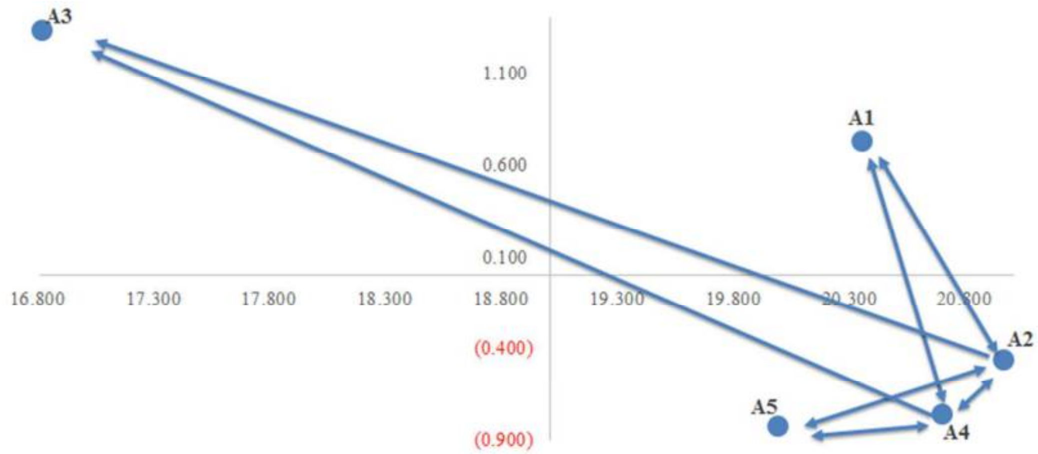

Figure 1. The causal diagram for business functions

Then, Table 4 presents the aggregated causal group for the 43 sub-criteria. The causal diagram is mapped based on the coordinates [(*D*+*R*), (*D*-*R*)] listed in Table 4. Once the mapping is completed, the decisive attributes are explored as shown in Figure 2. A total of 13 decisive attributes that allow companies to enhance eco-innovation fall onto the first quadrant in Figure 2. The analysis identifies C6, C8 and C10 et al. as the driving attributes for eco-innovation, as they are assigned greater influence than other attributes based on the analysis.

Moreover, attributes, C2, C3, C4 and C5 et al. are located in the core problem quadrant, which represents an essential need for improvement, although the improvement processes must first amend the driving attributes.

Table 4 Aggregated causal group for sub-criteria.

	FDMATEL			
	D	*R*	*D+R*	*D-R*
C1	1.78	2.45	4.24	(0.67)
C2	1.47	1.69	3.16	(0.22)
C3	1.55	1.93	3.48	(0.38)
C4	1.67	1.93	3.60	(0.26)
C5	1.66	1.78	3.44	(0.12)
C6	1.92	1.57	3.49	0.35
C7	1.58	1.27	2.85	0.30
C8	1.76	1.28	3.04	0.48
C9	1.73	1.43	3.15	0.30
C10	1.84	1.43	3.27	0.41
C11	1.74	1.52	3.27	0.22
C12	1.78	1.58	3.36	0.20
C13	1.62	1.40	3.02	0.22
C14	1.44	1.38	2.82	0.05
C15	1.77	1.71	3.47	0.06
C16	1.56	1.69	3.25	(0.13)
C17	1.56	1.40	2.96	0.15
C18	1.51	1.44	2.95	0.08
C19	1.69	1.44	3.13	0.24
C20	1.27	1.48	2.76	(0.21)
C21	1.04	1.27	2.31	(0.24)
C22	1.40	1.51	2.90	(0.11)
C23	1.05	1.10	2.15	(0.05)
C24	1.23	1.39	2.62	(0.16)
C25	1.17	1.11	2.28	0.07
C26	1.29	1.26	2.55	0.03
C27	1.00	1.12	2.12	(0.12)
C28	1.35	1.52	2.87	(0.16)
C29	1.41	1.46	2.87	(0.05)
C30	1.50	1.42	2.91	0.08
C31	1.51	1.40	2.91	0.11
C32	1.57	1.84	3.42	(0.27)
C33	1.69	1.84	3.53	(0.16)
C34	1.34	1.74	3.07	(0.40)
C35	1.01	0.98	1.98	0.03
C36	0.85	0.61	1.46	0.24
C37	1.14	1.62	2.76	(0.49)
C38	1.11	1.42	2.53	(0.30)

C39	1.22	1.14	2.36	0.08
C40	1.12	0.89	2.02	0.23
C41	1.21	1.24	2.45	(0.04)
C42	1.07	0.72	1.79	0.35
C43	1.05	0.80	1.86	0.25

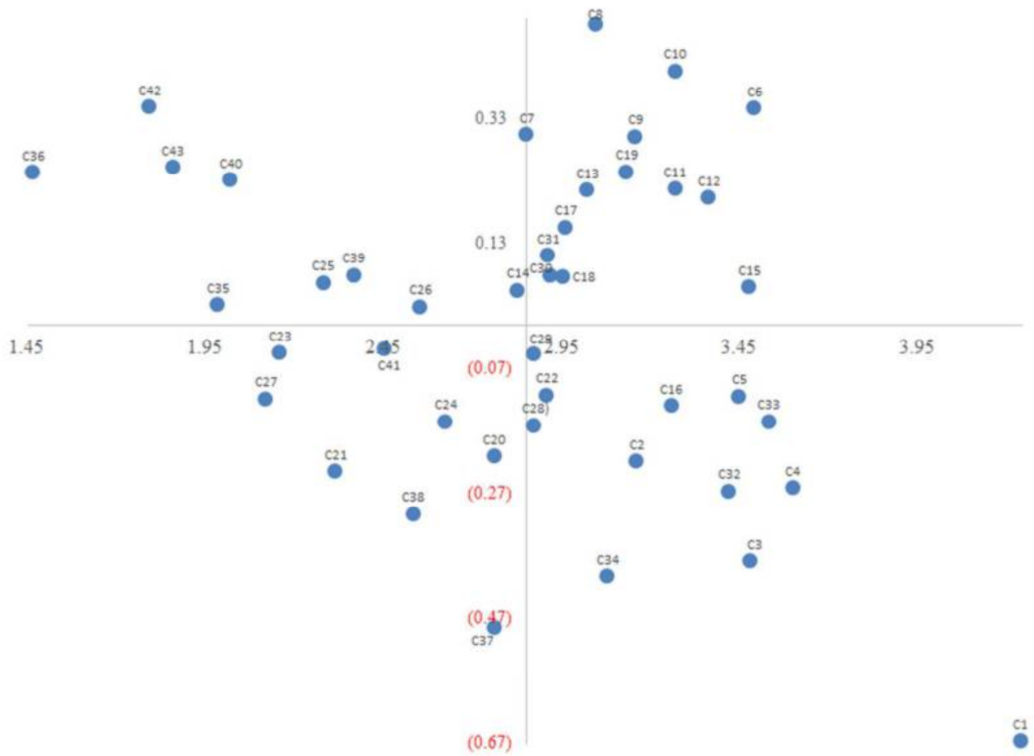

Figure 2. The FDEMATEL causal diagram according to various data aggregations

From the analysis obtained by FDEMATEL reveals that Product (A1) is the most important issue if a company would like to implement eco-innovation. In the meantime, many criteria under A1 are the driving factors for econ-innovation. Among these factors. “improving health and safety with green purchasing” (C6) and “complying with environmental standards” (C8) are the critical driving factors under A1. A2 (Marketing), A4 (R&D) and A5 (Finance) are the core problems that the company needs to overcome. Among the corresponding factors, the main driving factor is C10，which means the company can resolve the problems or challenges encountered during the process of eco-innovation via “Expanding intensity of market competition for promoting green products”.

4.2.2 ISM analysis

After the FDEMATEL analysis, ISM outlined in Section 3.3 can be applied to the analysis. Figure 3 presents the index layered using ISM. As depicted in Figure 3, the attributes are divided into 10 layers: Layer 1 is labelled operations, including C35, C36, C40, C42 and C43;

Layer 2 is about HRM, including C23, C25, C27 and C39; Layer 3 is called HR Storage, which is defined as the reserve of human recourse capability. This includes C21, C26 and C41; layer 4 is about Eco-technology Application, including the C7, C8, C18 and C24; layer 5 is Local Advantage Utilisation, including C9, C10, C13, C17 and C19, C20 and C30; layer 6 named Logistic Support, including C11, C14, C29, C31 and C38; layer 7 referred to Eco-awareness Enhancement, including C6, C12, C22 and C28; layer 8 is about Eco-marketing, including C5, C15 and C16; layer 9 named Eco-improvement, including C2, C3, C4 and C32, c 33, C34 and C37; layer 10 named Eco-certification Development, including C1.

Layer 1 constitutes the major activities that should be considered with high priority with respect to the development of eco-innovation. The factors in this layer are thus also the easiest factors to be realised in practice. In contrast, the last layer consists of one parameter only, which is eco-certification development. This is the ultimate goal for the company to achieve good performance regarding eco-innovation. The factors in this layer are also the most difficult factors to be realised. In practice, an organisation should aim to tackle the first layer first and then following the sequence layer-by-layer until the last layer, the ultimate goal, can be tackled.

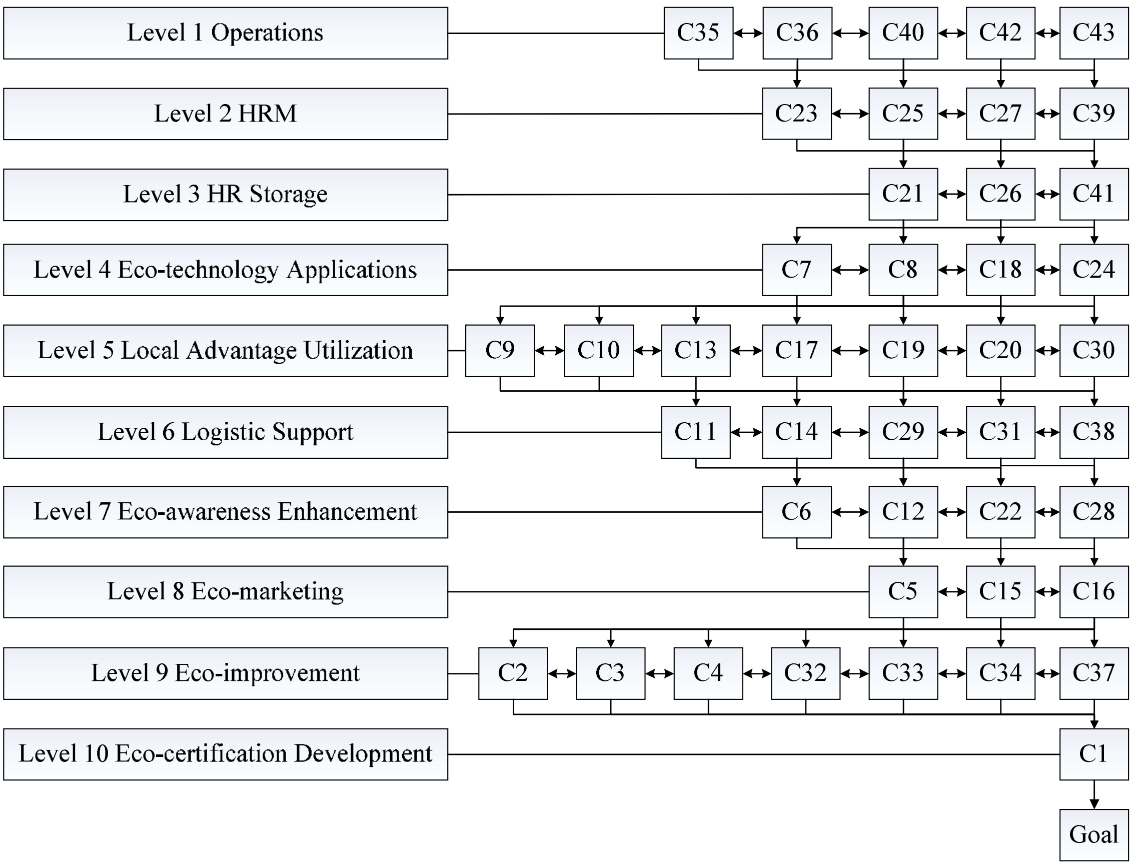

Figure 3. The ISM classification and rename for attributes

5 Theoretical and Managerial Implications

5.1 Theoretical implications

This study blends two methods to investigate the important factors in order to deliver good eco-innovation performance. More importantly, this study found that the usual business functions (A1to A5 in this study) cannot be used to evaluate eco-innovation performance and hence the corresponding drivers directly. By the proposed method, the original five-layer architecture (i.e., A1 to A5), gradually refined based on the characteristics of the case study company, Company L. The factors are layered using the ISM method, which will eventually evolve to ten aspects which is a reference for the company and thus enrich development in the theory aspects of company eco-innovation. One possible reason to explain the findings could be that the case company is in China, in contrast to many reported studies that were conducted in developed countries. This is further explained below.

As the world's largest emerging economy and manufacturing hub, China provides a justifiable context for conducting management research in contrast to other developed countries (Tsui et al., 2004). To name a few, Jia et al. (2012) developed a context-emic model to evaluate articles in Chinese context. Busch et al. (2013) analysed the difference of German employees' perception of Chinese leadership styles and German managers' method. Zhang et al. (2015) investigated the relationship between innovation performance, conflict management styles (CMSs) and emotional intelligence (EI) and tested the mediating effects of various types of CMSs of Chinese organisations. Li and Tsui (2002) investigated the management issues in Chinese organisations. They analysed 226 research articles published in 20 leading academic journals from 1984 to 1999 by performing a citation analysis. All these studies demonstrate that contextualisation in Chinese management is very important. However, there is a lack of development in management research, theories, and practices (White, 2002; Tsui et al., 2004; Meyer, 2006). It is reasonable to expect that different management practices should be applied under different cultural contexts (Rousseau & Fried, 2001; Lung-Tan & Yuan-Ho, 2005; Martinsons & Davison, 2007; Leung, 2007; Whetten, 2009).

There are two obvious limitations in the management research in the Chinese context. First, most studies focus on qualitative research, and there is limited systematic empirical evidence to support the need for management research in Chinese context (Peng et al., 2001; Meyer, 2006). One reason that may contribute to this is that the data management system in China, similar to many developing countries, is not as mature as developed countries. Second, there is no research on evaluating the contribution to management knowledge in the Chinese context using a systematic model or framework (Tsui, 2009). There is a need to adapt management theories, which are biased in the context of developed countries, to account for local context (Li et al., 2012). Also because of the differences in the evaluation of eco-innovation between developed and developing countries, it is impossible to compare the results of this study to previous studies that are tailored to developed countries. Therefore, future research can focus on this to develop a common standard or evaluation system for eco-innovation.

5.2 Managerial implications

Apart from the theoretical implications mentioned in the previous section, applying the proposed model in Company L also generated several managerial implications, particularly for the agricultural industry. Business function (A1), i.e., Product, is the most influential factor on eco-innovation. Therefore, product capacity must be considered and developed to enhance eco-innovation performance.

More specifically, three outstanding factors are worth mentioning. First, it is found that "Improving the health and safety with green purchasing" (C6) is one of the driving attributes behind the eco-innovation. It is worth mentioning because this can fundamentally change consumer consumption pattern that lead to realisation of innovation. Thus, core competitive advantage from such innovation can be adapted in response to the rapid market evolution. Furthermore, complying with environmental standards (C8) is another focal point. However, it would incur higher management cost and hence the return from eco-innovation with respect to this would be a challenge in practice. This may be the bottleneck of many companies in pursuing eco-innovation. However, in the long run, this may become a basic requirement for survival such that companies are advised to prepare for this or even to take action as soon as they can. Finally, companies in the agricultural sector should focus on Expanding intensity of market competition for promoting green products (C10).

From the ISM analysis, Operations is identified as the first layer of the model. The implication is that Operations is still the major activity that should be considered in the first place in relation to the development of eco-innovation. The results suggest that it can be used to improve business by Designing reverse logistics procedure (C35), Developing optimal inventory management (C36), Controlling capital efficiency (C40), Decreasing cost of revenue (C42) and Increasing profit margin (C43).

6. Conclusions

This study contributes to the knowledge domain by offering guidelines, particularly for Chinese companies, to enhance eco-innovation performance. This can be achieved by effectively utilising their resources and investments while developing sustainability. With respect to theoretical implications, product function is identified as the driving factor of green innovation, thus confirming that product quality is the company's key to survival and fundamental starting point for the eco-innovation. In addition, it is found from the ISM results that the ultimate goal of eco-innovation is eco-certification development, and it also requires an integral approach of green production to implement. However, possessing integral approach of green production (C1) is located in the last layer of ISM, and being located in the fourth quadrant represents a core problem: testifying integration of green production with the current method is still not an easy problem.

The results in this study are biased towards Chinese companies. In China, the external pressures which come from consumers' green demands, environmental regulations and competitors affect eco-innovation partially through internal drivers. Internally, more and more Chinese companies realise that if they want to achieve sustainable development, they must be transformed and upgraded through eco-innovation. The Chinese context must be considered. However, there is a lack of theoretical justification for developing countries (not only China) to pursue eco-innovation. In view of the Chinese context, the theories or methods proposed in the West are not always able to solve the specific and local problems of Chinese companies. Hence, this study attempted to identify the factors influencing Chinese companies' eco-innovation and extract a new management structure from the theoretical perspective.

This study has several limitations. Although the proposed attributes were identified through extensive literature reviews, the list is not exhaustive. Hence, more attributes can be considered in future research. In addition, this study only involves one case company. Although it is not uncommon to use single case study in previous studies (e.g., Hojnik & Ruzzier, 2016; Fernando et al., 2016; Vīgants et al., 2016), and in this study there are many subsidiaries of the case company (i.e., the case is not a simple single case), to a certain extent the setting still limits the generalisability of the findings. Future studies could expand this study to other industries and thus overcome the limitation.

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