

# Assessing sustainability performance of high-tech firms through a hybrid approach

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# Assessing sustainability performance of high-tech firms through a hybrid approach

## Abstract

**Purpose** — In light of the lack of subjective criteria and scientific rationality in current sustainability performance assessment, the present study was conducted to improve the sustainability performance assessment of high-tech firms by developing a hybrid approach that integrates quantitative and qualitative research methods.

**Design/methodology/approach** — This study proposed a hybrid approach that integrates word frequency analysis, cluster analysis, grey theory and the decision-making and trial evaluation laboratory method. Specifically, this study identifies useful criteria using quantitative word frequency analysis as well as qualitative literature research. Then, cluster analysis is used to divide these criteria into different categories. Subsequently, this study applies the grey theory associated with the decision-making and trial evaluation laboratory method to assess the sustainability performance of high-tech firms.

**Findings** — The results reveal that the socio-environment is an important aspect underlying the corporate sustainability performance of high-tech firms. Therefore, high-tech firms should enhance their pollution emission control capabilities and increase investment in energy-conservation and emission-reduction technologies to drive sustainable development. In addition, increasing green product sales revenue and improving the guiding capability of green consumption are core issues that firms must address.

**Originality/value** — This study assesses the sustainability performance of high-tech firms by applying a hybrid method. This method can be used to construct a framework for scientific sustainability performance assessment and to provide a clear direction for the sustainable development of firms.

**Keywords:** sustainability performance; high-tech firms; assessment

## 1 Introduction

The Millennium Ecosystem Assessment Synthesis Report shows that economic development brings unprecedented energy consumption and environmental pollution. Sixty percent of the world's ecosystems are deteriorating due to a lack of sustainability (Millennium Ecosystem Assessment, 2005; Szilagyi et al., 2018). Countries around the world not only encourage firms to voluntarily fulfil their environmental responsibilities but also issue laws to regulate their practices and to promote sustainable development (Tien-Shang et al., 2012). Currently, with the increasing environmental awareness of consumers and relevant government regulation restrictions, firms are facing great pressure regarding their environmental policies and procedures (Mathiyazhagan et al., 2014; Mumtaz et al., 2018). With the advent of the knowledge economy and the big data era, the

sustainable development of high-tech firms has become a hot research topic (Silva, 2008; Xu and Lin, 2018). High-tech firms are economic entities that increase production capacity, create economic benefits and win market competition through innovative technologies, research and development of new products and the use of advanced equipment (Bojnec and Fertő, 2014; Yu et al., 2018). As key players in the upgrading of industrial structure, high-tech firms are better than resource-based firms at using knowledge and technology to improve product and service quality and thereby increase economic returns (Lin et al., 2012; Kuo et al., 2014; Xie et al., 2018). As international competition becomes increasingly fierce, high-tech firms, as representative of national science and technology innovation strength, are crucial for increasing national competitiveness (Ester et al., 2010; Wonglimpiyarat, 2016). Under the pressures of rapid market changes and technology upgrades, the assessment of sustainability performance can help high-tech firms identify problems and determine the path towards sustainable development. Many studies have been conducted on the sustainability assessment of resource-based firms. Such firms usually focus on clean energy, waste recycling, and other factors. In contrast, high-tech firms pay more attention to innovation-driven practices (Chen et al., 2018). Therefore, a new assessment framework is needed to assess the sustainability performance of high-tech firms.

Constructing a scientific assessment framework is the basis for assessing the sustainability performance of high-tech firms, and it includes theoretical support and criteria selection (Haider et al., 2018; Pan et al., 2018). Using the Triple Bottom Line (TBL) theory as the theoretical basis is the most commonly used method in the previous studies assessing corporate sustainability performance (Ahi and Searcy, 2015; Padhi et al., 2018). TBL includes economic, environmental and social dimensions, which are known as the "three pillars" of sustainability, to measure and report corporate sustainability performance (Elkington, 2010; Büyüközkan and Karabulut, 2018). In subsequent studies, researchers have expanded the TBL to include cultural sustainability as the fourth aspect in building a framework of corporate sustainability performance (Soini and Birkeland, 2014; Swanson and Devereaux, 2017). With the development of scientific and technological innovation, studies have also considered the technological sustainability aspect (Xu et al., 2018). Furthermore, researchers have also focused on the fuzzy area of TBL. For instance, some criteria belong to the economic and environmental aspects at the same time. Therefore, Wu et al. (2018) proposed the Overlapping Bottom Line (OBL) theory to supplement the TBL. Because the OBL is more comprehensive in assessing sustainability performance, we use the OBL as the theoretical basis in this study. Criteria selection is another important problem to consider when building a corporate sustainability-performance framework (Buyukozkan and Karabulut, 2018).

In most studies, criteria were taken from the literature (Bhakar et al., 2018; Stoycheva et al., 2018), which may cause a problem if the criteria from the literature are inconsistent with those from the firm due to the lag in the publication of relevant studies. However, big data analysis can quickly and accurately select valuable information from a mass of data (Bibri et al., 2018; Lv et

al., 2018). Among these approaches, the word frequency statistics method is a commonly used statistical method in big data analysis, and it can extract the required criteria through efficient word frequency observation (Brysbaert et al., 2018). Therefore, we propose a hybrid approach that combines quantitative word frequency analysis with qualitative literature research to develop sustainability criteria. Specifically, we select criteria based on a literature review, and use word frequency statistics to identify useful criteria from reports on 34 high-tech firms that have made the list of “China’s top ten eco-innovation firms”. In addition, because previous studies generally identified the theory first and then selected the criteria based on the theory (Cai and Li, 2018), criteria selection was restricted by the theory and may have been inconsistent with the actual situations of the studied firms. Thus, after the criteria are developed, a cluster analysis is performed to divide these criteria into different aspects. Then, we verify the rationality of the selected theory according to the classification results.

Many assessment methods have been used to evaluate corporate sustainability performance, including the balanced scoreboard (Duarte and Cruzmachado, 2015; Thanki and Thakkar, 2018), the analytic hierarchy process (Chatzimouratidis and Pilavachi, 2009; Wu et al., 2018), the data envelopment analysis method (Lee and Saen, 2012; Fathi and Saen, 2018), the interpretative structural model (Cui, 2017; Bhakar et al., 2018), and the decision-making and trial evaluation laboratory (DEMATEL) method. Among them, the DEMATEL method can effectively analyse the causal relationships among the criteria in the system and define the strength of the correlations between criteria (Gandhi et al., 2015; Li and Mathiyazhagan, 2018). Thus, this method is conducive to identifying the driving factors and core problems that affect corporate sustainability performance (Cui et al., 2019). However, the traditional DEMATEL method cannot overcome the problem of expert semantic ambiguity (Ding and Liu, 2018). Therefore, grey theory is introduced into the DEMATEL method due to its ability to handle vague information (Xia et al., 2015; Wu et al. 2016; Singh and Srivastava, 2018). Even so, this method is still highly subjective because it relies heavily on expert experience. Therefore, in order to enhance the objectivity and persuasiveness of the research result, we propose an approach combining quantitative and qualitative methods that includes word frequency analysis, cluster analysis, grey theory and DEMATEL to assess the sustainability performance of high-tech firms.

The contributions of this study include the following: (1) High tech firms are the subject of our study due to their contribution to economic development. Many existing studies have conducted assessments on resource-based firms but not on high-tech firms, and thus, our study further fills the research gaps in firm sustainability performance. (2) A cluster analysis is used to classify the criteria into groups that represent different aspects of the sustainability framework to ensure objective connectivity between those aspects and the criteria, and those aspects are compared with the dimensions of the OBL theory to verify the rationality of and strengthen that theory. (3) A hybrid approach that integrates word-frequency analysis, cluster analysis, grey theory and DEMATEL is proposed to assess the sustainability performance of high-tech firms.

The word-frequency analysis of reports on high-tech firms' sustainable practices is used in conjunction with keyword-assisted literature research methods to construct the corporate sustainability performance evaluation framework. Cluster analysis is used to verify the objective connection between the sustainability criteria and the aspects of the framework. The application of grey theory combining with DEMATEL overcomes the problem of expert semantic ambiguity in the assessment process. This new research concept improves the accuracy of the assessment results. This study is organized as follows. Section 2 presents the literature review. Section 3 contains the proposed methods and research procedure. Section 4 presents the case background, analysis process and results. Section 5 elaborates on the theoretical and managerial implications. The final section provides the conclusions, research limitations and relevant future studies.

## **2. Literature review**

### **2.1 Sustainability framework and performance**

To solve the problems of resource shortages and environmental degradation, firms are forced to engage in the practice of sustainable development (Koh et al., 2012; Bai et al., 2015). Firms can continually balance their economic performance, social responsibility and environmental protection objectives in the process of sustainable development to ensure competitiveness in the market (Tomšič et al., 2015). In 1987, the United Nations first elaborated the concept of sustainable development, which is the ability to meet current needs without harming future generations (Koroneos and Rokos, 2012). Based on this political concept, corporate sustainability at the organizational level can be considered the corporate efforts to balance their environmental, social and economic goals to minimize the harm and increase the benefits to the natural environment and society (Dyllick and Hockerts, 2002; Klewitz and Hansen, 2014). Sustainability performance reflects a firm's sustainability practices. The sustainability framework plays an important role in assessing sustainability performance (Nuong, 2017). When assessing sustainability performance, different sustainability frameworks will lead to different results. The earliest research on sustainability frameworks only focused on the economic benefits of firms without considering the environmental and social issues in the firm life cycle (Moneva et al., 2007; Bergenwall et al., 2012; Heikkurinen and Bonnedahl, 2013). In 1995, Elkington first proposed the concept of the TBL, which considers not only the economic value but also the environmental and social value of firms (Elkington, 1997; Garbie, 2014). Subsequently, the TBL became a common theory to guide the construction of corporate sustainability frameworks (Dainienė and Dagilienė, 2015). At the end of the twentieth century, with the in-depth study of sustainable development, sustainable consumption and production (SCP) was widely used as a measure of a firm's sustainability framework (Tseng et al., 2018; Wu et al., 2018).

Many studies have focused on sustainability performance assessments that cover all aspects of life. Liu et al. (2018) established a sustainability framework of driver-pressure-state-impact-response (DPSIR), which evaluated the sustainability of the China Marine Biotechnology Park. Kamali et al. (2018) proposed a modular framework based on the TBL to assess the sustainability



performance throughout the firm lifecycle. In addition, because the SCP promotes energy and resource optimization, the United Nations has identified it as one of its sustainable development goals. Many studies have also introduced SCP into a firm's sustainability framework to assess sustainability performance (Dubey et al., 2018). Govindan (2018) explored the drivers and barriers of supply chain sustainability in the food industry under the SCP framework. Studies have also integrated the TBL, SCP and other theories to build sustainability frameworks to comprehensively reveal the sustainability performance of firms (Schweikert et al., 2018; Govindan, 2018). Study results on sustainability performance provide references for sustainability practices of firms, such as for information collection and development direction (Bragança et al., 2010).

However, deficiencies remain. First, assessing sustainability performance with the TBL alone is not comprehensive (Bond and Morrison-Saunders, 2011; Stuart et al., 2014) because the TBL only focuses on the environment, society and economy. Wu et al. (2016) argued that it is not enough for firms to consider TBL practices in their sustainable development and that firms must also consider the sustainability requirements of the TBL overlap areas. Certain sustainability assessment criteria cover several aspects. For example, "energy saving" involves both environmental and economic aspects in an overlapping area (Mickovski and Thomson, 2017). Wu et al. (2018) indicated that the sustainability criteria should be decomposed into a clear hierarchical structure, which not only enhances the understanding of TBL theory but also identifies the overlapping portions of TBL that are consistent with corporate sustainable development practices. Thus, Wu et al. (2018) proposed the theory of overlap bottom line (OBL) that includes the socio-environmental, eco-efficiency and socio-economic sustainability dimensions. Second, the assessment criteria of sustainability performance are mainly from the literature, and criteria selection is a subjective process based on the researcher's judgement (Hezri and Dovers, 2006). However, data-related technology can extract meaningful information that can compensate for the deficiency of the subjective judgement of researchers (Dubey et al., 2016; Dubey et al., 2017). However, few studies have used data to assess a firm's sustainability performance (Chen et al., 2012; Xavier et al., 2017). The utilization of data from firms should be considered.

## 2.2 High-tech firms and sustainability performance assessment

Since high-tech firms emphasize the transformation of knowledge and technology and the realization of technological achievements, they can utilize and allocate limited resources more effectively than other types of firms (Chapas et al., 2010). Thus, with the advent of the "third industrial revolution", the development of high-tech firms has reached a climax (Hung and Wang, 2012). Achieving sustainable development has gradually become a strategic goal for the long-term development of high-tech firms. The development model has also gradually shifted from efficiency driven to innovation driven (Chen et al., 2018). With the advent of the era of the knowledge economy and big data, high-tech firms, as representatives of knowledge-intensive enterprises, have developed the characteristics of high investment, high output and rapid



development (Lin et al., 2018). Compared with other types of firms, high-tech firms invest more in R&D innovation, product upgrades and new energy sources and are therefore more likely to meet rapidly changing market demands. High-tech firms adjust their business production strategies by rationally locating internal and external resources, relying on knowledge platforms, and adjusting their business production strategies (Pan et al., 2018). They can achieve sustainable development by improving their technological innovation capabilities and accelerating the upgrading of industrial structure (Balkin et al., 2000). In recent years, high-tech firms have gradually become the main actors promoting economic development and enhancing national strength. Therefore, assessing the sustainability performance of high-tech firms has become a focus of current firm management research.

Many scholars have assessed the sustainability performance of high-tech firms from different dimensions, exploring the influential factors in the development of high-tech firms and proposing scientific management ideas. Based on empirical data from companies, Zhang et al. (2013) proposed that the liquidity ratio and independent innovation ability are important factors affecting the trust risk of high-tech firms and that these factors indirectly affect the sustainable performance of the firms. It has been suggested that as the role of knowledge capacity in firm development becomes increasingly prominent, maintaining strong internal and external knowledge capacity can mitigate the impact of financial crisis on sustainable development (Zouaghi et al., 2018). To address the complexity of sustainable development, Sadeghi (2018) adopted a systematic approach and demonstrated that policies and regulations are the most important factors influencing the sustainable development of high-tech firms. They suggested that the government simplify relevant laws and create a sustainable regulatory environment for high-tech firms. In addition, due to the characteristics of high-tech firms, R&D intensity and scale effect are closely related to stock returns, which have profound impacts on expansion and sustainable development (Yu et al., 2018).

Although some studies have explored the development paths of high-tech firms, research on how high-tech firms can achieve sustainable development remains sparse (Law and Gunasekaran, 2012), and gaps remain in the assessment of the sustainability performance of high-tech firms. Most previous studies extracted sustainability criteria based on literature research; this approach does not consider the development status of high-tech firms (Lin et al., 2018). In addition, in previous work, the sustainability indicators of high-tech firms have mainly comprised financial indicators, whereas non-financial indicators for complex competitive environments and long-term sustainable performance of firms have largely been ignored (Tseng et al., 2009). Furthermore, most previous assessments of the influencing factors of high-tech firms have adopted linear parameter assessment models, ignoring the nonlinear relationships between influencing factors and thereby resulting in low practicability of the assessment results (Han et al., 2017). Therefore, this study constructs a scientific corporate sustainability framework that references the actual data of high-tech firms. Then, a multi-criteria decision making method (GDEMATEL) is employed to

explore the internal relationships among the criteria affecting the sustainability performance of high-tech firms and to provide scientific guidance for firm development.

### 2.3 Proposed method

Currently, various methods are used to assess corporate sustainability performance. The global reporting initiative (GRI) is recognized as an effective assessment framework (Hedberg and Malmberg, 2003; Brown et al., 2009). Srivastava and Raj (2018) used a multi-criteria decision approach to assess the sustainability performance of aircraft manufacturers based on the GRI. Subsequently, Kim et al. (2015) and Ekener et al. (2018) proposed the decision-making framework conforming to the characteristics of firms based on the GRI and provided decision support for the sustainability practices of the firm by using the life cycle assessment (LCA) method. Some studies have established sustainability conceptual frameworks based on the nature of the firm and used the AHP to assess the impact of sustainability criteria on firm sustainable performance (Hu et al., 2011; Dai and Blackhurst, 2012; Singh and Vinodh, 2017). In addition, some studies have used data envelopment analyses (DEAs) to assess the sustainability performance of high-tech firms according to input and output indicators (Hung and Wang, 2012). Although these methods have been widely used in the assessment of sustainability performance, the indicators are usually quantifiable (Lu et al., 2018) and thus do not apply to criteria that cannot be quantified.

To assess corporate sustainability performance comprehensively from multiple dimensions, a proper method must be used. Multi-criteria decision-making (MCDM) methods are usually used to deal with qualitative criteria, and they include the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), Interpretative Structural Modelling (ISM), the Analytic Network Process (ANP) and DEMATEL (Büyüközkan and Güler, 2018; Cui, 2017; Yilmaz and Nuriine, 2018). The DEMATEL method is especially capable of revealing the driving factors and core problems affecting corporate sustainability performance as well as the relationships between sustainability criteria (Lu et al., 2018). However, the traditional DEMATEL method cannot overcome the problem of expert semantic ambiguity (Lin et al., 2018); thus, researchers have improved upon this method. Song and Cao (2017) combined the rough set and DEMATEL to assess the causal relationship between the requirements of the product service system. Lin et al. (2018) integrated the fuzzy theory and DEMATEL to consider the sustainable decision-making of fuzzy variables or language variables in dynamic changes of the supply chain of a firm. Combining grey theory is also an effective way to overcome uncertainty (Wu et al., 2018; Tseng et al., 2018). Considering the purpose of this study, we use the GDEMATEL method to assess corporate sustainability performance.

In addition, most studies have used the literature review method to obtain assessment criteria (Song et al., 2016; Kumar et al., 2017). Due to limitations of publication time, the criteria from the literature may reflect the current situation, although the subjectivity of researchers also affects the reliability of sustainability criteria. In this situation, real firm data are necessary to assist the

criteria selection (Gaviglio et al., 2016). Word frequency statistics is an effective approach to obtaining data from corporate text materials (Wada et al., 2003; Yan and Minnhagen, 2016). Through high frequency word analyses, we can determine the views of firms regarding sustainability (Piantadosi, 2014; Lu et al., 2018). Moreover, although most studies are based on some theory, there is a lack of verification regarding the theory (Munier, 2011; Tokos et al., 2012; Bhakar et al., 2018). Clustering analysis is an exploratory data analysis tool that can divide the data into different categories (Horiuchi et al., 2018). Therefore, the use of cluster analysis to divide criteria into several categories and the construction of a scientific assessment framework for high-tech firms warrant exploration.

#### 2.4 Proposed measures

The selection of assessment criteria is the first step. We select “high-tech firms”, “sustainability” and related words as keywords to obtain the sustainability performance criteria. High-tech firms pay considerable attention to the product-processing stage, and the pollution emission control capability (B1) can directly reflect the extent of firm pollution (Khanna et al., 2009; Pei et al., 2015). To reduce the environmental impact of waste, increasing investment in energy-conservation and emission-reduction technologies (B2), increasing the number of patents (B3) and improving the waste recycling rate (B4) have become important eco-innovation methods used by firms (Zhu and Qian, 2015; Dong et al., 2018). Firms also need to strengthen the guidance of green consumption for consumers (B5), increase the market demand for green products (B6) and constantly improve their market competitiveness (Mohr and Shooshtari, 2003; Heikkurinen and Bonnedahl, 2013; Severo et al., 2018). Especially in this era, human capital, as an important firm resource, can provide sustainable motivation for firm competition (He et al., 2018). Therefore, the technical level of employees (B7), senior management's emphasis on eco-innovation (B8) and senior management's recognition of green production (B14) are the key criteria affecting corporate sustainability performance (Hoyt and Matuszek, 2001; Wagner, 2008; Leszczynska, 2010; Vathsala and Sampath, 2012). In addition, green product sales revenue (B9) and the cost of green product design and development (B10) are important criteria affecting the long-term development of firms (Rexhäuser and Löschel, 2015; Gaziulusoy, 2015; Kuo and Smith, 2018). Firms should also strengthen cooperation with stakeholders. Government support for environmental protection (B11) can grant firms with considerable funds for sustainable development (Graham, 2001; Ball et al., 2018), and cooperation between firms and scientific research institutions regarding eco-innovation technology (B12) enhances competitiveness (Rogers, 2001; Pan et al., 2018; Faria and Andersen, 2018). Finally, the social responsibility contribution (B13) input provides the benefit of improving the firm's image of corporate responsibility and promoting sustainable development (Carter, 2000; Ardito et al., 2018; Tseng et al., 2018).

Table 1 includes the proposed sustainability performance criteria for firms.

Table 1 Proposed sustainability performance criteria for firms.

| Criteria |   | References  |
|----------|---|---|
| B1       | Pollution emission control capability                                 | Khanna et al. (2009), Pei et al. (2015)   |
| B2       | Investment in energy-conservation and emission-reduction technologies | Horbach (2016)  |
| B3       | Number of patents on energy conservation and emission reduction       | Zhu and Qian (2015), Costantini et al. (2017)                                       |
| B4       | Waste recycling rate  | He et al. (2018), Dong et al. (2018)  |
| B5       | Guiding capability of green consumption                               | Severo et al. (2018)  |
| B6       | Market demand of green products                                       | Mohr and Shooshtari (2003), Rehfeld et al. (2007), Heikkurinen and Bonnedahl (2013) |
| B7       | Technical level of employees  | Hoyt and Matuszek (2001), Vathsala and Sampath (2012)                               |
| B8       | Senior management's emphasis on eco-innovation                        | Leszczynska (2010), Cai and Li (2018)   |
| B9       | Green product sales revenue   | Wang and Wang (2014), Rexhäuser and Löschel (2015)                                  |
| B10      | Cost of green product design and development                          | Wang and Lestari (2013), Gu et al. (2016), Han et al. (2017), Kuo and Smith (2018)  |
| B11      | Government support for environmental protection                       | Graham (2001), Hong et al. (2015), Ball et al. (2018)                               |
| B12      | Degree of cooperation on eco-innovation technology                    | Rogers (2001), Pan et al. (2018)  |
| B13      | Input cost of social responsibility contribution                      | Xia et al. (2018), Ardito et al. (2018)   |
| B14      | Senior management's recognition of green production                   | Rehfeld et al. (2007), Wagner et al. (2008)   |

3. Methods

A hybrid approach is used to assess corporate sustainability performance in this study. First, a qualitative literature research method is used to select a number of sustainability criteria. Based on these results, the quantitative statistics of word frequency analysis are used to assist in screening the criteria to enhance their objectivity. Second, according to the characteristics of the criteria and expert opinions, cluster analysis is used to divide the criteria into several sustainability aspects, and then a sustainability performance assessment framework is built. Finally, in order to overcome the problem of expert semantic ambiguity, grey theory and DEMATEL are combined to assess the sustainability performance of high-tech firms. The specific procedure is described as follows.

Step 1: word frequency statistics of firm features.

- (1) Collect the high-tech firms' features that reflect the status of firm operation.
- (2) Use the word frequency analysis tool "Tu Yue" to analyse and choose the words. Reserve the words that occur at a frequency greater than 20.
- (3) Compare these words with the criteria in Table 1 to ensure the selected criteria are credible.

Step 2: cluster analysis of sustainability performance criteria.

- (1) Construct the sample matrix according to the expert's assessment of the criteria.

$$S = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1m} \\ S_{21} & S_{22} & \cdots & S_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ S_{n1} & S_{n2} & \cdots & S_{4m} \end{bmatrix} \tag{1}$$

where  $S_{ij}$  ( $i = 1, 2, \dots, n; j = 1, 2, \dots, m$ ) represents the observed value of the  $j$ th variable of the  $i$ th sample.

(2) Use the Euclidean distance formula to calculate the similarity  $d_{ij}$  between samples. Then, calculate the value of the distance between the two categories by using the inter-group connection method (Everitt and Rabeheesketh, 1980; Zeng et al., 2008). The formulas are as follows:

$$d_{ij} = \sqrt{\sum_{k=1}^m (S_{ik} - S_{jk})^2} \quad (i = 1, 2, \dots, n; j = 1, 2, \dots, m) \quad (2)$$

$$D_{pq}^2 = \frac{1}{n_p n_q} \sum_{i \in Z_p} \sum_{j \in Z_q} d_{ij}^2 \quad (i = 1, 2, \dots, n; j = 1, 2, \dots, m) \quad (3)$$

where  $D_{pq}$  is the distance between categories  $Z_p$  and  $Z_q$ ;  $d_{ij}$  is the distance between any two categories  $Z_p$  and  $Z_q$ ; and  $n_p$  and  $n_q$  represent the number of samples in categories  $Z_p$  and  $Z_q$ , respectively.

(3) Divide the criteria according to the similarity of  $D_{pq}^2$  into several groups (Hardy, 1996; Arbolino et al., 2017).

(4) Name each group according to the aspect of assessing sustainability performance to complete the assessment framework of sustainability performance.

*Step 3:* Use GDEMATEL to assess the causal relationship between the sustainability criteria (Wu et al., 2017; Cui et al., 2019).

(1) The initial relational matrix of aspects and standards is constructed, which is defined as  $x_i$ ,  $i=1, 2, 3, \dots, n$ . Then, the initial relation matrix  $X$  is constructed as formula (4).

$$MATRIX \ X: \begin{matrix} & \begin{matrix} x_1 & x_2 & \cdots & x_n \end{matrix} \\ \begin{matrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{matrix} & \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & 0 \end{bmatrix} \end{matrix} \quad (4)$$

where  $x_i$  is the  $i$ th aspect or criterion in the system and  $x_{ij}$  denotes the degree to which the criteria  $i$  affect the criteria  $j$ .

(2) Grey theory is applied to convert the scores of experts into grey numbers, which solves the problem of expert semantic ambiguity. The expert scoring results are converted into the corresponding grey numbers (Chen, 2000). The linguistic scales for the corresponding grey numbers are shown in Table 2.

Table 2 Linguistic scales for the corresponding grey numbers.

| Scales | Linguistic terms              | Grey numbers |
|--------|-------------------------------|--------------|
| 0      | No influence/importance       | (0, 0)       |
| 1      | Very low influence/importance | (0, 0.25)    |
| 2      | Low influence/importance      | (0.25, 0.5)  |
| 3      | High influence/importance     | (0.5, 0.75)  |

4

Very high influence/importance

(0.75, 1.0)

(3) Calculate the left ( $l_{ij}^k$ ) and right ( $r_{ij}^k$ ) normalized values, where  $k$  is the number of experts.

$$xl_{ij}^k = (l_{ij}^k - \min l_{ij}^k) / \Delta_{\min}^{\max} \quad (5)$$

$$xr_{ij}^k = (r_{ij}^k - \min r_{ij}^k) / \Delta_{\min}^{\max} \quad (6)$$

where  $\Delta_{\min}^{\max} = \max r_{ij}^k - \min l_{ij}^k$

(4) Calculate the total normalized crisp value  $x_{ij}^k$  utilizing equation (7).

$$x_{ij}^k = [xl_{ij}^k(1 - xl_{ij}^k) + (xr_{ij}^k)^2] / [1 - xl_{ij}^k + xr_{ij}^k] \quad (7)$$

(5) Calculate the final crisp values by equation (8).

$$c_{ij} = (x_{ij}^1 + x_{ij}^2 + \dots + x_{ij}^k) / k \quad (8)$$

(6) Based on the direct relation matrix  $G_{n \times n} = [c_{ij}]_{n \times n}$ , the normalized direct relation matrix  $G^n$  can be obtained through equation (9).

$$G^n = G / \max_{1 \leq i \leq n} \sum_{j=1}^n c_{ij} \quad (9)$$

(7) Using equation (10) to obtain the total relation matrix  $G^t$ , where  $I$  is denoted as the identity matrix.

$$G^t = G^n(I - G^n)^{-1} \quad (10)$$

(8) Calculate the sum of rows ( $R$ ) and the sum of columns ( $D$ ).

$$G^t = [g_{ij}^t]_{n \times n}, i, j = 1, 2, \dots, n. \quad (11)$$

$$R = [\sum_{i=1}^n g_{ij}^t]_{n \times 1} = [g_j^t]_{n \times 1} \quad (12)$$

$$D = [\sum_{j=1}^n g_{ij}^t]_{1 \times n} = [g_i^t]_{1 \times n} \quad (13)$$

(9) Produce a cause and effect diagram from the dataset ( $D + R, D - R$ ).

## 4 Results and analysis

### 4.1 Case background

Under the background of China's High-tech R&D (863) Program and the China Torch Program, the Chinese government encourages the sustainable development of high-tech firms. Dalian High-tech Park is the first state-level high-tech industrial development zone approved by the Chinese government in March 1991. It is the highland for high-tech industrial agglomeration as well as a platform for independent innovation in Northeast China. However, in the process of establishing, planning and introducing projects, high-tech parks place more emphasis on economic benefits, whereas environmental treatment is still at the initial stage. Although certain economic benefits have been realized in the short term, a strong production and operations environment is the foundation for ensuring sustainable profitability and maintaining a positive social image in the long run. Because high-tech firms are characterized by high investment, large output and a long development cycle, it is difficult for them to realize economic benefits in the short term. In addition, due to the poor industrial structure and low level of environmental management in



Dalian High-tech Park, firms pursue sustainable development as an important means of maintaining long-term stability, and they are in urgent need of relevant performance assessment and guidance. Therefore, in the next section, we use the approach discussed in the previous section to assess the sustainability performance of the firms in Dalian High-tech Park.

## 4.2 Results

In this section, we assess and analyse sustainability performance of high-tech firms according to the procedure in section 3.

(1) The features of the high-tech firms are assessed using word frequency statistics. First, this study takes an “international financing” journal as the statistical source. The International Finance Journal is sponsored by the China Council for the Promotion of International Trade Promotion and Publication Centre. The journal is dedicated to comprehensively reporting policy and project information on international financial institutions' assistance to China and is concerned with the latest developments of listed companies in China and abroad. Many of the International Finance Journal's research results, academic viewpoints and market forecasts have become important references for policy making and investment decision-making in all sectors of society. Since 2010, the International Finance Journal has annually selected 10 eco-innovation companies that meet the requirements of sustainable development, and reported on their production and management methods in all aspects. The results of this report are published in a special issue to provide an important reference for the study of corporate sustainable practices. Thus, this study conducts a statistical analysis of the frequency of words used in the International Finance Journal's reports on 34 high-tech firms that have been made the journal's list of "China's top 10 eco-innovation firms" from 2010 to 2017. "Tu Yue" is the word frequency analysis tool used to analyse the special reports on the 34 high-tech firms. The statistical results show that 128 original high-frequency words were obtained by “Tu Yue”. Then, 51 words are selected as the final high-frequency words. The frequency of each word is 20 or greater. The total frequency of the final high-frequency words is 4581, thus accounting for 67.18% of the total frequency of the high-frequency words. Among them, the top ten words are technology, energy conservation, products, environmental protection, innovation, investment, energy, ecology, green and market. Finally, these words are compared with the criteria in Table 1 to determine the final sustainability performance assessment criteria. See Table 3.

Table 3 Proposed criteria and word frequency statistics.

|    | Criteria  | Word frequency statistics   |
|----|---|---|
| B1 | Pollution emission control capability                                 | craftwork (103), contaminate (77), discharge (78), reduce (52), monitor (23), govern (23)   |
| B2 | Investment in energy-conservation and emission-reduction technologies | technology (571), energy conservation (348), environmental protection (189), cost (96), science and technology (75), energy efficiency (33) |
| B3 | Number of patents on energy conservation and emissions reduction      | energy conservation (348), environmental protection (189), energy (179), environment (122), emission reduction (56), patent (32)            |



|     |  |  |
|-----|--|--|
| B4  | Waste recycling rate                                 | effluent (99), sewage (77), circulate (54), recycle (51), waste (26)   |
| B5  | Guiding capability for green consumption             | product (229), green (150), spread (76), sale (41)   |
| B6  | Market demand for green products                     | product (229), green (150), market (143), demand (24)  |
| B7  | Technical level of employees                         | technology (571), expert (36), specialty (31), professor (27)  |
| B8  | Senior management's emphasis on eco-innovation       | innovate (186), ecology (150), chairman (70), general manager (58), new energy (46), president (34)                    |
| B9  | Green product sales revenue                          | product (229), green (150), sale (41), revenue (37)  |
| B10 | Cost of green product design and development         | product (229), green (150), research and development (131), cost (96)  |
| B11 | Government support for environmental protection      | environmental protection (189), investment (186), financing (65), guarantee (25), government (21)                      |
| B12 | Degree of cooperation on eco-innovation technology   | technology (571), ecology (150), co-partner (54), cooperate (40)   |
| B13 | Input cost of the social responsibility contribution | investment (186), project (136), cost (96), responsibility (27)  |
| B14 | Senior management's recognition of green production  | Green (150), chairman (70), general manager (58), clean (43), new energy (46), president (34), energy consumption (31) |

The word frequency statistics in Table 3 show the sustainable practices on which the 34 high-tech firms focus. It can also be seen that these practices are consistent with the criteria proposed in the literature, which ensures the reliability of the criteria.

(2) Cluster analysis of criteria. In the studies on corporate sustainability assessment, most researchers have invited 6-10 senior experts to participate in questionnaires or interviews (Tseng, 2010). Accordingly, we invited nine experts to complete the questionnaires about the importance of sustainability performance criteria. The experts all have more than 5 years of work experience and extensive experience in corporate sustainable development. The experts comprise 2 university professors and 3 chairmen, 3 senior managers, and 1 deputy general manager from Dalian High-tech firms. A 5-point Likert scale is used, where 1 represents no importance, 2 represents very low importance, 3 represents low importance, 4 represents high importance, and 5 represents very high importance. The sample matrix is shown in Table 4.

| Table 4 Sample matrix |    |    |    |    |    |    |    |    |    |     |     |     |     |     |
|-----------------------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|
|                       | B1 | B2 | B3 | B4 | B5 | B6 | B7 | B8 | B9 | B10 | B11 | B12 | B13 | B14 |
| E1                    | 2  | 4  | 3  | 5  | 4  | 2  | 2  | 2  | 3  | 5   | 2   | 3   | 2   | 2   |
| E2                    | 3  | 5  | 4  | 4  | 3  | 3  | 5  | 3  | 4  | 5   | 2   | 2   | 2   | 3   |
| E3                    | 4  | 4  | 3  | 4  | 3  | 3  | 3  | 4  | 3  | 4   | 1   | 4   | 2   | 4   |
| E4                    | 4  | 5  | 3  | 5  | 4  | 3  | 4  | 4  | 4  | 4   | 2   | 5   | 2   | 4   |
| E5                    | 5  | 4  | 3  | 4  | 3  | 3  | 5  | 5  | 3  | 3   | 2   | 5   | 3   | 5   |
| E6                    | 4  | 4  | 4  | 4  | 2  | 1  | 4  | 4  | 3  | 3   | 1   | 5   | 3   | 4   |
| E7                    | 3  | 5  | 3  | 5  | 3  | 2  | 3  | 3  | 4  | 3   | 2   | 3   | 3   | 4   |
| E8                    | 5  | 4  | 2  | 4  | 3  | 3  | 5  | 5  | 4  | 3   | 3   | 5   | 2   | 3   |
| E9                    | 4  | 5  | 3  | 3  | 2  | 3  | 4  | 4  | 4  | 4   | 2   | 4   | 2   | 5   |

The criteria are classified according to the calculation results of formulas (2) and (3). We use SPSS 20.0 to show the cluster process by the inter-group association method in Table 5.

Table 5 Cluster table

| Stage | Cluster Combined |           | Coefficients | Stage Cluster First Appears |           | Next Stage |
|-------|------------------|-----------|--------------|-----------------------------|-----------|------------|
|       | Cluster 1        | Cluster 2 |              | Cluster 1                   | Cluster 2 |            |
| 1     | 1                | 8         | 0.000        | 0                           | 0         | 2          |
| 2     | 1                | 12        | 4.000        | 1                           | 0         | 4          |
| 3     | 2                | 4         | 6.000        | 0                           | 0         | 11         |
| 4     | 1                | 14        | 7.333        | 2                           | 0         | 8          |
| 5     | 11               | 13        | 8.000        | 0                           | 0         | 10         |
| 6     | 9                | 10        | 8.000        | 0                           | 0         | 9          |
| 7     | 5                | 6         | 8.000        | 0                           | 0         | 10         |
| 8     | 1                | 7         | 8.500        | 4                           | 0         | 12         |
| 9     | 3                | 9         | 9.000        | 0                           | 6         | 11         |
| 10    | 5                | 11        | 11.500       | 7                           | 5         | 13         |
| 11    | 2                | 3         | 12.667       | 3                           | 9         | 12         |
| 12    | 1                | 2         | 16.760       | 8                           | 11        | 13         |
| 13    | 1                | 5         | 28.600       | 12                          | 10        | 0          |

Table 5 shows that the coefficients change significantly until “Stage 3”. Therefore, we divide the criteria into three categories and name each category. The cluster results are shown in Table 6.

Table 6 Cluster results

| Aspects                        | Criteria   | Name |
|--------------------------------|--|------|
| Socio-Environmental<br>(A1)    | Pollution emission control capability (B1)                                 | C1   |
|                                | Technical level of employees (B7)  | C2   |
|                                | Senior management's emphasis on eco-innovation (B8)                        | C3   |
|                                | Degree of cooperation on eco-innovation technology (B12)                   | C4   |
|                                | Senior management's recognition of green production (B14)                  | C5   |
| Environmental-Economic<br>(A2) | Investment in energy conservation and emission reduction technologies (B2) | C6   |
|                                | Number of patents on energy conservation and emission reduction (B3)       | C7   |
|                                | Waste recycling rate (B4)  | C8   |
|                                | Green product sales revenue (B9)   | C9   |
|                                | Cost of green product design and development (B10)                         | C10  |
| Socio-Economic<br>(A3)         | Guiding capability for green consumption (B5)                              | C11  |
|                                | Market demand for green products (B6)                                      | C12  |
|                                | Government support for environmental protection (B11)                      | C13  |
|                                | Input cost of the social responsibility contribution (B13)                 | C14  |

In Table 6, we divide the criteria into 3 categories. Next, the criteria are renamed to facilitate

the assessment. The categories are named Socio-Environmental, Environmental-Economic and Socio-Economic, and they are the aspects of the assessment framework.

(3) The assessment analysis is based on the GDEMATEL method. According to Table 6, we redesign and send the expert questionnaires to the 9 experts. First, according to Table 2, the expert scoring results are converted into the corresponding grey numbers.

Then, the total relation matrix of the aspects and criteria are obtained by Eqs. (4) - (10), as shown in Tables 7-8.

Table 7 Total relation matrix of aspect

|    | A1    | A2    | A3    |
|----|-------|-------|-------|
| A1 | 3.008 | 3.192 | 3.146 |
| A2 | 3.273 | 2.862 | 3.099 |
| A3 | 3.654 | 3.515 | 3.123 |

Table 8 Total relation matrix of criteria

|     | C1    | C2    | C3    | C4    | C5    | C6    | C7    | C8    | C9    | C10   | C11   | C12   | C13   | C14   |
|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| C1  | 0.560 | 0.538 | 0.572 | 0.593 | 0.539 | 0.601 | 0.477 | 0.603 | 0.619 | 0.555 | 0.608 | 0.526 | 0.573 | 0.532 |
| C2  | 0.580 | 0.457 | 0.517 | 0.560 | 0.537 | 0.598 | 0.435 | 0.542 | 0.584 | 0.533 | 0.572 | 0.472 | 0.528 | 0.483 |
| C3  | 0.636 | 0.537 | 0.492 | 0.582 | 0.538 | 0.594 | 0.458 | 0.582 | 0.607 | 0.558 | 0.602 | 0.512 | 0.569 | 0.503 |
| C4  | 0.624 | 0.538 | 0.548 | 0.521 | 0.569 | 0.619 | 0.464 | 0.589 | 0.602 | 0.547 | 0.597 | 0.499 | 0.563 | 0.512 |
| C5  | 0.555 | 0.498 | 0.500 | 0.553 | 0.449 | 0.576 | 0.423 | 0.533 | 0.565 | 0.509 | 0.551 | 0.451 | 0.517 | 0.467 |
| C6  | 0.603 | 0.551 | 0.535 | 0.560 | 0.546 | 0.522 | 0.451 | 0.573 | 0.595 | 0.527 | 0.588 | 0.474 | 0.543 | 0.489 |
| C7  | 0.596 | 0.494 | 0.526 | 0.546 | 0.500 | 0.563 | 0.379 | 0.555 | 0.559 | 0.490 | 0.543 | 0.464 | 0.530 | 0.483 |
| C8  | 0.540 | 0.440 | 0.501 | 0.510 | 0.471 | 0.520 | 0.401 | 0.448 | 0.511 | 0.467 | 0.531 | 0.421 | 0.488 | 0.459 |
| C9  | 0.689 | 0.629 | 0.615 | 0.664 | 0.633 | 0.682 | 0.498 | 0.657 | 0.608 | 0.629 | 0.676 | 0.570 | 0.632 | 0.581 |
| C10 | 0.669 | 0.595 | 0.591 | 0.645 | 0.605 | 0.664 | 0.492 | 0.608 | 0.660 | 0.533 | 0.654 | 0.559 | 0.612 | 0.574 |
| C11 | 0.670 | 0.598 | 0.608 | 0.642 | 0.605 | 0.656 | 0.485 | 0.639 | 0.675 | 0.610 | 0.586 | 0.559 | 0.616 | 0.582 |
| C12 | 0.684 | 0.598 | 0.612 | 0.641 | 0.607 | 0.667 | 0.509 | 0.639 | 0.665 | 0.609 | 0.657 | 0.489 | 0.612 | 0.561 |
| C13 | 0.671 | 0.564 | 0.593 | 0.623 | 0.585 | 0.647 | 0.499 | 0.631 | 0.653 | 0.599 | 0.648 | 0.530 | 0.534 | 0.551 |
| C14 | 0.602 | 0.506 | 0.542 | 0.557 | 0.495 | 0.550 | 0.441 | 0.573 | 0.594 | 0.543 | 0.590 | 0.476 | 0.543 | 0.441 |

Subsequently, according to Eqs. (11) - (13), the sum of rows (R), the sum of columns (D), as well as (D+R) and (D-R) are calculated. The results are shown in Tables 9 and 10.

Table 9 Prominence and relation axis of aspects for the cause and effect groups.

|    | D     | R      | D+R    | D-R    |
|----|-------|--------|--------|--------|
| A1 | 9.936 | 9.347  | 19.283 | 0.589  |
| A2 | 9.570 | 9.234  | 18.804 | 0.335  |
| A3 | 9.368 | 10.293 | 19.660 | -0.925 |

Table 10 Prominence and relation axis of criteria for the cause and effect groups.

|    | D     | R     | D+R    | D-R    |
|----|-------|-------|--------|--------|
| C1 | 8.680 | 7.896 | 16.576 | 0.784  |
| C2 | 7.543 | 7.396 | 14.939 | 0.147  |
| C3 | 7.752 | 7.768 | 15.520 | -0.017 |
| C4 | 8.196 | 7.792 | 15.988 | 0.404  |

|     |       |       |        |        |
|-----|-------|-------|--------|--------|
| C5  | 7.679 | 7.148 | 14.826 | 0.531  |
| C6  | 8.460 | 7.559 | 16.019 | 0.902  |
| C7  | 6.415 | 7.229 | 13.644 | -0.814 |
| C8  | 8.172 | 6.707 | 14.880 | 1.465  |
| C9  | 8.497 | 8.763 | 17.260 | -0.266 |
| C10 | 7.711 | 8.462 | 16.173 | -0.751 |
| C11 | 8.402 | 8.529 | 16.932 | -0.127 |
| C12 | 7.000 | 8.551 | 15.551 | -1.552 |
| C13 | 7.860 | 8.329 | 16.189 | -0.469 |
| C14 | 7.216 | 7.453 | 14.668 | -0.237 |

In Table 9 and Table 10, (D+R) is termed “Prominence”, which represents the importance of the aspects or criteria. Correspondingly, (D-R) is named “Relation”. If (D-R) is positive, then the corresponding aspects or criteria are formulated into a cause group; otherwise, they are grouped into the effect group. Taking (D+R) as the horizontal axis and (D-R) as the vertical axis, the causal diagrams of the aspects and criteria are depicted in Fig. 1 and Fig. 2, respectively.

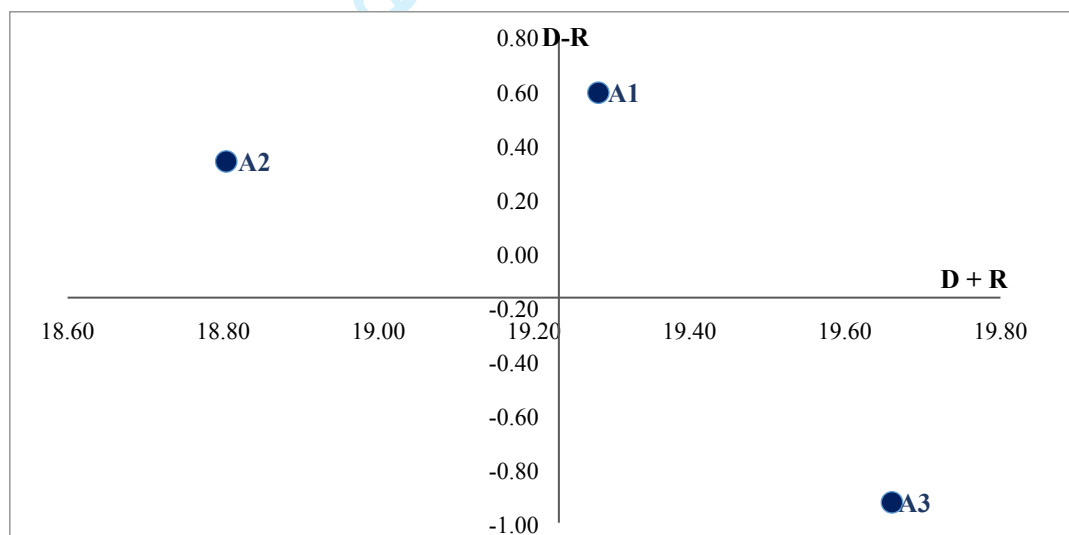


Fig. 1. Causal diagram of aspects.

In Fig. 1, A1 is located in the first quadrant of the coordinate system, which is called the driving aspect of corporate sustainability performance. Therefore, A1 (Socio-Environmental) is the most important aspect and has the strongest influence among the aspects for high-tech firms, and it represents a key aspect for measuring the level of corporate sustainability performance. A3 (Socio-Economic), which is located in the fourth quadrant, represents the core problem of the sustainability performance of high-tech firms. Therefore, A3 is important to the firm but has little impact on the other aspects, although it still requires the attention of firms. A2 (Environmental-Economic) is located in the second quadrant and is the voluntary aspect of the sustainability of high-tech firms, and it has a strong influence on the other aspects but is not important for the firm. Therefore, the importance of the aspects for the sustainability performance

of high-tech firms decreases in the order A1, A3 and A2.

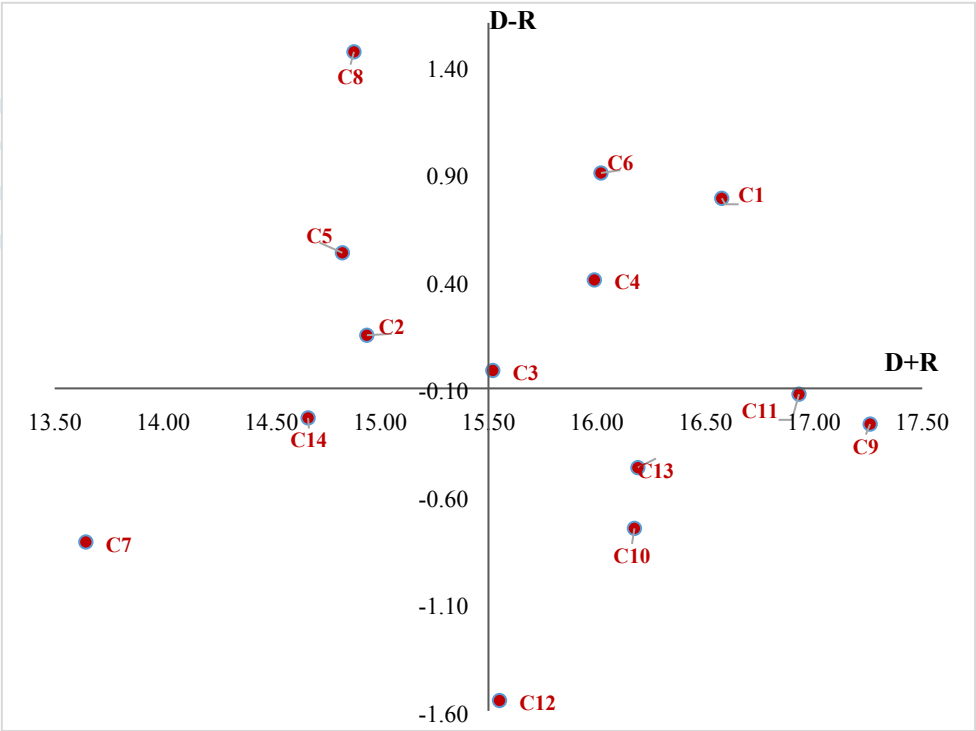


Fig. 2. Causal diagram of criteria.

Similarly, in Fig. 2, a total of four determinant criteria, C1, C3, C4 and C6, are located in the first quadrant. Positive (D-R) values indicate that these criteria have more significant impacts on the other criteria. The values of (D+R) are positive, indicating the importance of the criteria, and they are the driving factors for the sustainability performance of high-tech firms and thus have greater influence and importance than do the other criteria. The criteria near the upper right are more critical. Therefore, the pollution emission control capability (C1) is the most important driving factor of firm sustainability. Senior management's emphasis on eco-innovation (C3) is less important. These four factors are considered the key factors affecting corporate sustainability performance. In addition, the criteria C9, C10, C11, C12 and C13 in the fourth quadrant represent the core problems of corporate sustainability performance. These criteria have lower influence but greater importance. Although they are unable to affect the sustainability performance of high-tech firm's directly, they can have indirect effects through the criteria in the first quadrant. Thus, high-tech firms cannot ignore the criteria in this quadrant.

5. Implications

5.1 Theoretical implications

Certain theoretical implications in this study must be addressed. First, we propose a hybrid approach to assessing the sustainability performance of high-tech firms. Because most previous studies have used assessment data from the literature but not from firms (Chardine-Baumann and Botta-Genoulaz, 2014; Huang and Coelho, 2017; Bhakar et al., 2018), the accuracy and reliability of the research results of these studies are influenced by the literature selection and publication

time. To overcome this problem, we not only study the literature qualitatively but also refer to the characteristics of 34 high-tech firms that made the list of "China's top 10 eco-innovation firms" from 2010 to 2017. The word frequency statistics method is used to quantitatively obtain high frequency words that reflect the sustainable practices of high-tech firms. Specifically, through the word frequency analysis method, the high-frequency vocabulary reflecting the sustainable development practices of the 34 high-tech firms is identified, and this vocabulary objectively proves the importance and reliability of the criteria proposed for assessing the sustainability performance of high-tech firms. This approach leads to assessment results that are more effective to guide the sustainable practices of high-tech firms.

Second, we propose a new concept that verifies the research theory. The existing studies usually choose a theory according to the research problem and then select the assessment criteria (Gong et al., 2018). However, whether the criteria based on this theory are consist with realistic criteria remains unclear. Therefore, we propose a new concept to solve this problem. First, we do not construct the "aspects" of the assessment framework but rather the "criteria". Through a cluster analysis, we divide the criteria into three categories and name them as follows: Socio-Environmental, Environmental-Economic and Socio-Economic. These categories are similar to aspects of existing theories, especially the OBL theory proposed by Wu et al. (2018), and they are focused on the overlapping parts of economy, society and environment and based on the TBL and the proposed OBL theory, which includes the dimensions of eco-efficiency, socio-economic and socio-environmental. Our research, which considers socio-environmental, environmental-economic and socio-economic aspects as important for measuring corporate sustainability, demonstrates the consistency of the practical criteria and theories.

Third, we assess the aspects of the sustainability performance of high-tech firms by the GDEMATEL method. The three aspects of corporate sustainability performance are Socio-Environmental (A1), Environmental-Economic (A2) and Socio-Economic (A3). The results show that the socio-environmental (A1) aspect is the driving force underlying the sustainability performance of high-tech firms. This finding is inconsistent with the conclusion of previous studies that the economy is the core pillar of sustainability. Social harmony and environmental friendliness have gradually become the catalysts for the sustainable development of high-tech firms (Pullman et al., 2009; Banerjee and Gupta, 2018). Therefore, high-tech firms should improve their awareness of eco-innovation and social responsibility (Xia et al., 2018; Severo et al., 2018). In addition, the socio-economic aspect (A3) is the core problem that affects the sustainability performance of high-tech firms. Although this aspect cannot directly influence the performance, high-tech firms need to overcome the social and economic pressures hindering sustainable development (Pillain et al., 2017; Shan et al., 2018). For instance, high-tech firms can strengthen communication with stakeholders and improve the qualities of products and services (Preeker and De, 2018). Firms can also expand financing channels to provide financial support for sustainable development (Bobinaite and Tarvydas, 2014; Moreira, 2016).

5.2 Managerial implications

Several managerial implications are identified based on the assessment results. The pollution emission control capability (C1) is one of the important driving factors for the sustainability performance of high-tech firms. Under environmental degradation, resource shortages and government pressure, the pollution emission control capability is not only the embodiment of corporate social responsibility but also the key to enhancing market competitiveness (Dimitrova et al., 2007). To improve pollution emission control capability, high-tech firms can take measures based on the following three aspects. First, firms should avoid disposing of pollutants emitted directly, and they can increase the waste recovery link and strive to use recycled materials to save costs. Second, firms can use substitutes for highly polluting raw materials to reduce or eliminate pollutant emissions. This approach is simple and easy but is limited by the availability and cost of substitutes. Third, firms can fundamentally improve their pollution emissions control capability by changing the production process. High-tech firms, especially new ones, can select the most suitable processes through adequate market research before initiating production and avoid unnecessary pollution discharge. In addition, all sectors of society should resolutely curb the excessive growth of energy-consuming and high-emission industries.

Investment in energy-conservation and emission-reduction technologies (C6) is another important driving factor of sustainability performance. This finding indicates that improving the sustainable development performance of high-tech firms requires increased investment of technology capital to reduce the negative impacts of production activities on the environment. Although some high-tech firms have some technical support for independent research and development, they lack the funds necessary to ensure the continuous upgrading and improvement of energy-saving and environmental protection technologies (Zhao et al., 2014). Energy-saving and emission-reducing technologies can reduce the environmental pollution due to corporate activities and meet the market demand for environmentally friendly products. Therefore, advanced, serialized and standardized technologies are very important for the sustainability performance of high-tech firms. Firms can improve their sustainable performance by applying large-scale production technology and introducing information management systems to achieve efficient operation (Koskinen and Hilmola, 2008). The senior managers of firms should pay attention to energy conservation, consumption reduction, comprehensive utilization of resources, and similar measures (Agnieszka, 2010). Firms can use energy-saving technologies to promote sustainable production practices (Miao et al., 2018). Furthermore, high-tech firms can expand their financing channels to provide sufficient financial support for energy conservation and emissions reductions, and they should not only establish special funds but also actively introduce external special investment. In addition, financial information should be published and disclosed regularly to ensure the transparency of funding of energy-conservation and emission-reduction technologies.

Green product sales revenue (C9) is one of the core problems affecting the sustainability



performance of high-tech firms. Currently, many high-tech firms are mainly technology-oriented, but under fierce market competition, technological innovation needs to meet the sustainable development requirements of dynamic markets. Green product sales revenue reflects the market's acceptance of corporate products and services. In addition, the higher the sales revenue of green products, the more beneficial it is for firms to carry out technological upgrading and invest in environmental protection, which thereby improves the sustainable performance of firms. To achieve these goals, high-tech firms need to conduct adequate market research to understand consumer preferences and specific details. Furthermore, they should obtain certification for their green products by authoritative organizations and use green packaging for these products. In addition, it is necessary for high-tech firms to develop scientific, rational publicity plans, broaden the sales channels of green products (Shukla et al., 2018), and provide convenient support for consumers to achieve green purchasing behaviour

The guiding capability of green consumption (C11) is another key problem of the sustainability performance of high-tech firms. At present, consumer awareness of environmental protection is weak, and the price of products remains the focus of consumers. The purchasing power of green environmental protection products and services is obviously insufficient, which hinders improvements to the sustainability performance of firms (Tan et al., 2016). Thus, high-tech firms should guide consumers to buy green products or enjoy green services. Moreover, high-tech firms should encourage consumers to save resources and reduce pollution in the process of consumption. To these ends, high-tech firms can improve the guiding capability of green consumption from the following aspects. First, high-tech firms can increase the publicity of green products and improve the degree of recognition of consumers for environmental products. Second, firms can carry out green product certification to improve the consumers' trust in green products. Third, green product diversification is conducive to attracting consumers with different preferences. Last, high-tech firms can open up special sales channels for green products to guide consumers to purchase them (So and Sculli, 2002; Yi-Chan and Tsai, 2007).

## 6. Conclusion

Sustainability performance assessments can provide high-tech firms with clear directions for their sustainable development. Since the third scientific and technological revolution, high-tech firms have attained key roles in adjusting the industrial structure and promoting sustainable economic development. Building a scientific framework of sustainability assessment is an important part of studying the sustainability performance of high-tech firms. Although studies have assessed corporate sustainability from many perspectives, knowledge gaps remain. With the rapid development of society, the understanding of sustainability is changing. In addition, the criteria for assessing corporate sustainability performance are becoming more complicated. In this situation, the existing assessment systems or methods may no longer be appropriate. Therefore, to address this research problem, we propose a hybrid approach to assessing the sustainability performance of high-tech firms. First, the assessment criteria of sustainability are obtained from

the literature as well as a high frequency word analysis of firm features. Thus, the constructed assessment framework is more scientific and comprehensive. Second, we propose obtaining the assessment aspects via a cluster analysis and verifying the current theory. Finally, we use the GDEMATEL to evaluate firms in the Dalian High-tech Zone to explore the aspects and criteria that represent driving factors and core problems in the sustainability performance of high-tech firms.

The sustainability performance criteria for high-tech firms are clustered into three aspects: socio-environmental, environmental-economic and socio-economic. These aspects are similar to the theory of the OBL (Wu et al., 2018), which means that the theory and practice are correlated. In addition, the assessment of aspects showed that the socio-environmental aspect is considered the driving aspect of sustainability performance, which means that the economic aspect is no longer the only consideration. Firms need to pay more attention to their sustainable social and environmental strategies to improve sustainability performance. Moreover, the specific measures of corporate sustainability need to reference the evaluation results of the criteria. "Pollution emission control capability" and "Investment in energy-conservation and emission-reduction technologies" are the most important factors influencing the sustainability performance of high-tech firms. Firms need to prioritize to these two criteria and formulate timely measures. "Green product sales revenue" and "Guiding capability of green consumption" are the most prominent core problems affecting corporate sustainability performance. Firms need to improve their sustainable competitiveness by meeting the dynamic needs of the market and improving consumers' awareness of environmental protection.

This study contains some limitations but also implications for possible future research. First, this paper focuses on the sustainability performance of high-tech firms. Although this is a new perspective, in the future, more types of firms can be studied to understand the differences between the firm types. Second, we only used the data from the International Finance Journal from 2010 to 2017, and the problem of data lag still exists to some extent. In future research, we will seek to obtain data from more sources, such as corporate websites and reports.

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Dear Editor,

Thank you for giving us a chance to modify our manuscript. We have revised the manuscript according to the reviewers' comments. Point-by-point responses to the comments are appended at the end. We have also highlighted the changes in this revision. We hope that the new revision will be satisfactory to the reviewers.

Regards,  
Authors of the paper

**Reviewer 1:**

**Comment:**

The paper has been improved and revised. Reference Agnieszka L. (2010) should be checked: first, whether it is cited in the text, and second, whether Agnieszka is not given name and L... first (family) name.

**Our response:**

Thanks for providing the comment. We revised this reference in the section of 2.4, Table 1 and references.

**Comment:**

1. Originality: Does the paper contain new and significant information adequate to justify publication?: The paper has been improved and contain significant information adequate to justify publication.

**Our response:**

Thanks for the encouraging comments.

**Comment:**

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: The relationship to literature has been clarified in terms of both an adequate understanding of the relevant literature in the field and citing an appropriate range of literature sources. However, reference Agnieszka L. (2010) should be checked: first,

whether it is cited in the text, and second, whether Agnieszka is not given name and L... first (family) name.

**Our response:**

Thank you for providing the comment. The same response as general comment.

**Comment:**

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate? Methodology has been clarified and employed appropriate.

**Our response:**

Thanks for the encouraging comments.

**Comment:**

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper? Results have been explained more detail.

**Our response:**

Thanks for the encouraging comments.

**Comment:**

5. Implications for research, practice and/or society. Does the paper identify clearly between any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper? Implications and conclusions are suitable.

**Our response:**

Thanks for the encouraging comments.

**Comment:**

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has

attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Reference Agnieszka L. (2010) should be checked: first, whether it is cited in the text, and second, whether Agnieszka is not given name and L... first (family) name.

**Our response:**

Thank you for providing the comment. The same response as general comment.