Technological and Economic Development of Economy
ISSN: 2029-4913 / eISSN: 2029-4921
2019 Volume 25 Issue 5: 774–801
https://doi.org/10.3846/tede.2019.9385

AN ECO-INNOVATIVE FRAMEWORK DEVELOPMENT FOR SUSTAINABLE CONSUMPTION AND PRODUCTION IN THE CONSTRUCTION INDUSTRY

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Received 21 October 2018; accepted 26 January 2019

Abstract. Sustainable consumption and production have been increasingly required in the construction industry. However, previous studies have not yet comprehensively developed evaluation tools and methods to implement sustainable consumption and production. To achieve this objective, we utilized the eco-innovation, which provides effective analysis of sustainable consumption and production for the construction firms by eliminating subjectivity and ambiguity of evaluations. We adopted the fuzzy set theory to overcome the uncertainty occurring from the judgments of experts and utilized decision-making trial and evaluation laboratory approach to analyse the causal relationships between our methods and evaluation criteria. The results showed that environment and sustainable consumption are the key factors, while life cycle assessment, eco-labels, and environmental certification as well as improving eco-efficiency are critical to realizing sustainable consumption and production. The study enhances the understanding of the major players to achieve sustainable consumption and production, and link sustainable consumption and production with the eco-innovative practices. Our approach also improves the assessment accuracy, and the results provide viable suggestions for practical applications.

Keywords: sustainable consumption and production, fuzzy set theory, eco-innovation, decision-making trial and evaluation laboratory.

JEL Classification: D81, E21, E23, Q56.

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Introduction

Construction industry generates a heavy burden on the environment and society with the increasing pace of economic development (Gan, Zuo, Ye, Skitmore, & Xiong, 2015). Current consumption patterns and production systems rely on traditional practices and older technologies that are highly inefficient, generating a great amount of waste and high energy consumption; thus, they cause various environmental issues, such as environmental pollution, greenhouse gas emission, and excessive consumption of resources (Berg, 2011; Akbiyikli, Eaton, & Dikmen, 2012; Govindan, 2018). These problems impede construction firms to implement sustainable consumption and production (SCP) strategies. To alleviate these problems, eco-innovation has received widespread attention from the construction firms for achieving sustainable development and thereby gaining competitive advantages (Cai & Li, 2018). However, practical methods that can be adopted by construction firms to understand and apply the theoretical framework of eco-innovation and thereby achieve SCP are still lacking.

Eco-innovation has emerged as a new business value in the construction sector recently. Kiefer, Carrillo-Hermosilla, Del Río, and Callealta Barroso (2017) indicated that eco-innovation could narrow the influence of production and consumption activities on the environment. It is also believed that eco-innovation is a critical player to produce a more sustainable economy and society where both competitiveness and sustainability can be maintained. Eco-innovation can provide environmental, economic and social benefits, create a win-win situation, and improve sustainable performance (Wu, Liao, Chen, Lin, & Tsai, 2016). In addition, Michaelis (2003) emphasized that eco-innovation not only allows firms to incorporate into the conventional business model with environmental concern but also brings more sustainable consumption patterns. According to Machiba (2010), eco-innovation leads firms towards sustainable production by raising efficiency in resources and green growth. Dočekalová, Doubravský, Dohnal, and Kocmanová (2017) stated that corporate governance is positively related to sustainable performance. Moreover, Carrillo-Hermosilla, Del González, and Könnölä (2009) proposed eco-innovation is applied across the business from the strategy and business model via a variety of operational activities (e.g., design, production, purchasing, and marketing). In short, eco-innovation affects sustainable consumption and production from multiple perspectives.

Even though some studies have demonstrated that SCP has an aggregate and multidimensional characteristic (Tseng, Chiu, & Liang, 2018; Govindan, 2018), a comprehensive analysis of SCP undertaking its multidimensional nature has not been investigated. Previous studies have explored SCP through literature reviews, basic statistical methods and in-depth interviews (Geels, McMeekin, Mylan, & Southerton, 2015; Dubey et al., 2016; Thongplew, Spaargaren, & van Koppen, 2017), but these studies focused primarily on the small-scale industries and ignored the correlation between eco-innovation and SCP. Therefore, to seek the drivers to SCP adoption in the construction industry, quantitative analysis should be conducted with the help of experts' opinion in order to identify the importance of each influencing factor. In this study, a fuzzy decision-making trial and evaluation laboratory (FDEMATEL) method was adopted in this paper to understand and evaluate the performance of SCP based on an eco-innovative framework. The fuzzy set theory was utilized to transfer the experts' linguistic preferences into quantitative measurements and address the ambiguity in the decision-making process (Keršulienė & Turskis, 2011; Zhang & Guan, 2018). Furthermore, the DEMATEL method was used to analyze both the causal relationship and the impact of the target system's factors (Pourahmad et al., 2015). Then, the influence of the factors was presented using a visual diagram (Wu, Liao, Tseng, & Chiu, 2015).

Thus, the objectives of the study are to find SCP factors through accurately evaluating their performance and to provide precise guidelines to the construction firms for eco-innovative applications. First, this study has developed a novel measure for evaluating SCP in the construction industry. Second, the proposed method can help firms assess performance toward achieving sustainability. Third, our work can provide precise guidelines for the construction firms on the quintessential eco-activities for attaining SCP in the production process.

The organization of this paper is presented as follows: Section 2 gives a literature review on SCP and eco-innovation. Section 3 introduces the hybrid method and the analytical steps utilized in this work, while Section 4 shows the case study and the empirical results. Then, the implications regarding the theoretical and managerial perspectives are presented in Section 5. Finally, Section 6 provides conclusions, contributions, limitations, and prospects of the study.

1. Literature review

The relevant literature on SCP and eco-innovation is shown in this section. The research gaps are also discussed.

1.1. Sustainable consumption and production (SCP)

Ongoing demand for the transformation of conventional approaches towards SCP in the construction sector plays an essential role in implementing sustainable practices in the whole world (Luthra, Govindan, & Mangla, 2017; Govindan, 2018). The initial concept of SCP was proposed during the *World Summit on Sustainable Development* in 1992, focusing the research to tackle sustainability challenges (Akenji & Bengtsson, 2014). SCP was defined as "the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of further generations" (Oslo Symposium, 1994). During the *World Summit on Sustainable Development* in 2002, the SCP concept was recognized as a fundamental goal for achieving sustainable development (Jackson, 2006). At the conference Rio+20 in 2012, world leaders asserted strongly again on the commitment to reach SCP by adopting a 10-year framework of SCP programs (Akenji & Bengtsson, 2014; Govindan, 2018).

Previous studies offer fluid and scattered analyses of SCP; hence, exploring SCP within a unified framework is critical to realize real-world applications (Bai, Shah, Zhu, & Sarkis, 2018). Several studies have identified two main instruments: responsible consumption and responsible production (Geels et al., 2015; Liobikienė & Dagiliūtė, 2016). Because the patterns of consumption and production have direct or indirect impacts on resource efficiency, environmental pollution, and waste, they influence the pursuit of sustainability (Schinkel & Spiegel, 2017). SCP can transform environments, economies, as well as societies to realize sustainability for humans (Blok et al., 2015; Luthra et al., 2017). Azapagic, Stamford, Youds, and Barteczko-Hibbert (2016) stated that moving toward SCP should balance a plethora of economic, environmental, and social aspects. Moreover, corporate governance, which can lead firms to accommodate more sustainability practices through making strategies has also been proposed (Aras & Crowther, 2008; Dočekalová et al., 2017).

Numerous studies have demonstrated the importance of achieving SCP to minimize environmental regulatory pressure, enhance competitiveness, and improve firms' sustainable performance (Stevens, 2010; Wong, Soh, & Chong, 2016; Tseng & Tan, 2016). For example, Zhao and Schroeder (2010) summarized existing policies in Asian countries regarding the development of a green economy and concluded that SCP is a comprehensive method to address the global environmental challenge. Blok et al. (2015) conducted an overview of SCP and found that SCP practices can not only promote firm's sustainable development but also promote a balance between the development of global economy and that of political systems. Since the construction industry has been striving to achieve SCP to increase competitiveness, eco-innovation studies are essential to offer viable solutions to improve the sustainable performance of the industry.

1.2. Eco-innovation

Kemp and Pearson (2007) defined the eco-innovation as "production, application or exploitation of a good, service, production process, organizational structure, management or business method that is novel to the firm or user and which results, throughout its lifecycle, in a reduction of environmental risk, pollution and the negative impacts of resources use (including energy use) compared to relevant alternatives." Kiefer et al. (2017) summarized previous definitions and stated, "eco-innovations, or innovations which reduce the environmental impact of production and consumption activities, are generally considered key in the transition towards more sustainable economies and societies and help mitigate the traditional dichotomy between competitiveness and sustainability." These definitions demonstrate the involvement of crucial elements for eco-innovation. Eco-innovation is not only an important factor for firms' clean production and their sustainability but also at the core of the promotion of sustainability and "smart growth" (Horbach, 2008).

As a critical driving force, eco-innovation can improve the firm's sustainability performance, and thus its implementation should include diverse practices and initiatives (Wu et al., 2016; Cui, 2017). Hojnik and Ruzzier (2016) analyzed different drivers of eco-innovation and found influential variables, such as demand-pull and cost-saving, as well as internal and international factors. Cui (2017) investigated the driving factors of eco-innovation, such as improving health and safety with green purchasing to enhance business functions in a developing country. Roddis (2018) identified 15 innovation examples at the sector of wind energy in the UK and found that eco-process and eco-organizational innovations were the most sensitive to the institutional and political influences. He also found that eco-product innovations were the most sensitive to supply-side factors. Nevertheless, viable eco-innovations have been applied in various fields and sectors; hence, eco-innovations are diverse as well as industry-specific. Therefore, a new set of measures is needed to meet the skills and capabilities of the construction industry.

Bossle, Dutra De Barcellos, Vieira, and Sauvée (2016) investigated why and how firms integrated environmental sustainability with the innovation process and concluded that firms should focus on eco-innovation to be one of the explicit goals of their strategies to boost performance. Wu et al. (2016) explored eco-innovation in dynamic organizational capability when information is incomplete in the lighting industry at Taiwan and found that improving this dynamic organizational capacity of single firms can explore several eco-innovation opportunities in green markets. Additionally, Cai and Li (2018) investigated the relationship between drivers, eco-innovation behaviors, and firm's performance of 442 Chinese firms, and showed that eco-innovation behavior could significantly enhance the environmental performance of a firm. Nevertheless, previous studies demonstrated the correlation between eco-innovation and a firm's performance but did not propose an effective method for assessing their relationship. This study presents a hybrid approach to evaluate eco-innovation performance and identify specific SCP factors to achieve sustainability.

1.3. The research gaps

For the better understanding of analytical frameworks, prior research has utilized qualitative methods, case studies as well as literature reviews to explore SCP (Seyfang, 2004; Berg, 2011; Dubey et al., 2016). Pallaro, Subramanian, Abdulrahman, and Liu (2015) applied an integrated review framework based on 42 relevant articles published between 2004 and 2014 to understand the sustainability challenges and drivers in the consumption and production stages. Azapagic et al. (2016) used a novel decision-support framework and case study to test whether achieving SCP needs a systematic approach based on life cycle thinking, as well as integration in economic, environmental, and social aspects. In addition, Luthra et al. (2017) developed a structural model for the evaluation of SCP drivers and improvement of sustainability aspects in the supply chain scenario under the uncertain environment. However, a comprehensive approach to performance evaluation has not been addressed to date.

Previous studies have utilized a variety of methods to explore eco-innovation. For example, Doran and Ryan (2012) conducted an empirical analysis to explore the driving factors of eco-innovation and test whether adopting eco-innovation can improve firms' performance using 2,181 firms as samples. Scarpellini, Valero-Gil, and Portillo-Tarragona (2016) analyzed the determinants of eco-innovation projects through 44 applied cases. Del Río, Carrillo-Hermosilla, Könnölä, and Bleda (2016) developed an integrated framework to explore how the internal factors (e.g., resources, capabilities, and competences) and the external factors (e.g., policies and stakeholders) affect the implementation and development of eco-innovation. These studies all indicated that eco-innovation is a feasible direction towards sustainable development, but few studies explored the sustainability of eco-innovation and SCP. Thus, the link between eco-innovation and SCP remains incomplete.

In this study, we aimed at adopting the fuzzy set theory integrated with decision making trial and evaluation laboratory (DEMATEL) to overcome the aforementioned research gaps. The fuzzy set theory was utilized to transform linguistic preferences into comparable crisp values (Tseng, Lim, Wong, Chen, & Zhan, 2018). During decision-making procedures, decision-makers are often in the uncertain environment due to time pressure, lack of knowledge, limited attention and insufficient information, all of which increase the complexity and contradictions of subjective judgments (Wu, Tseng, Chiu, & Lim, 2017). Thus, the fuzzy set theory was used to overcome these issues and shift the linguistic preferences to quantitative analysis (Wang, Ma, Wu, Chiu, & Nathaphan, 2018). Subsequently, DEMATEL was utilized for the determination of the cause and effect relationship between the aspects of SCP and criteria of eco-innovation that enable decision makers to develop long-standing strategies for achieving the desired objectives (Heravi & Charkhakan, 2014; Kumar & Dixit, 2018).

2. Research methodology

This section presents the proposed measures (shown in Table 1) and the methods utilized in the study.

2.1. The proposed measures

Numerous studies confirmed that SCP should involve the economic aspect (A1) (Azapagic et al., 2016). Hence, five criteria of eco-innovation were proposed to enhance the understanding of SCP. Firm's R&D expenditure (C1) facilitates economic rent, develops technological capabilities, and gains a first-mover advantage, thus contributes to the firm's future performance (Dong, Wang, Jin, Qiao, & Shi, 2014; R. Wang, F. Wang, Xu, & Yuan, 2017). Eco-innovation takes advantage of capital and technology, so increasing investments in equipment and technology reformation (C2) can increase the regional green products' productivity and their market share (Hitchens, 1999; Santos, Basso, Kimura, & Sobreiro, 2015). Access to the existing subsidies and fiscal incentives (C3) can motivate firms to adopt sustainable development practices more actively (Triguero, Moreno-Mondéjar, & Davia, 2013). Furthermore, controlling capital efficiency (C4) plays a vital role in improving corporate performance, profitability and value creation (Hahn & Figge, 2011; Cui, 2017). The potential for cost savings (C5), such as through the reduction of required input is also the driver of eco-innovation, which can enhance competitiveness (Roddis, 2018).

Eco-innovation can transform the innovation system to build sustainable processes after the environmental aspect (A2) is brought into discussions. Life cycle assessment (C6) is selected as a valuable tool for the industry's environmental sustainability (Sanni, 2018). Compliance with environmental regulations (C7) is found as the most cited factor along with normative pressure and the efficiency's need (Bossle et al., 2016; Hojnik & Ruzzier, 2016). Firms play a dramatic role as the largest consumers of natural resources and the main factors causing environmental degradation (Cohen & Winn, 2007), so strengthening management of natural resources and waste (C8) and adoption of clean technologies (C9) have a direct influence on relieving environmental pressures (Zollo, Cennamo, & Neumann, 2013; de Jesus & Mendonça, 2018). Eco-labels and environmental certification (C10) can improve firms' environmental awareness and market recognition as intangible assets (Segarra-Oña, Peiró-Signes, & Cervelló-Royo, 2015).

Firms usually focus on environmental and economic factors, often neglecting vital social aspect (A3), which is an essential element for achieving SCP (Yiftachel & Hedgcock, 1993;

Azapagic et al., 2016). Corporate reputation (C11) has been mentioned as a corporate asset that adds value to the actual worth of a firm and can increase firm's competitiveness (Hong, Shin, & Kim, 2016; Hojnik & Ruzzier, 2016). Corporate social responsibility (CSR) (C12) motivates firms to implement eco-innovation, and the adoption of CSR may reflect the firm's strategy reinforcement or reorientation by signaling a commitment to green issues and establishing the firm's green image (Kesidou & Demirel, 2012). Increased competitive pressure (C13) are forcing firms to continuously develop and innovate to improve the competitiveness of green products, such as product design and quality, technology service, and reliability (Hojnik & Ruzzier, 2016). Moreover, access to external knowledge (C14) and staff training (C15) can enhance absorptive capacity and competitiveness of firms as they help generate and consolidate new knowledge and skills, which could help engender innovations (Martin, McNeill, & Warren-Smith, 2013; Sanni, 2018).

Corporate governance (A4) is fundamental to the operation of any firms and has a significant impact on achieving sustainability (Aras & Crowther, 2008). Abilities to perform organizational adjustments (C16) refer to the allocation of resources according to the task, and to control, motivate, and coordinate the process of group activities so that they can be integrated to achieve organizational goals (Wu et al., 2016). Product orientation (C17) can assist firms to concentrate on the increase of the products' quality or number, thus increasing market share (Segarra-Oña et al., 2015). Creating an effective and functional team (C18) enables firms to be innovative and flexible while maintaining a high level of performance (Latif & Williams, 2017; Ociepa-Kubicka & Pachura, 2017). Cooperation with external partners (C19) helps cross-fertilization of knowledge and sources, enabling the integration of several innovative abilities to produce novel and useful products and services (Bönte & Dienes, 2013; Lin, 2017). In addition, strategic planning (C20) is to define its strategy or direction and make decisions on the allocation of its resources to achieve the strategy (García-Pozo, Sánchez-Ollero, & Marchante-Lara, 2015).

Sustainable consumption (A5) has emerged as a critical priority area in research and decision-making associated with sustainable development (Liu, Valentine, Vanderbeck, McQuaid, & Diprose, 2018). Providing eco-demand for the customer (C21) fulfills not only the physical and social needs for customers but also the consumption of green products and services (Horbach, Rammer, & Rennings, 2012; Tseng & Tan, 2016). Consumer participation (C22) (e.g., reviewing the consumers' views) can help assure the transparency, credibility as well as information provision's robustness (Horbach et al., 2012). Enhance communication (C23) can increase an in-depth comprehension of the responsibilities and obligations of participants so that the firm's strategy can be effectively implemented (Jones, Stanton, & Harrison, 2001). Improving eco-efficiency (C24) and reuse and recycling (C25) can decrease the consumption of resources, energy, and the environmental load during production or operation of a firm (Faucheux & Nicolaï, 2011; F. Yang & M. Yang, 2015).

Sustainable production (A6) is becoming increasingly vital for production and operation of firms, mainly because production is the source of many environmental and ecological problems (Luo et al., 2017). From the beginning to the end of a project, pollution control and prevention (C26) and utilizing sustainable operational processes (C27) play a key role in reducing environmental impacts and achieving clean production (Wu et al., 2015). Eco-design strategies (C28) usually recommend using cleaner or more appropriate natural materials to reduce environmental risks and improve product performance during production (Wang, Chan, Lee, & Li, 2015; Shi et al., 2017). Using eco-materials and clean energy (C29) can help reduce the environmental costs of products during their extraction, manufacturing, use, and end-of-life (Triguero et al., 2013). The number of patent applications (C30) reflects the firm's innovation and technological capabilities and promotes the production and operation (Dong et al., 2014).

Table 1. Evaluation aspects and criteria for SCP

Aspects		Criteria	
A1	Economic	C1	Firm's R&D expenditure
		C2	Investments in equipment and technology reformation
		C3	Access to existing subsidies and fiscal incentives
		C4	Controlling capital efficiency
		C5	The potential for cost saving
A2	Environmental	C6	Life cycle assessment
		C7	Compliance with environmental regulations
		C8	Strengthen management of natural resources and waste
		C9	Adoption of clean technologies
		C10	Eco-labels and environmental certification
A3	Social	C11	Corporate reputation
		C12	Corporate social responsibility
		C13	Increased competition pressures
		C14	Access to external knowledge
		C15	Staff training
A4	Corporate governance	C16	Abilities to perform organizational adjustments
		C17	Product orientation
		C18	Creating an effective and functional team
		C19	Cooperation with external partners
		C20	Strategic planning
A5	Sustainable consumption	C21	Providing eco-demand for customer
		C22	Consumer participation
		C23	Enhance communication
		C24	Improving eco-efficiency
		C25	Reuse and recycling
A6	Sustainable production	C26	Pollution control and prevention
		C27	Utilizing sustainable operational processes
		C28	Eco-design strategies
		C29	Using eco-materials and clean energy
		C30	The number of patent applications

2.2. The fuzzy set theory

During the decision-making process, experts usually make judgments based on their experience and expertise and evaluate the factors' relationships using linguistic preferences (Table 2). The qualitative expression of experts' subjective preferences is affected by uncertainty. For example, the terms "excellent," "very good," "high influence" expressed by experts include vagueness or fuzziness. The fuzzy set theory provides an objective way of taking the uncertainty of judgment into account, which can be used to handle such problems (Jang, Lee, & Han, 2018).

Table 2. Linguistic Scales for Corresponding TFNs proposed by Wu et al. (2015)

Scales	Linguistic Preferences	Corresponding Triangular Fuzzy Numbers
1	No influence or importance	(0, 0.1, 0.3)
2	Very low influence or importance	(0.1, 0.3, 0.5)
3	Medium influence or importance	(0.3, 0.5, 0.7)
4	High influence or importance	(0.5, 0.7, 0.9)
5	Very high influence or importance	(0.7, 0.9, 1.0)

Assuming that there is a universe of discourse $Y=\{y_1, y_2, \ldots, y_n\}$. Then, fuzzy set $\tilde{Z}$ of Y is adopted to represent a set of ordered pairs $\{(y_1, f_{\tilde{Z}}(y_1)), (y_2, f_{\tilde{Z}}(y_2)), \ldots, (y_n, f_{\tilde{Z}}(y_n))\}$, where $f_{\tilde{Z}}: Y \to [0,1]$ represents the membership function of $\tilde{Z}$, and $f_{\tilde{Z}}(y_i)$ represents the membership degree of y_i in $\tilde{Z}$. This study was based on definitions and notations of the fuzzy set theory from Lin, Tseng, Chen, and Chiu (2011) and Wu et al. (2015). Some definitions are as follows:

Definition 1. Whether Y is an infinite or finite set affects the fuzzy set $\tilde{Z}$ expressed as $\tilde{Z}_i$ or $\tilde{Z}_f$

$$\begin{cases} \tilde{Z}_i = \dfrac{\int_y f_{\tilde{Z}}(y_i)}{y}, \ y \in Y, \text{ when } Y \text{ is an infinite set} \\ \tilde{Z}_f = \dfrac{\sum_i f_{\tilde{Z}}(y_i)}{(y_i)}, \ y_i \in Y, \text{ when } Y \text{ is a finite set} \end{cases}.$$

Definition 2. If the fuzzy set $\tilde{Z}$ of universe of discourse Y is normal, the corresponding membership function $f_{\tilde{Z}}(y)$ must satisfy $\max f_{\tilde{Z}}(y) = 1$.

Definition 3. The fuzzy number is a fuzzy subset in the universe of discourse Y, and it is normal rather than convex.

Definition 4. The fuzzy $\alpha - cut$ $\tilde{Z}_\alpha$ and strong $\alpha - cut$ $\tilde{Z}_{\alpha+}$ of the fuzzy set $\tilde{Z}$ in the universe of discourse Y is defined by

$$\tilde{Z}_\alpha = \{y_i | f_{\tilde{Z}}(y_i) \geq \alpha, y_i \in Y\}, \text{ where } \alpha \in [0,1];$$

$$\tilde{Z}_{\alpha+} = \{y_i | f_{\tilde{Z}}(y_i) \geq \alpha, y_i \in Y\}, \text{ where } \alpha \in [0,1].$$

Definition 5. If the fuzzy set $\tilde{Z}$ of the universe of discourse Y is convex and each $\tilde{Z}_\alpha$ is convex, $\tilde{Z}_\alpha$ is a close internal b. This can be written as

$$\tilde{Z}_\alpha = \left[\beta_1^\alpha, \beta_2^\alpha\right], \text{ where } \alpha \in \left[0,1\right].$$

Definition 6. A triangular fuzzy number (TFN) is defined by a triplet $\left(l_1, m_2, r_3\right)$. The membership function of the fuzzy number $\tilde{Z}$ is written as

$$f_{\tilde{Z}}\left(y\right) = \begin{cases} 0, \; y \prec l_1 \\ \left(y - l_1\right) / \left(m_2 - l_1\right), l_1 \le y \le m_2 \\ \left(r_3 - y\right) / \left(r_3 - m_2\right), m_2 \le y \le r_3 \\ 0, \; y \succ r_3 \end{cases}.$$

Assuming that the experts' committee consists of h respondents, and the linguistic scale of their judgments should be transferred to $\tilde{T}_{ij}^h = \left(t_{1ij}^h, t_{2ij}^h, t_{3ij}^h\right)$, which means the degree to which attribute i influences attribute j according to the h^{th} response. However, these fuzzy numbers still have the incomparable feature. The defuzzification process requires that the triangular fuzzy numbers must be transformed into crisp values, and this study adopted max-min to conduct the process. The max-min normalization process is displayed as follows.

Normalization:

$$\begin{aligned} yt_{1ij}^h &= \left(t_{1ij}^h - \min t_{1ij}^h\right) / \Delta_{\min}^{\max}; \\ yt_{2ij}^h &= \left(t_{2ij}^h - \min t_{2ij}^h\right) / \Delta_{\min}^{\max}; \\ yt_{3ij}^h &= \left(t_{3ij}^h - \min t_{3ij}^h\right) / \Delta_{\min}^{\max}, \end{aligned} \tag{1}$$

where $\Delta_{\min}^{\max} = \max t_{3ij}^h - \min t_{1ij}^h$.

Computing left (lq) and right (rq) normalized values:

$$\begin{aligned} ylq_{ij}^h &= yt_{2ij}^h / \left(1 + yt_{2ij}^h - yt_{1ij}^h\right); \\ yrq_{ij}^h &= yt_{3ij}^h / \left(1 + yt_{3ij}^h - yt_{2ij}^h\right). \end{aligned} \tag{2}$$

Developing total normalized crisp values:

$$y_{ij}^h = \left[ylq_{ij}^h\left(1 - lq_{ij}^h\right) + \left(yrq_{ij}^h\right)^2\right] / \left(1 - ylq_{ij}^h + yrq_{ij}^h\right). \tag{3}$$

Calculating the crisp values:

$$w_{ij}^h = \min t_{1ij}^h + y_{ij}^h \Delta_{\min}^{\max}. \tag{4}$$

The final step of the process is aggregating the crisp values:

$$\tilde{w}_{ij} = \sum_1^h w_{ij}^h \Big/ h, \; h = 1, 2, \cdots, n. \tag{5}$$

2.3. The DEMATEL method

As a practical and useful approach, DEMATEL method can display the complex relationship through cause and effect diagram (Pourahmad et al., 2015). Obtaining the diagram should begin with the evaluation from the expert group. After the crisp aggregating crisp values are calculated using the fuzzy set theory, then the following progress is used to generate the cause and effect diagram.

Arranging these crisp values $\tilde{w}_{ij}$ into direct relation matrix $M = \left[\tilde{w}_{ij}\right]_{n\times n}$, then according to direct relation matrix M, the normalized direct relation matrix $\overline{M}$ is obtained using Eqs (6) and (7):

$$\overline{M} = p \times M; \tag{6}$$

$$p = 1 \Big/ \max_{1\le i\le n} \sum_{j=1}^{n} \tilde{w}_{ij}. \tag{7}$$

Subsequently, the normalized direct relation matrix $\overline{M}$ should integrate with identity matrix O to acquire the total relation matrix K:

$$K = \overline{M} \times \left(O - \overline{M}\right)^{-1}. \tag{8}$$

Lastly, based on the total relation matrix K, the sum of rows $\left(V^d\right)$ and columns V^r are calculated by the following equations:

$$K = \left[k_{ij}\right]_{n\times n}, i, j = 1, 2, \cdots, n; \tag{9}$$

$$V^d = \left[\sum_{j=1}^{n} k_{ij}\right]_{1\times n} = \left[k_j\right]_{1\times n}; \tag{10}$$

$$V^r = \left[\sum_{i=1}^{n} k_{ij}\right]_{n\times 1} = \left[k_i\right]_{n\times 1}. \tag{11}$$

Therefore, $\left(V^d - V^r\right)$ and $\left(V^d + V^r\right)$ are the vertical and horizontal axis in the cause and effect diagram, respectively. If $\left(V^d - V^r\right)$ is negative, the factors are deemed effect, and conversely, the factors are cause. Moreover, $\left(V^d + V^r\right)$ shows the importance of the factors.

2.4. The proposed analytical steps

1. The proposed measurements were developed from a relatively thorough literature review, and by consulting the experts' committee. This study has formed a two-member committee, which consisted of industry experts and academic professors to confirm the reliability of the measurements. The form of communication was mainly through face-to-face interviews or by phone.
2. Subsequently, each expert used survey instruments to make judgments on the importance and performance of the measurements identified above in linguistic terms individually based on their rich knowledge and experience in the industry. After careful consideration and judgment, the experts provided feedback on the questionnaire.
3. Transforming the linguistic preferences into crisp values were performed. After collecting the experts' response, the linguistic preferences should be transferred into triangular fuzzy numbers first based on Table 2. Then, the fuzzy numbers were converted into

crisp values. Acquiring crisp values $\widetilde{w}_{ij}$ for the defuzzification and aggregation process was performed using Eqs (1)–(5).

4. Cause and effect diagram through DEMATEL was created. The crisp values were composed into the initial direct relation matrix, and the normalized direct relation matrix was acquired according to Eqs (6)–(8). Subsequently, the cause and effect diagram through Eqs (9)–(11) was produced. The procedures of the analytical steps are shown in Figure 1.

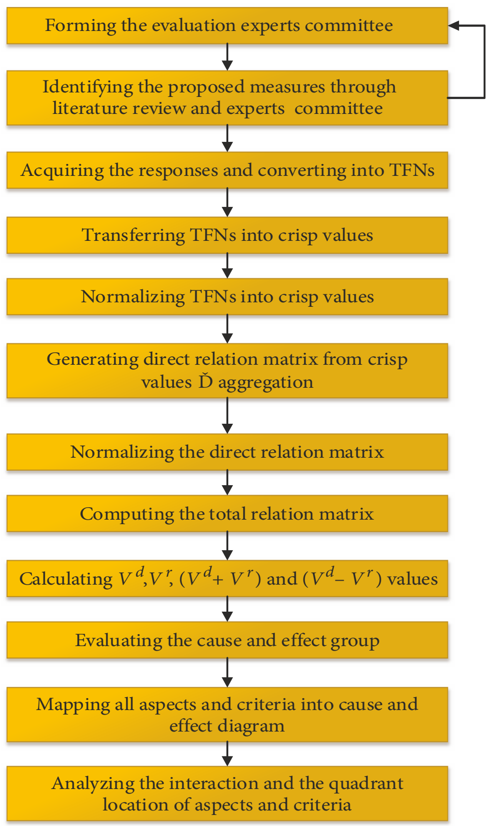

Figure 1. Flowchart of fuzzy DEMATEL evaluation

3. Results

3.1. Case information

The case firm (Firm L) is one of the largest property developers in China that was ranked in the Fortune Global 500 in 2016. Firm L does business in a variety of areas, such as property management and investment, decoration, and hotel development and management. In the downturn Chinese property industry, Firm L has gone retrograde. The sales volume and area of the contracts have increased substantially, ranking the first in the industry. Unlike other firms that focus on big cities, Firm L's strategies and focus of work concentrate on small and medium-sized cities, with investments across the country. However, due to widespread investment scope, Firm L is facing financial pressure and can only produce quickly to return the funds. Therefore, the phenomenon of unsustainable consumption and production occurs frequently. Firm L seeks to adopt eco-innovation toward achieving SCP.

Firm L has realized that SCP can help save costs, acquire recognition and increase competitiveness in the competitive market environment, and positively made huge investments and considerable resources to change consumption and production patterns toward sustainability. However, there is still limited research on the objective evaluation of eco-innovation and its mechanism for assessing SCP. Many firms still use empirical and traditional quantitative approaches to evaluate performance, but encounter difficulties in the identification of SCP in the rapidly changing competitive market. Therefore, this study utilizes FDEMATEL to assist Firm L in assessing its current eco-innovation performance and identifying SCP scheme. The empirical results are presented in the next sub-section and provide guidelines to Firm L for the implementation.

3.2. Empirical results

1. This study proposes six aspects and thirty criteria (as shown in Table 1) which were first identified from the literature to utilize the eco-innovative framework to explore and implement SCP in the construction industry. Then, they were discussed and confirmed by the expert group, which is recommended by case firm. The expert group with fifteen members consisted of four professors with at least ten years of industry consulting experience, and industry experts including four general managers, three assistant general managers, two senior managers, and two senior engineers, all of whom had at least eight-year experience in the construction industry. In addition, the expert group members have long cooperated with or provided consulting services to case firms, and these experts are committed to developing innovative practices in the construction industry. The relevant information of experts is shown in Table 3.
2. Experts made pair-wise comparisons among the final determined aspects and criteria using a linguistic scale provided in Table 2. Table 4 shows the criteria sample assessment from Expert 1.
3. The experts' judgments were converted into TFNs and normalized to crisp numbers by using Eqs (1)–(4) to develop the initial direct relation matrix; then, the 15 experts' feedback was aggregated into the subjective judgment adopting Eq. (5) to obtain the crisp values $\widetilde{w}_{ij}$. Table 5 shows the fuzzy initial direct relation matrix of the criteria.
4. The normalized direct relation matrix was achieved using Eqs (6)–(7). The total direct relation matrix of the criteria was acquired using Eq. (8), which is shown in Table 6. The $\left(V^d + V^r\right)$ and $\left(V^d - V^r\right)$ were identified utilizing Eqs (9)–(11) as shown in Tables 7 and 8. The sum of rows and columns of the total direct relation matrix generated vectors V^d and V^r, respectively. An aspect or criteria is grouped into a member of the cause group if $\left(V^d - V^r\right)$ is positive, otherwise, in the case of its negative value, the aspect or criteria attributes it to the effect group. $\left(V^d + V^r\right)$, which is the horizontal axis termed "Prominence" stands for the factors' importance; similarly, $\left(V^d - V^r\right)$, which is the vertical axis named "Relation" formulates the factors into a cause group. Hence, the cause and effect diagram is mapped by the values of $\left(V^d + V^r, V^d - V^r\right)$, as shown in Figures 2 and 3.

Table 3. The experts' information

	Age	Gender	Title	Working Unit	Industry consulting Experience or Working Experience
Expert 1	45	Male	Professor	University	13 years
Expert 2	44	Male	Professor	University	11 years
Expert 3	52	Female	Professor	University	20 years
Expert 4	50	Male	Professor	University	17 years
Expert 5	35	Male	General managers	Construction unit	9 years
Expert 6	33	Female	General managers	Construction unit	8 years
Expert 7	39	Male	General managers	Construction unit	14 years
Expert 8	33	Male	General managers	Construction unit	9 years
Expert 9	32	Male	Assistant general managers	Construction unit	8 years
Expert 10	34	Male	Assistant general managers	Construction unit	10 years
Expert 11	31	Female	Assistant general managers	Construction unit	8 years
Expert 12	40	Male	Senior managers	Construction unit	15 years
Expert 13	42	Male	Senior managers	Construction unit	13 years
Expert 14	48	Male	Senior engineers	Construction unit	21 years
Expert 15	39	Male	Senior engineers	Construction unit	11 years

We separated the influence among the SCP aspects and within the criteria of eco-innovation. Among the six core aspects of SCP, the results revealed that A2 and A5 are the driving factors for SCP because the values of $\left(V^d + V^r, V^d - V^r\right)$ are positive. It means that they are the major players in achieving SCP for construction firms. A4, A6, and A1 represent the core attributes. Although their impact is not as significant as A2 and A5, they are important for the improvement. In addition, A3 denotes the voluntary attribute which is not essential to the firm, although its impact is high. To this end, different factors' priority is in the order of A2, A5, A4, A6, A1, and A3.

Moreover, within the criteria of eco-innovation, nine decisive criteria that can assist firms to utilize eco-innovation and achieve SCP effectively fall into the first quadrant in Figure 2. We identified C6, C10, and C24 as the driving factors for SCP since they are endowed with greater influence compared to other criteria. Moreover, C7, C8, C9, C21, and C25 are ranked in the core attributes quadrant, which constitutes the basic requirement for improvement, though this improvement process should first modify the driving factors.

In summary, the results indicated that the environment (A2) and sustainable consumption (A5) are the most important aspects for the construction firms to implement SCP. In the meantime, life cycle assessment (C6) and eco-labels and environmental certification (C10) are the important driving factors under A2. Improving eco-efficiency (C24) is also an important driving factor under A5. Corporate governance (A4), sustainable production (A6), and economic (A1) aspects are the core issues that should be evaluated. Similarly, C19, C17, C26, C30, C2, and C1 are the corresponding driving factors that can help solve the issues or challenges encountered during SCP.

Table 4. The sample assessment of the SCP criteria by Expert 1

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C1	0	5	3	2	3	2	1	2	4	3	2	1	2	4	4	2	2	1	1	3	2	2	1	4	4	4	4	4	3	5
C2	3	0	4	4	4	3	4	4	5	4	4	2	3	2	2	1	2	2	3	3	3	1	2	5	5	5	4	3	3	4
C3	4	4	0	4	3	1	3	3	5	2	1	1	2	2	2	2	3	1	2	4	1	1	1	2	4	4	4	4	5	3
C4	3	4	2	0	2	2	1	3	3	2	1	1	3	2	2	2	1	3	3	2	1	1	1	4	4	3	4	3	3	4
C5	4	4	2	2	0	3	3	3	4	3	1	1	2	2	2	4	1	2	4	3	3	2	1	3	5	3	4	4	4	3
C6	3	3	3	4	4	0	3	4	3	4	2	2	2	1	2	1	5	1	2	4	4	3	1	4	4	5	4	5	4	2
C7	3	3	4	2	1	2	0	4	4	4	5	3	2	1	3	1	3	2	3	4	2	2	3	3	4	5	4	5	5	4
C8	1	3	4	3	1	3	4	0	4	5	4	3	2	1	2	1	2	2	2	3	3	4	4	4	5	5	4	3	4	2
C9	4	4	3	3	4	4	4	4	0	5	5	2	3	3	3	2	3	1	2	2	3	2	2	4	3	5	5	3	4	4
C10	4	3	5	3	2	2	2	3	3	0	5	2	4	4	4	2	5	3	4	4	3	1	2	3	2	3	3	4	4	2
C11	2	2	4	1	1	1	3	2	2	3	0	4	2	2	3	2	2	2	3	2	3	3	4	3	2	2	2	2	2	1
C12	2	3	2	2	1	1	4	4	4	2	5	0	3	2	3	2	2	2	3	4	1	2	2	3	3	3	2	4	2	1
C13	5	5	3	4	1	1	3	2	3	4	1	1	0	4	4	5	3	4	5	4	2	2	2	3	3	3	2	4	3	4
C14	4	4	1	2	4	2	1	2	4	3	1	1	3	0	5	4	2	3	3	2	1	1	1	4	4	2	2	2	3	4
C15	3	3	1	2	3	3	3	4	3	3	1	1	4	4	0	5	1	5	4	3	4	2	4	4	4	4	5	2	3	3
C16	1	2	2	3	2	1	2	2	2	1	1	1	2	2	3	0	1	5	4	3	1	1	2	3	2	2	2	2	2	1
C17	3	4	3	4	2	3	3	4	4	4	2	2	3	2	2	1	0	1	4	5	5	3	1	3	4	4	4	5	4	2
C18	3	3	1	4	2	1	2	2	2	1	2	1	3	2	3	5	2	0	4	3	2	2	3	4	4	4	5	3	3	1
C19	2	2	1	2	3	2	2	2	2	1	1	1	4	5	3	3	2	3	0	3	2	1	1	2	3	3	3	2	2	3
C20	4	4	3	3	3	4	3	3	3	4	2	2	2	2	3	3	5	2	3	0	3	2	1	3	3	3	3	5	4	4
C21	2	2	2	2	2	2	3	3	4	3	3	1	2	1	2	2	4	2	2	3	0	5	4	2	2	2	2	2	2	1
C22	1	1	1	1	2	2	2	2	2	1	3	3	2	1	2	1	4	1	2	3	4	0	5	2	2	2	1	2	2	1
C23	1	1	1	1	1	1	3	2	2	1	3	3	1	1	2	1	2	1	2	2	3	4	0	1	1	2	1	2	2	1
C24	2	3	3	3	4	4	2	3	2	3	3	3	3	1	3	2	2	3	2	3	4	2	2	0	4	4	5	4	3	4
C25	3	4	3	4	5	4	4	5	4	4	5	4	3	2	2	2	3	2	2	3	2	2	2	5	0	5	4	4	4	4
C26	4	5	4	3	3	4	5	5	5	4	5	4	3	2	3	1	2	2	2	3	4	3	3	4	4	0	3	4	4	2
C27	3	4	3	3	4	3	3	4	4	4	3	3	3	2	3	1	2	2	2	3	3	1	1	4	4	4	0	5	4	3
C28	4	4	3	3	3	3	4	4	4	4	3	4	3	2	3	2	4	2	3	5	3	3	3	5	4	4	4	0	4	3
C29	3	4	4	4	3	5	5	5	5	4	5	4	4	2	3	1	3	1	2	3	3	3	2	4	4	5	3	3	0	2
C30	5	5	3	2	4	2	2	2	2	3	1	1	4	5	4	1	2	1	3	3	2	1	1	3	3	2	4	2	2	0

Table 5. Initial direct relation matrix of the SCP criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C1	0.000	0.562	0.445	0.342	0.457	0.394	0.329	0.285	0.504	0.370	0.354	0.445	0.406	0.382	0.389	0.330	0.445	0.331	0.406	0.426	0.316	0.343	0.330	0.383	0.432	0.414	0.341	0.376	0.324	0.406
C2	0.419	0.000	0.382	0.356	0.368	0.406	0.445	0.313	0.463	0.471	0.520	0.278	0.404	0.406	0.337	0.229	0.521	0.290	0.483	0.401	0.407	0.395	0.316	0.378	0.381	0.414	0.344	0.350	0.336	0.380
C3	0.457	0.393	0.000	0.367	0.356	0.329	0.443	0.453	0.476	0.485	0.394	0.304	0.265	0.394	0.284	0.446	0.406	0.291	0.431	0.530	0.317	0.303	0.317	0.444	0.367	0.350	0.331	0.389	0.413	0.483
C4	0.444	0.420	0.457	0.000	0.317	0.368	0.278	0.362	0.388	0.291	0.303	0.292	0.394	0.252	0.349	0.304	0.292	0.342	0.355	0.297	0.420	0.432	0.368	0.344	0.254	0.375	0.369	0.451	0.324	0.408
C5	0.242	0.433	0.380	0.252	0.000	0.419	0.433	0.376	0.363	0.342	0.330	0.330	0.367	0.329	0.298	0.418	0.268	0.407	0.458	0.387	0.368	0.393	0.343	0.432	0.367	0.374	0.329	0.388	0.312	0.354
C6	0.444	0.380	0.406	0.407	0.420	0.000	0.393	0.376	0.415	0.407	0.239	0.354	0.341	0.329	0.425	0.253	0.457	0.368	0.484	0.338	0.432	0.267	0.330	0.469	0.420	0.400	0.357	0.312	0.287	0.278
C7	0.459	0.432	0.291	0.405	0.394	0.444	0.000	0.285	0.337	0.420	0.406	0.419	0.456	0.342	0.400	0.369	0.483	0.354	0.407	0.350	0.418	0.280	0.328	0.342	0.433	0.323	0.355	0.466	0.388	0.354
C8	0.419	0.342	0.405	0.330	0.380	0.392	0.304	0.000	0.375	0.419	0.445	0.406	0.392	0.343	0.247	0.354	0.496	0.534	0.342	0.440	0.368	0.458	0.380	0.484	0.521	0.451	0.483	0.273	0.402	0.432
C9	0.523	0.458	0.393	0.278	0.368	0.548	0.394	0.517	0.000	0.240	0.304	0.380	0.304	0.445	0.492	0.367	0.471	0.227	0.483	0.284	0.405	0.213	0.380	0.394	0.368	0.309	0.394	0.555	0.452	0.382
C10	0.433	0.291	0.521	0.317	0.343	0.379	0.355	0.401	0.348	0.000	0.419	0.315	0.305	0.381	0.338	0.330	0.420	0.406	0.344	0.403	0.355	0.189	0.380	0.266	0.356	0.235	0.367	0.388	0.300	0.419
C11	0.291	0.419	0.407	0.240	0.341	0.292	0.405	0.452	0.259	0.433	0.000	0.343	0.381	0.431	0.401	0.253	0.329	0.304	0.292	0.312	0.266	0.406	0.420	0.380	0.406	0.401	0.483	0.273	0.350	0.355
C12	0.458	0.341	0.355	0.355	0.356	0.419	0.509	0.313	0.377	0.406	0.521	0.000	0.355	0.419	0.364	0.457	0.330	0.355	0.291	0.505	0.342	0.445	0.380	0.278	0.342	0.413	0.341	0.327	0.374	0.368
C13	0.344	0.278	0.406	0.342	0.382	0.254	0.393	0.247	0.338	0.368	0.343	0.408	0.000	0.368	0.325	0.393	0.420	0.355	0.380	0.403	0.353	0.279	0.368	0.432	0.381	0.412	0.355	0.478	0.222	0.444
C14	0.444	0.445	0.292	0.419	0.317	0.341	0.266	0.361	0.428	0.292	0.382	0.317	0.202	0.000	0.516	0.266	0.433	0.459	0.420	0.401	0.330	0.331	0.343	0.383	0.342	0.451	0.367	0.402	0.425	0.547
C15	0.356	0.484	0.446	0.406	0.225	0.317	0.380	0.516	0.375	0.367	0.394	0.458	0.342	0.369	0.000	0.342	0.267	0.419	0.394	0.389	0.369	0.457	0.355	0.393	0.470	0.389	0.394	0.439	0.299	0.419
C16	0.355	0.369	0.430	0.496	0.379	0.419	0.380	0.323	0.377	0.342	0.381	0.343	0.341	0.329	0.362	0.000	0.316	0.431	0.421	0.414	0.355	0.304	0.407	0.380	0.418	0.451	0.265	0.350	0.375	0.330
C17	0.483	0.330	0.380	0.266	0.406	0.266	0.393	0.517	0.440	0.432	0.444	0.405	0.367	0.419	0.350	0.267	0.000	0.356	0.432	0.451	0.446	0.263	0.265	0.291	0.355	0.390	0.368	0.439	0.401	0.394
C18	0.356	0.407	0.343	0.382	0.331	0.367	0.393	0.233	0.336	0.432	0.394	0.331	0.471	0.432	0.426	0.368	0.483	0.000	0.433	0.618	0.291	0.252	0.381	0.330	0.330	0.528	0.419	0.234	0.388	0.368
C19	0.433	0.368	0.484	0.328	0.382	0.406	0.393	0.337	0.349	0.471	0.176	0.266	0.368	0.342	0.388	0.368	0.341	0.433	0.000	0.478	0.343	0.381	0.356	0.305	0.380	0.492	0.483	0.297	0.399	0.433
C20	0.342	0.406	0.342	0.444	0.432	0.367	0.394	0.439	0.416	0.343	0.438	0.317	0.395	0.484	0.273	0.290	0.457	0.355	0.240	0.000	0.394	0.303	0.318	0.445	0.318	0.337	0.329	0.386	0.402	0.304
C21	0.367	0.291	0.432	0.368	0.303	0.407	0.382	0.414	0.363	0.471	0.376	0.278	0.458	0.471	0.412	0.379	0.368	0.330	0.483	0.517	0.000	0.406	0.395	0.318	0.367	0.298	0.420	0.439	0.272	0.229
C22	0.329	0.394	0.369	0.266	0.316	0.251	0.367	0.375	0.388	0.329	0.438	0.240	0.318	0.267	0.437	0.330	0.343	0.330	0.495	0.336	0.446	0.000	0.420	0.433	0.522	0.298	0.330	0.350	0.259	0.317
C23	0.483	0.470	0.252	0.471	0.292	0.355	0.483	0.297	0.465	0.406	0.496	0.343	0.254	0.318	0.261	0.291	0.420	0.407	0.458	0.364	0.381	0.394	0.000	0.368	0.445	0.361	0.317	0.425	0.467	0.382
C24	0.253	0.483	0.444	0.291	0.267	0.343	0.305	0.362	0.324	0.354	0.331	0.509	0.387	0.240	0.337	0.252	0.290	0.367	0.406	0.465	0.521	0.315	0.381	0.000	0.369	0.402	0.343	0.453	0.324	0.331
C25	0.342	0.521	0.393	0.420	0.483	0.381	0.330	0.465	0.338	0.470	0.353	0.484	0.479	0.342	0.311	0.189	0.394	0.355	0.420	0.376	0.380	0.367	0.354	0.368	0.000	0.402	0.380	0.466	0.287	0.472
C26	0.368	0.342	0.380	0.357	0.419	0.407	0.291	0.362	0.323	0.381	0.470	0.445	0.478	0.228	0.300	0.356	0.444	0.419	0.292	0.376	0.292	0.368	0.471	0.330	0.395	0.000	0.291	0.442	0.427	0.510
C27	0.458	0.431	0.279	0.420	0.381	0.419	0.356	0.274	0.427	0.342	0.419	0.469	0.280	0.393	0.325	0.382	0.444	0.393	0.420	0.453	0.316	0.459	0.393	0.369	0.279	0.286	0.000	0.311	0.439	0.431
C28	0.317	0.355	0.342	0.316	0.367	0.510	0.484	0.403	0.377	0.470	0.457	0.343	0.367	0.394	0.336	0.457	0.382	0.522	0.393	0.362	0.317	0.380	0.394	0.355	0.381	0.298	0.446	0.000	0.517	0.342
C29	0.418	0.459	0.405	0.330	0.406	0.396	0.509	0.351	0.311	0.331	0.470	0.304	0.344	0.317	0.412	0.278	0.419	0.459	0.406	0.453	0.432	0.279	0.303	0.521	0.431	0.413	0.394	0.375	0.000	0.292
C30	0.317	0.599	0.279	0.329	0.304	0.393	0.304	0.413	0.388	0.394	0.408	0.292	0.369	0.510	0.478	0.343	0.419	0.446	0.407	0.286	0.367	0.305	0.330	0.356	0.420	0.374	0.382	0.296	0.399	0.000

Table 6. Total direct relation matrix of the SCP criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C1	0.537	0.609	0.564	0.516	0.536	0.553	0.552	0.538	0.566	0.566	0.568	0.531	0.537	0.539	0.533	0.485	0.585	0.549	0.585	0.593	0.535	0.501	0.524	0.550	0.567	0.557	0.540	0.558	0.528	0.563
C2	0.568	0.558	0.555	0.513	0.525	0.550	0.557	0.536	0.558	0.570	0.577	0.513	0.532	0.537	0.525	0.473	0.587	0.542	0.586	0.587	0.538	0.501	0.519	0.546	0.559	0.552	0.536	0.551	0.525	0.556
C3	0.573	0.593	0.525	0.516	0.526	0.546	0.559	0.549	0.561	0.573	0.569	0.517	0.523	0.538	0.523	0.493	0.580	0.544	0.584	0.599	0.533	0.495	0.521	0.553	0.560	0.549	0.537	0.556	0.534	0.566
C4	0.527	0.548	0.519	0.445	0.481	0.506	0.502	0.499	0.511	0.513	0.517	0.475	0.492	0.484	0.486	0.444	0.525	0.505	0.533	0.534	0.499	0.467	0.484	0.502	0.506	0.508	0.497	0.517	0.484	0.516
C5	0.521	0.560	0.523	0.476	0.465	0.520	0.525	0.510	0.519	0.528	0.530	0.488	0.500	0.501	0.492	0.462	0.534	0.521	0.552	0.553	0.505	0.473	0.492	0.519	0.526	0.519	0.504	0.523	0.494	0.522
C6	0.552	0.571	0.540	0.502	0.513	0.499	0.536	0.524	0.537	0.547	0.537	0.504	0.511	0.514	0.516	0.461	0.563	0.531	0.569	0.564	0.524	0.475	0.504	0.536	0.544	0.535	0.520	0.531	0.505	0.531
C7	0.569	0.591	0.546	0.516	0.526	0.551	0.519	0.531	0.546	0.564	0.566	0.523	0.535	0.530	0.529	0.483	0.582	0.545	0.578	0.581	0.537	0.490	0.519	0.541	0.561	0.544	0.535	0.559	0.528	0.552
C8	0.587	0.607	0.576	0.529	0.545	0.568	0.565	0.528	0.570	0.585	0.591	0.542	0.550	0.551	0.536	0.500	0.605	0.581	0.595	0.611	0.554	0.523	0.543	0.573	0.589	0.575	0.566	0.564	0.549	0.580
C9	0.585	0.606	0.565	0.516	0.534	0.571	0.562	0.561	0.529	0.560	0.569	0.530	0.533	0.549	0.546	0.493	0.592	0.546	0.596	0.587	0.547	0.495	0.533	0.556	0.567	0.553	0.549	0.577	0.544	0.565
C10	0.529	0.541	0.527	0.474	0.486	0.509	0.512	0.505	0.511	0.491	0.530	0.480	0.487	0.498	0.488	0.448	0.538	0.513	0.535	0.546	0.496	0.450	0.488	0.499	0.517	0.500	0.500	0.515	0.486	0.520
C11	0.518	0.551	0.518	0.468	0.486	0.502	0.516	0.509	0.503	0.527	0.495	0.483	0.493	0.502	0.493	0.442	0.531	0.505	0.531	0.539	0.490	0.468	0.491	0.508	0.522	0.513	0.510	0.506	0.490	0.516
C12	0.566	0.582	0.548	0.509	0.520	0.547	0.558	0.531	0.547	0.560	0.573	0.486	0.524	0.534	0.523	0.488	0.567	0.543	0.566	0.590	0.529	0.501	0.520	0.533	0.551	0.548	0.531	0.545	0.524	0.551
C13	0.528	0.547	0.524	0.482	0.495	0.506	0.521	0.499	0.516	0.528	0.530	0.493	0.468	0.503	0.493	0.459	0.545	0.515	0.544	0.553	0.503	0.463	0.493	0.518	0.526	0.520	0.505	0.529	0.485	0.529
C14	0.558	0.583	0.536	0.508	0.510	0.534	0.532	0.529	0.545	0.544	0.555	0.506	0.506	0.493	0.529	0.467	0.568	0.545	0.570	0.575	0.522	0.486	0.511	0.535	0.545	0.545	0.527	0.544	0.522	0.559
C15	0.566	0.601	0.563	0.521	0.517	0.546	0.555	0.555	0.554	0.565	0.571	0.531	0.531	0.537	0.500	0.486	0.570	0.556	0.582	0.589	0.538	0.509	0.526	0.550	0.569	0.554	0.543	0.561	0.525	0.563
C16	0.547	0.572	0.543	0.511	0.511	0.536	0.537	0.521	0.536	0.543	0.550	0.504	0.513	0.516	0.512	0.441	0.554	0.538	0.565	0.572	0.519	0.480	0.512	0.531	0.546	0.540	0.515	0.536	0.514	0.537
C17	0.566	0.578	0.548	0.500	0.522	0.533	0.547	0.546	0.550	0.560	0.565	0.517	0.523	0.532	0.520	0.472	0.537	0.541	0.575	0.584	0.535	0.485	0.509	0.532	0.550	0.544	0.532	0.552	0.525	0.551
C18	0.556	0.585	0.545	0.510	0.516	0.540	0.547	0.523	0.542	0.560	0.561	0.512	0.532	0.533	0.526	0.479	0.577	0.511	0.575	0.598	0.523	0.484	0.519	0.536	0.548	0.556	0.536	0.536	0.523	0.549
C19	0.560	0.579	0.554	0.503	0.518	0.541	0.544	0.529	0.540	0.560	0.541	0.504	0.521	0.523	0.521	0.477	0.563	0.545	0.537	0.584	0.525	0.492	0.514	0.531	0.550	0.550	0.538	0.538	0.522	0.552
C20	0.539	0.568	0.530	0.500	0.510	0.525	0.532	0.525	0.533	0.537	0.549	0.496	0.511	0.522	0.499	0.460	0.559	0.526	0.544	0.531	0.517	0.474	0.499	0.530	0.532	0.525	0.514	0.533	0.510	0.528
C21	0.556	0.573	0.551	0.507	0.512	0.542	0.544	0.536	0.542	0.562	0.558	0.506	0.529	0.535	0.524	0.479	0.566	0.538	0.578	0.588	0.497	0.495	0.518	0.533	0.550	0.535	0.535	0.551	0.513	0.536
C22	0.520	0.548	0.514	0.469	0.483	0.498	0.511	0.502	0.512	0.518	0.530	0.473	0.488	0.488	0.495	0.447	0.531	0.506	0.546	0.540	0.503	0.433	0.490	0.511	0.530	0.504	0.497	0.512	0.481	0.511
C23	0.571	0.594	0.542	0.520	0.517	0.544	0.558	0.532	0.556	0.562	0.573	0.516	0.518	0.528	0.517	0.476	0.576	0.549	0.582	0.581	0.534	0.499	0.491	0.543	0.562	0.546	0.532	0.555	0.534	0.554
C24	0.521	0.562	0.527	0.478	0.486	0.513	0.514	0.508	0.515	0.528	0.529	0.501	0.500	0.493	0.494	0.448	0.534	0.516	0.546	0.558	0.516	0.466	0.494	0.482	0.525	0.519	0.504	0.527	0.493	0.519
C25	0.568	0.607	0.562	0.524	0.540	0.554	0.554	0.554	0.554	0.576	0.570	0.535	0.544	0.538	0.529	0.476	0.583	0.553	0.588	0.591	0.542	0.505	0.528	0.551	0.533	0.558	0.545	0.567	0.527	0.570
C26	0.553	0.575	0.544	0.504	0.520	0.540	0.535	0.530	0.537	0.552	0.563	0.517	0.529	0.513	0.512	0.475	0.570	0.543	0.560	0.574	0.519	0.490	0.522	0.532	0.550	0.508	0.522	0.548	0.523	0.556
C27	0.564	0.587	0.540	0.512	0.520	0.544	0.544	0.526	0.549	0.552	0.563	0.522	0.516	0.530	0.518	0.480	0.574	0.544	0.574	0.584	0.525	0.500	0.519	0.539	0.544	0.536	0.501	0.541	0.527	0.553
C28	0.569	0.597	0.560	0.519	0.534	0.567	0.570	0.551	0.560	0.579	0.582	0.527	0.538	0.545	0.534	0.500	0.585	0.570	0.589	0.594	0.540	0.508	0.534	0.553	0.568	0.553	0.553	0.531	0.549	0.562
C29	0.569	0.598	0.558	0.513	0.530	0.551	0.564	0.540	0.548	0.560	0.575	0.517	0.530	0.532	0.533	0.479	0.580	0.557	0.582	0.593	0.542	0.493	0.520	0.559	0.564	0.554	0.542	0.555	0.499	0.551
C30	0.548	0.594	0.535	0.500	0.509	0.537	0.534	0.532	0.540	0.551	0.557	0.503	0.518	0.534	0.526	0.472	0.566	0.543	0.568	0.565	0.524	0.483	0.509	0.532	0.550	0.538	0.528	0.535	0.519	0.513

Table 7. Sum of influences given and received on the SCP criteria

Criteria	V^d	V^r	$V^d + V^r$	$V^d - V^r$
C1	16.465	16.339	32.803	0.126
C2	17.232	16.207	33.440	1.025
C3	16.154	16.270	32.425	(0.116)
C4	14.947	14.910	29.857	0.037
C5	15.277	15.240	30.517	0.037
C6	15.950	15.674	31.624	0.276
C7	16.083	16.152	32.235	(0.068)
C8	15.744	16.819	32.563	(1.075)
C9	16.072	16.499	32.571	(0.427)
C10	16.394	15.005	31.398	1.389
C11	16.518	15.010	31.529	1.508
C12	15.136	16.071	31.207	(0.936)
C13	15.411	15.203	30.614	0.208
C14	15.552	15.870	31.422	(0.318)
C15	15.355	16.309	31.664	(0.954)
C16	14.038	15.728	29.767	(1.690)
C17	16.797	16.009	32.806	0.788
C18	15.998	16.011	32.009	(0.014)
C19	16.885	15.934	32.819	0.951
C20	17.117	15.546	32.663	1.571
C21	15.590	15.965	31.555	(0.376)
C22	14.474	14.975	29.449	(0.501)
C23	15.232	16.139	31.370	(0.907)
C24	15.892	15.198	31.090	0.694
C25	16.285	16.399	32.684	(0.114)
C26	16.025	15.903	31.928	0.121
C27	15.673	16.004	31.678	(0.331)
C28	16.137	16.503	32.640	(0.365)
C29	15.372	16.273	31.646	(0.901)
C30	16.205	15.843	32.049	0.362

Table 8. Sum of influences given and received on the aspects

Aspects	V^d	V^r	$V^d + V^r$	$V^d - V^r$
A1	2.414	3.730	6.145	(1.316)
A2	4.559	3.852	8.412	0.707
A3	2.522	1.874	4.396	0.648
A4	4.040	4.265	8.305	(0.225)
A5	4.465	2.946	7.411	1.520
A6	2.644	3.978	6.622	(1.334)

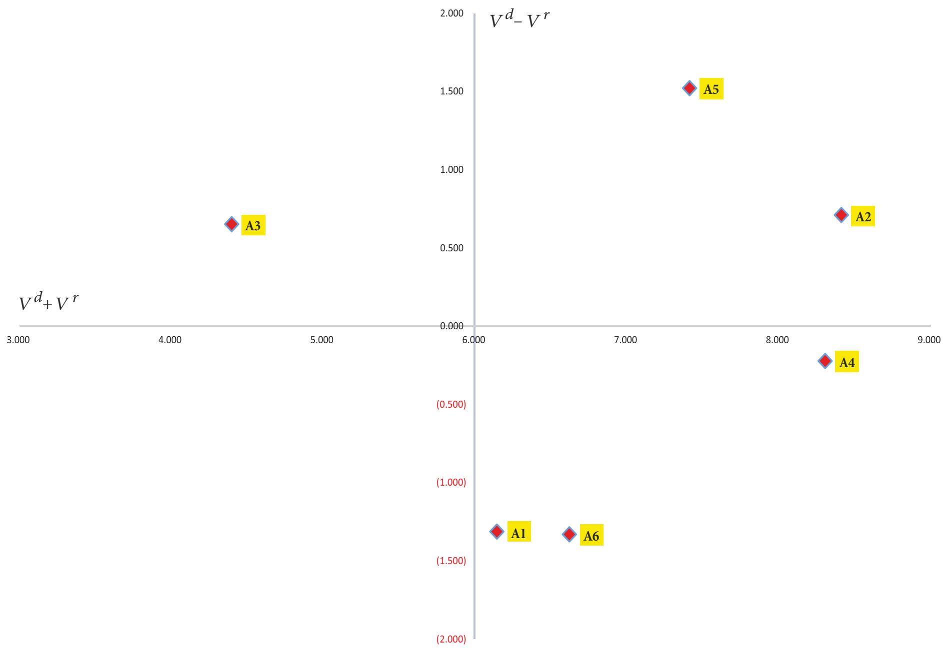

Figure 2. The cause and effect diagram of the aspects

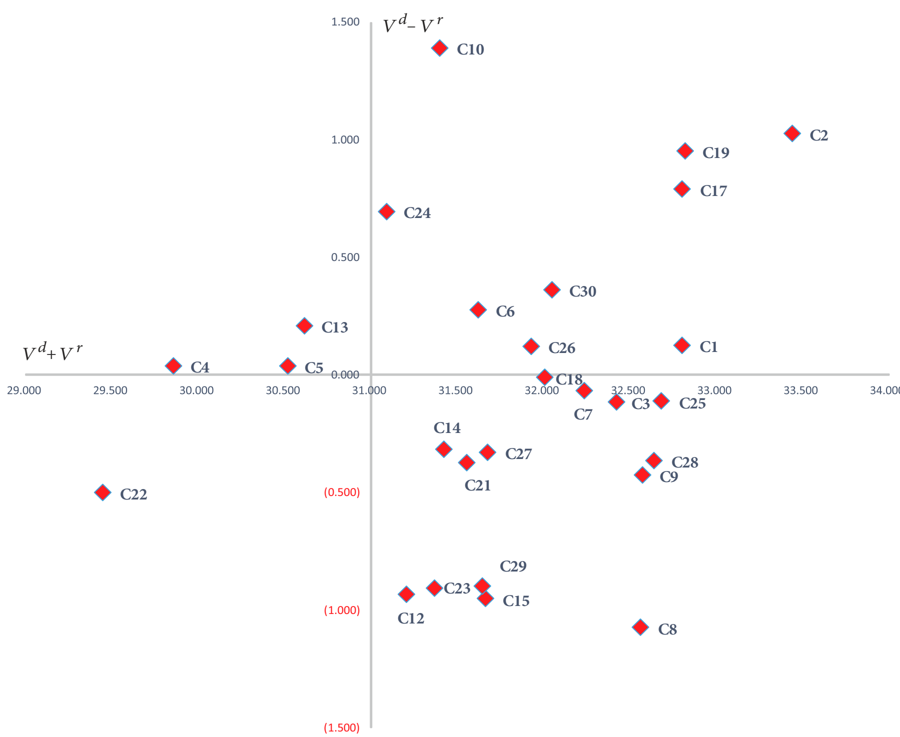

Figure 3. The cause and effect diagram of the SCP criteria

4. Discussion and implications

4.1. Theoretical implications

Several theoretical implications can be concluded from the results of the study. First, the study adopts the eco-innovation theory to explore SCP in the rapidly changing environment through multidimensional evaluation, which can establish a theoretical framework between eco-innovation and SCP. Second, the results which showed that SCP could be achieved by applying the eco-innovation agree with previous studies that suggest eco-innovation is the driver of SCP in some specific environment and practices (Giacomo et al., 2014). Finally, the study overcomes the drawback of DEMATEL by adopting the fuzzy set theory, which can reduce the uncertainty caused by experts' evaluation. Therefore, the empirical results are more accurate and reliable.

Furthermore, two important aspects should be discussed. Environment (A2) aspect, which stresses that the global environment is closely related to production and consumption trends, is considered to have the highest impact on SCP. Therefore, firms must consider the environment when making strategies towards SCP. However, development without sacrificing the environment has been emphasized and appealed for many years, but firms are profit-oriented and tend to ignore environmental issues. The results indicated that life cycle assessment, as well as eco-labels and environmental certification, are practical and rational ways to pursue SCP for firms without damaging the environment. Life cycle assessment can avoid and reduce environmental burden (Wu & Ma, 2018), and eco-labels and environmental certification can verify the overall environmental performance of a product or service within a particular product category (Cai, Xie, & Aguilar, 2017). In short, this aspect can lead firms to comply with regulations and policies and gain customer recognition.

Sustainable consumption (A5) is important to meet basic needs, improve life quality, and minimize the consumption of natural resources (Lim, 2017). It has become one of the policy factors that are increasingly important in strategies of national sustainable development (Seyfang, 2006). However, a clear understanding of the key drivers of sustainable consumption is a significant challenge for many firms. The results confirmed that although this aspect is the driving factor of SCP, the actions taken by firms are insufficient. Therefore, the study suggested that providing eco-demand for the customer, enhanced communication, and reuse and recycling can be adopted to improve the situation. It can be concluded that the comprehensive integration of sustainable consumption is not only a business strategy but also an effective management and market-based demand (Jones et al., 2014).

4.2. Managerial implications

As a valuable tool for sustainability assessment, life cycle assessment (C6) provides quantitative and overall information on the consumption of resources and potential environmental impacts. However, an increasing number of firms have realized that life cycle assessment can bring many benefits, but the practice is still insufficient due to management philosophy and limited resources. Accordingly, life cycle assessment is usually made up of four stages (Sharma, Saxena, Sethi, & Shree, 2011). First, firms should define the analysis aim, system boundary, and the functional unit and assumption. Second, establishing an analysis of inventory is required for when data about materials and energy consumption as well as wastes and emissions are collected, identified and quantified. Third, assessing the environmental impact of the previous stage by classifying, characterizing, normalizing, evaluating, and setting impact categories is necessary. Finally, based on the information gathered from the second and third stages, firms should analyze the inventory and environmental impact assessment while assisting in the decision-making.

Eco-labels and environmental certification (C10) can help increase firms' competitiveness and brand awareness, acquire customers' recognition, and support product differentiation. Currently, adopting this practice means firms may change the production structure, increase investments and utilize complex technologies. In the long term, it can generate positive impacts. Therefore, if firms want to make greener products or services, they should adjust traditional production mode, increase investments in adopting clean technologies and environmentally friendly packaging, and compile independently verified environmental information into a report format. Moreover, firms can also make their products or services evaluated or validated by authorities or governments, such as ISO certification, to gain client trust and market recognition.

Improving eco-efficiency (C24) can assist firms towards qualitative growth, increasing productivity, profits and value, rather than converting a larger quantity of materials into energy and waste. The adoption of this practice can also save time, reduce pollution, and produce higher-quality products. Moreover, firms can reduce the consumption of resources for goods and services and toxic substance dispersion, improve materials recyclability, and maximize the utilization of renewable resources to improve sustainable consumption performance. In addition, the increase in product durability, value aggregation to products and services, as well as the enhancement of employees' skills are feasible to improve eco-efficiency for firms.

Apart from the three criteria discussed above, other criteria located in the first quadrant are thought to be the driving factors that allow firms to explore SCP. Investments in equipment and technology reformation (C2) and Firm's R&D expenditure (C1) are under economic (A1) aspect. In corporate governance (A4) aspect, firms can adopt the practices of cooperation with external partners (C19) and product orientation (C17). The number of patent applications (C30) and pollution control and prevention (C26) are under sustainable production (A6).

Conclusions

Pursuing a sustainable pattern of both consumption and production has become a vital strategy for many construction firms. Eco-innovation can be a noteworthy measure for firms to accomplish their aims and improve sustainable performance. However, the issues defining SCP and the role of eco-innovation remain unclear. Therefore, thirty criteria of eco-innovation as evaluating factors were successfully proposed in six aspects based on SCP through literature review and expert discussion. The evaluation process was conducted using the fuzzy DEMATEL method and based on the expert committee's response. Meanwhile, the fuzzy set theory was adopted to overcome uncertain information generated by experts' assessments and transform qualitative information into quantitative assessments. Then, the DEMATEL method was used to investigate the causal inter-relationship among different aspects and criteria, and generate more valuable information that can provide a precise guide for practical applications.

Several contributions are provided in this work. This study reinforces the understanding of SCP and theoretically establishes its link with eco-innovation. In addition, convincing explanations of SCP development can be seen in the framework proposed in this study. The study provides a managerial contribution to the construction firms in China by assisting them to improve the patterns of consumption and production through the proposed criteria of eco-innovation to develop sustainable practices. With regard to the methodological contribution, the proposed FDEMATEL method can overcome the uncertain information generated by experts' judgments and create clear cause and effect diagrams, which can help decision-makers reduce assessment complexity and simplify decision-making processes.

The results also indicated that launching eco-innovation helps the construction firms achieve SCP. Environment and sustainable consumption are significant decisive aspects of SCP. Therefore, the majority of resources should be shifted by construction firms to enhance the performance toward environmentally friendly production activities and sustainable consumption patterns. The study suggests that the life cycle assessment, eco-labels and environmental certification as well as improving eco-efficiency are the preferred measures when the construction firms implement SCP strategy. In addition, several practices under the other aspects are equally the driving factors for SCP, such as investments in equipment and technology reformation and cooperation with external partners. Thus, if firms have suitable resources and conditions, these sustainable practices can also be taken into account.

Furthermore, firms should clearly understand the four processes of life cycle assessment: set aims and boundaries, inventory analysis, impact assessment, and making interpretations for giving conclusions and advice. Eco-labels and environmental certification are the practice that suggests firms using advanced technologies, adopting green packaging as well as providing environmental information report. Firms should acquire eco-certification, such as ISO certification. In addition, it is recommended that improving eco-efficiency should firstly reduce unnecessary resources consumption and toxic substance dispersion and then improve reuse and recycling performance. Enhancing product durability, aggregating product and service value, and improving employee skills also help to improve firms' eco-efficiency. In short, these eco-innovation practices provide insights for construction firms to improve effectiveness, reduce pollution and waste generation, and minimize resource consumption, thereby successfully implementing SCP strategy.

However, the proposed six aspects of SCP and thirty criteria of the eco-innovation utilized in the analysis may not be exhaustive. Therefore, the evaluation process could include more aspects and criteria for future research. This study researched the construction industry only in China. Therefore, the generalizability of the findings may be limited. Future research will expand the evaluation process to analyze other sectors or more case studies in other countries to make a comparative analysis. Furthermore, the experts involved in the study were specialized in the construction industry. Thus, other experts from various fields can form an expert group to bring different values and advice for future research.

Acknowledgements

The authors would like to thank the anonymous referees for their valuable comments and suggestions. The funding of this study was supported by the National Social Science Funding Program (15BGL023).

Funding

This work was supported by the <National Social Science Funding Program> under Grant [15BGL023].

Author contributions

Author Contributions: Li Ma contributed to research design, organization of survey, data collection and analysis, and discussion; Liang Wang contributed to literature review, factor identification, and data analysis; Mirosław J. Skibniewski contributed to research design, linguistic check and modification; Waldemar Gajda contributed to linguistic check and modification.

Disclosure statement

The authors declare no conflict of interest.

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