



Cui, L., Zhai, M., Dai, J., Liu, Y. and Zhang, P. (2019) Assessing sustainability performance of high-tech firms through a hybrid approach. *Industrial Management and Data Systems*, 119(8), pp. 1581-1607. (doi: [10.1108/IMDS-02-2019-0066](https://doi.org/10.1108/IMDS-02-2019-0066))

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

Journal:	<i>Industrial Management & Data Systems</i>
Manuscript ID	IMDS-02-2019-0066.R2
Manuscript Type:	Research Paper
Keywords:	sustainability performance, high-tech firms, assessment

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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

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

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27 Constructing a scientific assessment framework is the basis for assessing the sustainability
28 performance of high-tech firms, and it includes theoretical support and criteria selection (Haider et
29 al., 2018; Pan et al., 2018). Using the Triple Bottom Line (TBL) theory as the theoretical basis is
30 the most commonly used method in the previous studies assessing corporate sustainability
31 performance (Ahi and Searcy, 2015; Padhi et al., 2018). TBL includes economic, environmental
32 and social dimensions, which are known as the "three pillars" of sustainability, to measure and
33 report corporate sustainability performance (Elkington, 2010; Büyüközkan and Karabulut, 2018).
34 In subsequent studies, researchers have expanded the TBL to include cultural sustainability as the
35 fourth aspect in building a framework of corporate sustainability performance (Soini and
36 Birkeland, 2014; Swanson and Devereaux, 2017). With the development of scientific and
37 technological innovation, studies have also considered the technological sustainability aspect (Xu
38 et al., 2018). Furthermore, researchers have also focused on the fuzzy area of TBL. For instance,
39 some criteria belong to the economic and environmental aspects at the same time. Therefore, Wu
40 et al. (2018) proposed the Overlapping Bottom Line (OBL) theory to supplement the TBL.
41 Because the OBL is more comprehensive in assessing sustainability performance, we use the OBL
42 as the theoretical basis in this study. Criteria selection is another important problem to consider
43 when building a corporate sustainability-performance framework (Buyukozkan and Karabulut,
44 2018).

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54 In most studies, criteria were taken from the literature (Bhakar et al., 2018; Stoycheva et al.,
55 2018), which may cause a problem if the criteria from the literature are inconsistent with those
56 from the firm due to the lag in the publication of relevant studies. However, big data analysis can
57 quickly and accurately select valuable information from a mass of data (Bibri et al., 2018; Lv et
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3 al., 2018). Among these approaches, the word frequency statistics method is a commonly used
4 statistical method in big data analysis, and it can extract the required criteria through efficient
5 word frequency observation (Brysbart et al., 2018). Therefore, we propose a hybrid approach that
6 combines quantitative word frequency analysis with qualitative literature research to develop
7 sustainability criteria. Specifically, we select criteria based on a literature review, and use word
8 frequency statistics to identify useful criteria from reports on 34 high-tech firms that have made
9 the list of “China’s top ten eco-innovation firms”. In addition, because previous studies generally
10 identified the theory first and then selected the criteria based on the theory (Cai and Li, 2018),
11 criteria selection was restricted by the theory and may have been inconsistent with the actual
12 situations of the studied firms. Thus, after the criteria are developed, a cluster analysis is
13 performed to divide these criteria into different aspects. Then, we verify the rationality of the
14 selected theory according to the classification results.

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

47 The contributions of this study include the following: (1) High tech firms are the subject of
48 our study due to their contribution to economic development. Many existing studies have
49 conducted assessments on resource-based firms but not on high-tech firms, and thus, our study
50 further fills the research gaps in firm sustainability performance. (2) A cluster analysis is used to
51 classify the criteria into groups that represent different aspects of the sustainability framework to
52 ensure objective connectivity between those aspects and the criteria, and those aspects are
53 compared with the dimensions of the OBL theory to verify the rationality of and strengthen that
54 theory. (3) A hybrid approach that integrates word-frequency analysis, cluster analysis, grey
55 theory and DEMATEL is proposed to assess the sustainability performance of high-tech firms.
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3 The word-frequency analysis of reports on high-tech firms' sustainable practices is used in
4 conjunction with keyword-assisted literature research methods to construct the corporate
5 sustainability performance evaluation framework. Cluster analysis is used to verify the objective
6 connection between the sustainability criteria and the aspects of the framework. The application of
7 grey theory combining with DEMATEL overcomes the problem of expert semantic ambiguity in
8 the assessment process. This new research concept improves the accuracy of the assessment
9 results. This study is organized as follows. Section 2 presents the literature review. Section 3
10 contains the proposed methods and research procedure. Section 4 presents the case background,
11 analysis process and results. Section 5 elaborates on the theoretical and managerial implications.
12 The final section provides the conclusions, research limitations and relevant future studies.
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18 **2. Literature review**

19 **2.1 Sustainability framework and performance**

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21 To solve the problems of resource shortages and environmental degradation, firms are forced
22 to engage in the practice of sustainable development (Koh et al., 2012; Bai et al., 2015). Firms can
23 continually balance their economic performance, social responsibility and environmental
24 protection objectives in the process of sustainable development to ensure competitiveness in the
25 market (Tomšič et al., 2015). In 1987, the United Nations first elaborated the concept of
26 sustainable development, which is the ability to meet current needs without harming future
27 generations (Koroneos and Rokos, 2012). Based on this political concept, corporate sustainability
28 at the organizational level can be considered the corporate efforts to balance their environmental,
29 social and economic goals to minimize the harm and increase the benefits to the natural
30 environment and society (Dyllick and Hockerts, 2002; Klewitz and Hansen, 2014). Sustainability
31 performance reflects a firm's sustainability practices. The sustainability framework plays an
32 important role in assessing sustainability performance (Nuong, 2017). When assessing
33 sustainability performance, different sustainability frameworks will lead to different results. The
34 earliest research on sustainability frameworks only focused on the economic benefits of firms
35 without considering the environmental and social issues in the firm life cycle (Moneva et al.,
36 2007; Bergenwall et al., 2012; Heikkurinen and Bonnedahl, 2013). In 1995, Elkington first
37 proposed the concept of the TBL, which considers not only the economic value but also the
38 environmental and social value of firms (Elkington, 1997; Garbie, 2014). Subsequently, the TBL
39 became a common theory to guide the construction of corporate sustainability frameworks
40 (Dainienė and Dagilienė, 2015). At the end of the twentieth century, with the in-depth study of
41 sustainable development, sustainable consumption and production (SCP) was widely used as a
42 measure of a firm's sustainability framework (Tseng et al., 2018, Wu et al., 2018).
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54 Many studies have focused on sustainability performance assessments that cover all aspects
55 of life. Liu et al. (2018) established a sustainability framework of driver-pressure-state-impact-
56 response (DPSIR), which evaluated the sustainability of the China Marine Biotechnology Park.
57 Kamali et al. (2018) proposed a modular framework based on the TBL to assess the sustainability
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3 performance throughout the firm lifecycle. In addition, because the SCP promotes energy and
4 resource optimization, the United Nations has identified it as one of its sustainable development
5 goals. Many studies have also introduced SCP into a firm's sustainability framework to assess
6 sustainability performance (Dubey et al., 2018). Govindan (2018) explored the drivers and barriers
7 of supply chain sustainability in the food industry under the SCP framework. Studies have also
8 integrated the TBL, SCP and other theories to build sustainability frameworks to comprehensively
9 reveal the sustainability performance of firms (Schweikert et al., 2018; Govindan, 2018). Study
10 results on sustainability performance provide references for sustainability practices of firms, such
11 as for information collection and development direction (Bragança et al., 2010).

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

36 37 38 39 40 41 42 43 44 45 **2.2 High-tech firms and sustainability performance assessment**

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47 Since high-tech firms emphasize the transformation of knowledge and technology and the
48 realization of technological achievements, they can utilize and allocate limited resources more
49 effectively than other types of firms (Chapas et al., 2010). Thus, with the advent of the "third
50 industrial revolution", the development of high-tech firms has reached a climax (Hung and Wang,
51 2012). Achieving sustainable development has gradually become a strategic goal for the long-term
52 development of high-tech firms. The development model has also gradually shifted from
53 efficiency driven to innovation driven (Chen et al., 2018). With the advent of the era of the
54 knowledge economy and big data, high-tech firms, as representatives of knowledge-intensive
55 enterprises, have developed the characteristics of high investment, high output and rapid
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3 development (Lin et al., 2018). Compared with other types of firms, high-tech firms invest more
4 in R&D innovation, product upgrades and new energy sources and are therefore more likely to
5 meet rapidly changing market demands. High-tech firms adjust their business production
6 strategies by rationally locating internal and external resources, relying on knowledge platforms,
7 and adjusting their business production strategies (Pan et al., 2018). They can achieve sustainable
8 development by improving their technological innovation capabilities and accelerating the
9 upgrading of industrial structure (Balkin et al., 2000). In recent years, high-tech firms have
10 gradually become the main actors promoting economic development and enhancing national
11 strength. Therefore, assessing the sustainability performance of high-tech firms has become a
12 focus of current firm management research.
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18 Many scholars have assessed the sustainability performance of high-tech firms from different
19 dimensions, exploring the influential factors in the development of high-tech firms and proposing
20 scientific management ideas. Based on empirical data from companies, Zhang et al. (2013)
21 proposed that the liquidity ratio and independent innovation ability are important factors affecting
22 the trust risk of high-tech firms and that these factors indirectly affect the sustainable performance
23 of the firms. It has been suggested that as the role of knowledge capacity in firm development
24 becomes increasingly prominent, maintaining strong internal and external knowledge capacity can
25 mitigate the impact of financial crisis on sustainable development (Zouaghi et al., 2018). To
26 address the complexity of sustainable development, Sadeghi (2018) adopted a systematic approach
27 and demonstrated that policies and regulations are the most important factors influencing the
28 sustainable development of high-tech firms. They suggested that the government simplify relevant
29 laws and create a sustainable regulatory environment for high-tech firms. In addition, due to the
30 characteristics of high-tech firms, R&D intensity and scale effect are closely related to stock
31 returns, which have profound impacts on expansion and sustainable development (Yu et al.,
32 2018).
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41 Although some studies have explored the development paths of high-tech firms, research on
42 how high-tech firms can achieve sustainable development remains sparse (Law and Gunasekaran,
43 2012), and gaps remain in the assessment of the sustainability performance of high-tech firms.
44 Most previous studies extracted sustainability criteria based on literature research; this approach
45 does not consider the development status of high-tech firms (Lin et al., 2018). In addition, in
46 previous work, the sustainability indicators of high-tech firms have mainly comprised financial
47 indicators, whereas non-financial indicators for complex competitive environments and long-term
48 sustainable performance of firms have largely been ignored (Tseng et al., 2009). Furthermore,
49 most previous assessments of the influencing factors of high-tech firms have adopted linear
50 parameter assessment models, ignoring the nonlinear relationships between influencing factors
51 and thereby resulting in low practicability of the assessment results (Han et al., 2017). Therefore,
52 this study constructs a scientific corporate sustainability framework that references the actual data
53 of high-tech firms. Then, a multi-criteria decision making method (GDEMATEL) is employed to
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3 explore the internal relationships among the criteria affecting the sustainability performance of
4 high-tech firms and to provide scientific guidance for firm development.
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6 **2.3 Proposed method**

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8 Currently, various methods are used to assess corporate sustainability performance. The
9 global reporting initiative (GRI) is recognized as an effective assessment framework (Hedberg and
10 Malmberg, 2003; Brown et al., 2009). Srivastava and Raj (2018) used a multi-criteria decision
11 approach to assess the sustainability performance of aircraft manufacturers based on the GRI.
12 Subsequently, Kim et al. (2015) and Ekener et al. (2018) proposed the decision-making
13 framework conforming to the characteristics of firms based on the GRI and provided decision
14 support for the sustainability practices of the firm by using the life cycle assessment (LCA)
15 method. Some studies have established sustainability conceptual frameworks based on the nature
16 of the firm and used the AHP to assess the impact of sustainability criteria on firm sustainable
17 performance (Hu et al., 2011; Dai and Blackhurst, 2012; Singh and Vinodh, 2017). In addition,
18 some studies have used data envelopment analyses (DEAs) to assess the sustainability
19 performance of high-tech firms according to input and output indicators (Hung and Wang, 2012).
20 Although these methods have been widely used in the assessment of sustainability performance,
21 the indicators are usually quantifiable (Lu et al., 2018) and thus do not apply to criteria that cannot
22 be quantified.
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25 To assess corporate sustainability performance comprehensively from multiple dimensions, a
26 proper method must be used. Multi-criteria decision-making (MCDM) methods are usually used
27 to deal with qualitative criteria, and they include the Technique for Order Preference by Similarity
28 to an Ideal Solution (TOPSIS), Interpretative Structural Modelling (ISM), the Analytic Network
29 Process (ANP) and DEMATEL (Büyüközkan and Gülerüz, 2018; Cui, 2017; Yilmaz and
30 Nuriine, 2018). The DEMATEL method is especially capable of revealing the driving factors and
31 core problems affecting corporate sustainability performance as well as the relationships between
32 sustainability criteria (Lu et al., 2018). However, the traditional DEMATEL method cannot
33 overcome the problem of expert semantic ambiguity (Lin et al., 2018); thus, researchers have
34 improved upon this method. Song and Cao (2017) combined the rough set and DEMATEL to
35 assess the causal relationship between the requirements of the product service system. Lin et al.
36 (2018) integrated the fuzzy theory and DEMATEL to consider the sustainable decision-making of
37 fuzzy variables or language variables in dynamic changes of the supply chain of a firm.
38 Combining grey theory is also an effective way to overcome uncertainty (Wu et al., 2018; Tseng
39 et al., 2018). Considering the purpose of this study, we use the GDEMATEL method to assess
40 corporate sustainability performance.
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43 In addition, most studies have used the literature review method to obtain assessment criteria
44 (Song et al., 2016; Kumar et al., 2017). Due to limitations of publication time, the criteria from the
45 literature may reflect the current situation, although the subjectivity of researchers also affects the
46 reliability of sustainability criteria. In this situation, real firm data are necessary to assist the
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3 criteria selection (Gaviglio et al., 2016). Word frequency statistics is an effective approach to
4 obtaining data from corporate text materials (Wada et al., 2003; Yan and Minnhagen, 2016).
5 Through high frequency word analyses, we can determine the views of firms regarding
6 sustainability (Piantadosi, 2014; Lu et al., 2018). Moreover, although most studies are based on
7 some theory, there is a lack of verification regarding the theory (Munier, 2011; Tokos et al., 2012;
8 Bhakar et al., 2018). Clustering analysis is an exploratory data analysis tool that can divide the
9 data into different categories (Horiuchi et al., 2018). Therefore, the use of cluster analysis to
10 divide criteria into several categories and the construction of a scientific assessment framework
11 for high-tech firms warrant exploration.

12 **2.4 Proposed measures**

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14 The selection of assessment criteria is the first step. We select “high-tech firms”,
15 “sustainability” and related words as keywords to obtain the sustainability performance criteria.
16 High-tech firms pay considerable attention to the product-processing stage, and the pollution
17 emission control capability (B1) can directly reflect the extent of firm pollution (Khanna et al.,
18 2009; Pei et al., 2015). To reduce the environmental impact of waste, increasing investment in
19 energy-conservation and emission-reduction technologies (B2), increasing the number of patents
20 (B3) and improving the waste recycling rate (B4) have become important eco-innovation methods
21 used by firms (Zhu and Qian, 2015; Dong et al., 2018). Firms also need to strengthen the guidance
22 of green consumption for consumers (B5), increase the market demand for green products (B6)
23 and constantly improve their market competitiveness (Mohr and Shooshtari, 2003; Heikkurinen
24 and Bonnedahl, 2013; Severo et al., 2018). Especially in this era, human capital, as an important
25 firm resource, can provide sustainable motivation for firm competition (He et al., 2018).
26 Therefore, the technical level of employees (B7), senior management's emphasis on
27 eco-innovation (B8) and senior management's recognition of green production (B14) are the key
28 criteria affecting corporate sustainability performance (Hoyt and Matuszek, 2001; Wagner, 2008;
29 **Leszczynska, 2010**; Vathsala and Sampath, 2012). In addition, green product sales revenue (B9)
30 and the cost of green product design and development (B10) are important criteria affecting the
31 long-term development of firms (Rexhäuser and Löschel, 2015; Gaziulusoy, 2015; Kuo and
32 Smith, 2018). Firms should also strengthen cooperation with stakeholders. Government support
33 for environmental protection (B11) can grant firms with considerable funds for sustainable
34 development (Graham, 2001; Ball et al., 2018), and cooperation between firms and scientific
35 research institutions regarding eco-innovation technology (B12) enhances competitiveness
36 (Rogers, 2001; Pan et al., 2018; Faria and Andersen, 2018). Finally, the social responsibility
37 contribution (B13) input provides the benefit of improving the firm's image of corporate
38 responsibility and promoting sustainable development (Carter, 2000; Ardito et al., 2018; Tseng et
39 al., 2018).

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41 Table 1 includes the proposed sustainability performance criteria for firms.
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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.

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

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 Rabehesketh, 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).

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

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)

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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 (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 (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 (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.

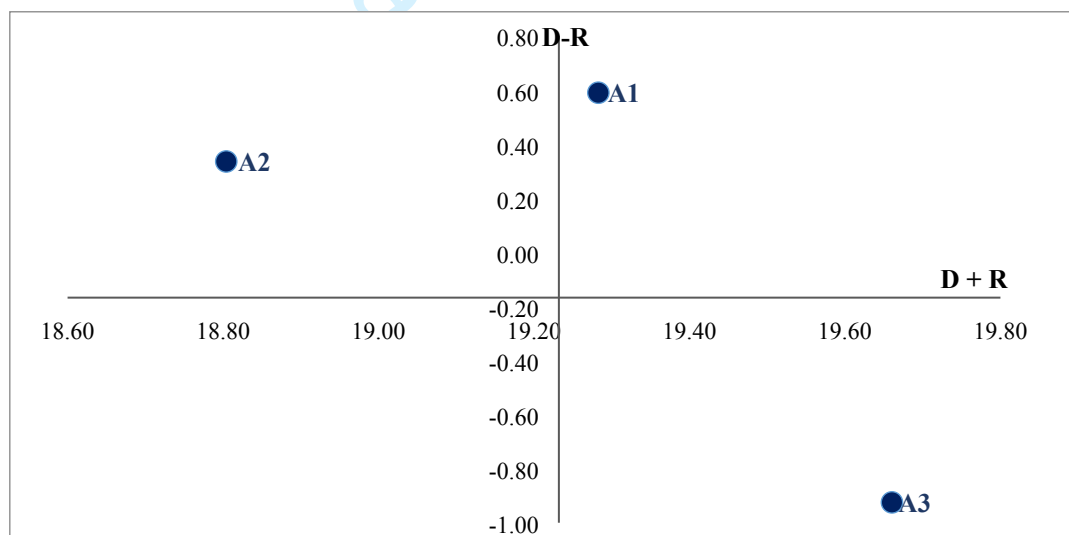


Fig. 1. Causal diagram of aspects.

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.

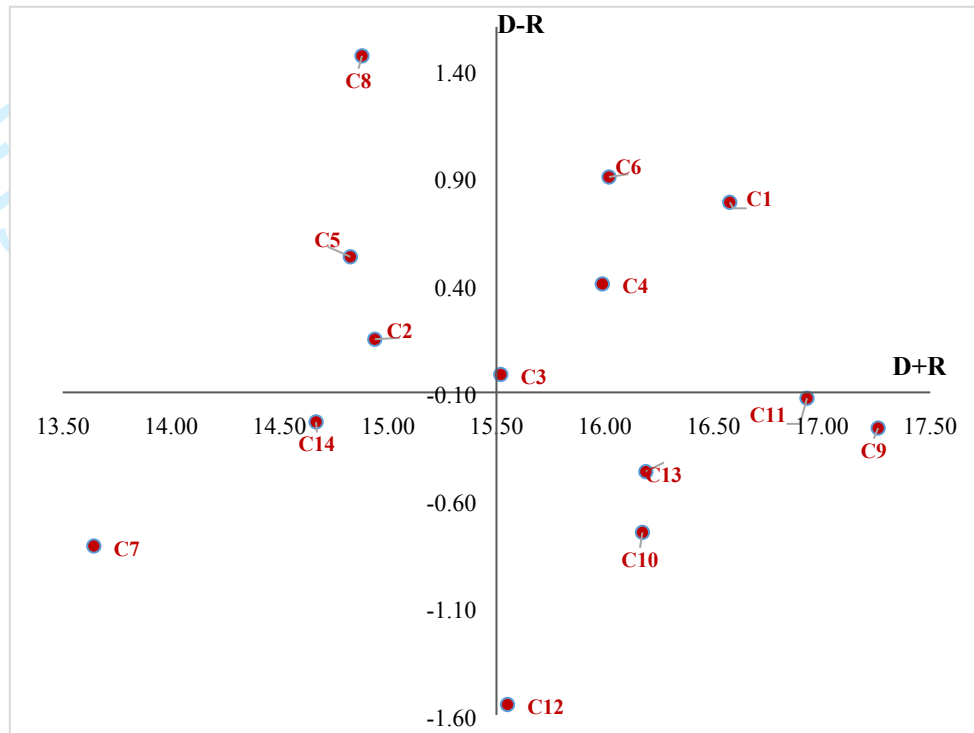


Fig. 2. Causal diagram of criteria.

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

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3 time. To overcome this problem, we not only study the literature qualitatively but also refer to the
4 characteristics of 34 high-tech firms that made the list of "China's top 10 eco-innovation firms"
5 from 2010 to 2017. The word frequency statistics method is used to quantitatively obtain high
6 frequency words that reflect the sustainable practices of high-tech firms. Specifically, through the
7 word frequency analysis method, the high-frequency vocabulary reflecting the sustainable
8 development practices of the 34 high-tech firms is identified, and this vocabulary objectively
9 proves the importance and reliability of the criteria proposed for assessing the sustainability
10 performance of high-tech firms. This approach leads to assessment results that are more effective
11 to guide the sustainable practices of high-tech firms.
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17 Second, we propose a new concept that verifies the research theory. The existing studies
18 usually choose a theory according to the research problem and then select the assessment criteria
19 (Gong et al., 2018). However, whether the criteria based on this theory are consistent with realistic
20 criteria remains unclear. Therefore, we propose a new concept to solve this problem. First, we do
21 not construct the "aspects" of the assessment framework but rather the "criteria". Through a
22 cluster analysis, we divide the criteria into three categories and name them as follows:
23 Socio-Environmental, Environmental-Economic and Socio-Economic. These categories are
24 similar to aspects of existing theories, especially the OBL theory proposed by Wu et al. (2018),
25 and they are focused on the overlapping parts of economy, society and environment and based on
26 the TBL and the proposed OBL theory, which includes the dimensions of eco-efficiency,
27 socio-economic and socio-environmental. Our research, which considers socio-environmental,
28 environmental-economic and socio-economic aspects as important for measuring corporate
29 sustainability, demonstrates the consistency of the practical criteria and theories.
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36 Third, we assess the aspects of the sustainability performance of high-tech firms by the
37 GDEMATEL method. The three aspects of corporate sustainability performance are
38 Socio-Environmental (A1), Environmental-Economic (A2) and Socio-Economic (A3). The results
39 show that the socio-environmental (A1) aspect is the driving force underlying the sustainability
40 performance of high-tech firms. This finding is inconsistent with the conclusion of previous
41 studies that the economy is the core pillar of sustainability. Social harmony and environmental
42 friendliness have gradually become the catalysts for the sustainable development of high-tech
43 firms (Pullman et al., 2009; Banerjee and Gupta, 2018). Therefore, high-tech firms should
44 improve their awareness of eco-innovation and social responsibility (Xia et al., 2018; Severo et al.,
45 2018). In addition, the socio-economic aspect (A3) is the core problem that affects the
46 sustainability performance of high-tech firms. Although this aspect cannot directly influence the
47 performance, high-tech firms need to overcome the social and economic pressures hindering
48 sustainable development (Pillain et al., 2017; Shan et al., 2018). For instance, high-tech firms can
49 strengthen communication with stakeholders and improve the qualities of products and services
50 (Preeker and De, 2018). Firms can also expand financing channels to provide financial support for
51 sustainable development (Bobinaite and Tarvydas, 2014; Moreira, 2016).
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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

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

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

30 31 32 33 34 35 36 37 38 39 40 41 42 43 **6. Conclusion**

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

Acknowledgements

This study is supported by National Natural Science Foundation (71602096 and 71602181), Key Program of National Natural Science Foundation of China (71632004), China Postdoctoral Science Foundation Funded Project (2018M631826) and Fundamental Research Funds for the Central Universities (DUT18RW103).

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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,

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

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6 **Our response:**

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8 Thank you for providing the comment. The same response as general comment.
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11 **Comment:**

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

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21 Thanks for the encouraging comments.
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24 **Comment:**

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26 4. Results: Are results presented clearly and analysed appropriately? Do the conclusions
27 adequately tie together the other elements of the paper? Results have been explained more
28 detail.
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31 **Our response:**

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33 Thanks for the encouraging comments.
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36 **Comment:**

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

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49 Thanks for the encouraging comments.
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52 **Comment:**

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54 6. Quality of Communication: Does the paper clearly express its case, measured against the
55 technical language of the field and the expected knowledge of the journal's readership? Has
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3 attention been paid to the clarity of expression and readability, such as sentence structure,
4 jargon use, acronyms, etc.: Reference Agnieszka L. (2010) should be checked: first,
5 whether it is cited in the text, and second, whether Agnieszka is not given name and L... first
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10 **Our response:**

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