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# Integrating corporate website information into qualitative assessment for benchmarking green supply chain management practices for the chemical industry

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A R T I C L E I N F O

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A B S T R A C T

The China's chemical industry has been endeavouring to promote sustainable development through practicing green supply chain management (GSCM). This paper proposes a multi-criteria decision framework with twenty practices to guide companies in the industry to enact GSCM effectively. The exploratory factor analysis (EFA) has been used to cluster the proposed practices. We found five aspects, including economic initiatives, environmental management, eco-design, resource recycling, and stakeholder and employee, constitute the underlying structure of GSCM. A mixed decision tool combining the entropy weight method (EWM) and the analytic hierarchy process (AHP) has been developed and applied to identify key factors. Official website information has been collected and used to analyse the website contents of five benchmarking companies in the China's chemical industry. The results reveal that the aspects of environmental management, eco-design and resource recycling are the most important GSCM themes. Moreover, the top five practices are top management support, performing life cycle assessment, managing environmental risks, advancing recycling technologies and integrating reverse logistics. Conceptual and practical implications are discussed.

## 1. Introduction

Aiming at sustainable development, industrial development and environmental stewardship should go hand in hand (Zhao et al., 2014; Li et al., 2021). Under the United Nations 2030 agenda for sustainable development, the China's chemical industry has been striving to seek paths to promote sustainability performance (Walmsley et al., 2014; Rexhäuser &Löschel, 2015; Røyne et al., 2015). The industry is under great pressure not only from the governmental monitoring and legislation, but also the requests for greener manufacturing and eco-friendly products from the customers and the wider public. Thus, many chemical companies in China have proposed green strategies to improve their environmental performance through green technology advancement, chemical process management, supply chain network design and customer awareness enhancement. In turn, researchers have worked on embedding sustainability concept into supply chain management to further incorporate the perspective of environmental performance in the industry and alter the traditional unsustainable profit-oriented business strategies.

Supply chain management focuses on “the integration and coordination of business processes and strategy alignment throughout the supply chain” (Green et al, 2006, 2008, 2012). Green supply chain management (GSCM) thus requires the incorporation of the environmental perspective into the corporate supply chain management practices including purchasing, manufacturing, logistics, information systems, and stakeholder engagement, in order to meet the requirement

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of governmental regulations, and reduce corporate environment-related impacts and risks (Green et al., 2012; Hu and Hsu, 2010). Moreover, from the resource-based view, these companies actually have limited resources that can be invested into tackling the environmental issues, so the guidance for the operationalisation of GSCM must be both effective and cost-effective. In other words, these chemical companies endeavour to capture the most decisive factors and integrate them into their strategies to efficaciously enact GSCM in an economical way. However, to the best of our knowledge, there is no study has been done to identify the critical GSCM measures for the chemical companies. Therefore, this paper centres on how to fill in this gap to assist the China's chemical companies in practicing GSCM.

Business managers may encounter diverse uncertainties whilst trying to make rational strategic decisions. This paper proposes that one solution to this issue is to (a) first develop a multi-criteria decision framework with a set of aspects covering theoretical themes and indicators covering good business practices, and (b) then systematically compare each element in the framework through aggregating all useful information into the decision model to identify priorities. Many previous studies that contributed to aid decision-making processes through selecting key indicators normally draw on qualitative information (i.e. experts' assessment) to weigh each proposed element and generate ranking systems (Tseng et al., 2019; Uygun and Dede, 2016). Though the systems can provide powerful evidence to inform decision-makers, other types of information should also be considered to help modify these systems and enhance decision-making accuracy, such as the corporate website information (Xia et al., 2020).

Corporate websites have been used by many companies worldwide as a tool to communicate with the companies' internal and external audiences. These websites contain a great amount of information concerning corporate performance and strategies. However, many previous studies that tried to select important GSCM practices often fail to consider the official website data (Rostamzadeh et al., 2015; Islam et al., 2018). As mentioned before, these studies mainly use decision systems that rely on experts' evaluations to sift the key practices out. Yet, these experts' judgements can be subjective and even occasionally arbitrary (Xia et al., 2020), while transforming official website information into entropy weights and integrating this kind of information with qualitative evaluations could improve the accuracy of decision-making and reduce information bias. Thus, this paper attempts to develop a new decision-making tool for business operations and apply it in the case of GSCM in China's chemical industry. To our knowledge, official website information has not been studied for decision-making in the existing GSCM literature.

To sum up, this paper aims to identify the key GSCM themes and practices for the China's chemical industry using official website information and qualitative assessment data. The contribution of this research is three-fold: (1) establishing a GSCM decision framework to help managers implement GSCM; (2) using corporate official website and qualitative assessment information to identify the important factors in the proposed framework to support GSCM actions; (3) developing a mixed corporate decision instrument to strengthen the decision-making process. In the next section, previous literature is reviewed and a framework of GSCM practices is proposed for decision analysis. In section 3, the decision methodology is carefully discussed. Section 4 presents the results with analytical procedures. Section 5 discusses the conceptual and practical implications. Finally, section 6 concludes the study.

## 2. Literature review

### 2.1. Green supply chain management

GSCM refers to the management of resources, materials, components, processes with considering all the environmental impacts on the stakeholders all the way through the supply chain (Hu and Hsu, 2010). Practicing GSCM aims to help companies meet the requirement of the governments, reduce corporate environment-related risks and negative impacts along the supply chain, and promote the social reputation and corporate image among the stakeholders and in the broader society. There is a broad consensus that environmental management in the organisations takes a key role to improve GSCM performance (Zhu and Sarkis, 2004; Zhu et al., 2008). To achieve environmental excellence, senior managers must make commitments so that other staff can be supportive of actively implementing GSCM (Zhu et al., 2008; Lozano, 2013; Tseng et al., 2018). Also, economic activities play a significant part in GSCM practices, such as purchasing and procurement, and research and development (R&D). Additionally, eco-design is a key aspect, referring to the integration of green issues into the design of products or processes. Eco-design can reduce the adverse social and environmental impacts and meanwhile reduce the costs and improve the marketability of the products (Hu and Hsu, 2010). Furthermore, performing GSCM requires the involvement of stakeholders and employees, indicating the importance of communications and collaborations with upstream and downstream stakeholders, as well as the participation of the employees within the organisations. Finally, resource recycling is another key component for acting GSCM. It aims to close the loop of the supply chain in order to conserve the industrial resources and improve resource efficiencies in a circular economy.

In order to systematically manage green supply chain, framework development for GSCM practices has been discussed in previous studies for some industries. For instance, Wu et al. (2012) proposed a framework with 14 measures and 4 aspects for GSCM practices for the Taiwan's textile and apparel industry using exploratory factor analysis (EFA). Hu & Hsu et al. (2010) developed a framework with 20 practices and 4 dimensions and identified the key GSCM practices using EFA for the electrical and electronics industry. Sellitto et al. (2019) identified 21 green practices under the GSCM objective for the footwear industry. The chemical industry, as the provider of various chemical products that support other sectors, can do an inestimable harm on the environment and the society along the supply chain. Yet, discussion on developing GSCM frameworks for the chemical industry is still lacking.

### 2.2. Proposed practices

The main aim of practicing GSCM in the chemical industry is to preserve resources in the industrial system and control the harmful impacts on the environment. Though GSCM has been applied in diverse industries within different contexts, its application in the chemical industry could be a different story. In this section, the triple bottom line concept (economy, society, and environment; Elkington, 1997) is borrowed to systematically propose the GSCM practices. These practices will be reframed into a new structure in section 4.

#### 2.2.1. Economy

From the economic perspective, chemical companies need to green their purchasing and procurement behaviours and make their consumption of goods and services more environmentally and socially responsible. This requires them to enact environmentally preferable purchasing (M1) with properly established environmental requirements (M2) (Hu and Hsu, 2010; Evans and Johnson, 2005; Rostamzadeh et al., 2015). The standards are set to minimise the potential negative effects of a purchasing item on the environment, ecosystem, society, and public health. Setting these requirements in one company can promote joint commitment among the supply chain stakeholders for improving the environmental benefits of the products, and encourage other companies in the supply chain to set higher environmental standards.

Moreover, the public can fairly obtain some understanding of a chemical company's environmental performance simply through reading the list of suppliers that the company selected or knowing the criteria that the company use to select suppliers (Islam et al., 2018; Gualandris and Kalchschmidt, 2014; Rostamzadeh et al., 2015; Hu and

 

**Table 1**
Proposed GSCM practices.

| | GSCM Practices | Representative References |
|---|---|---|
| M1 | Environmentally preferable purchasing | Su et al. (2015); Lin et al. (2014); Rostamzadeh et al. (2015) |
| M2 | Environmental requirements for purchasing | Hu and Hsu (2010); Evans and Johnson (2005); Rostamzadeh et al. (2015) |
| M3 | Selecting green suppliers | Islam et al. (2018); Gualandris and Kalchschmidt (2014); Rostamzadeh et al. (2015) |
| M4 | Collaborative R&D | Rao (2002); Su et al. (2015); Young and Kielkiewicz-Young (2001) |
| M5 | Supplier meeting | Young and Kielkiewicz-Young (2001); Hu and Hsu (2010) |
| M6 | Supplier survey | Hu and Hsu (2010); Evans and Johnson (2005) |
| M7 | Establishing communication platform | Wu et al. (2019a); Lippmann (1999) |
| M8 | Training and education | Islam et al. (2018); Rostamzadeh et al. (2015) |
| M9 | Cross-functional team | Hu and Hsu (2010); Evans and Johnson (2005); Rao (2002); Young and Kielkiewicz-Young (2001) |
| M10 | Top management support | Lozano (2015); Lozano (2013); Tseng et al. (2018); Lin et al. (2014) |
| M11 | Product testing report | Evans and Johnson (2005); Hu and Hsu (2010) |
| M12 | Environmental auditing | Islam et al. (2018); Zhu et al. (2005); Rostamzadeh et al. (2015) |
| M13 | Managing environmental risks | Garengo and Biazzo (2012); Tseng et al. (2018) |
| M14 | Performing life cycle assessment | Su et al. (2016); Shi et al. (2017); Lin et al. (2014) |
| M15 | Environmental information systems | Shi et al. (2017); Evans and Johnson (2005) |
| M16 | Environmental policy regarding GSCM | Young and Kielkiewicz-Young (2001); Hu and Hsu (2010) |
| M17 | Integrating reverse logistics | Tseng et al. (2019); Shi et al. (2017); |
| M18 | Advancing recycling technologies | Hu and Hsu (2010); Rostamzadeh et al. (2015) |
| M19 | Joining local organisations for collaborative recycling | Hu and Hsu (2010); Rao (2002) |
| M20 | Green transportation | Tseng et al. (2020); Wu et al. (2019a) |

Hsu, 2010; Godfrey, 1998). Thus, selecting green suppliers (M3) can be an imperative practice. In the chemical industry, moving towards GSCM requires companies to select raw material suppliers, equipment suppliers, and service suppliers in an environmentally friendly way. Particularly, they should prefer to select suppliers that provide sustainable energy resources such as biomass for eco-friendly manufacturing, as well as high-grade materials and specialised products for efficient production.

Besides, collaborative R&D (M4) has become a vital practice to bring innovations for corporate long-term competitiveness in the chemical industry (Rao, 2002; Su et al., 2015; Young and Kielkiewicz-Young, 2001). Developing collaborative R&D requires the involvement of customers to effectively capture core problems and design R&D processes for accurately solving these problems, as well as the collaboration with partners and the academia for resource sharing and knowledge exchange.

### 2.2.2. Society

From the social perspective, practicing GSCM in the chemical industry needs the involvement of different stakeholders as well as employees. Chemical companies that strives to communicate their environmental requirements and expectations with their suppliers can engage with them through supplier meetings (M5) or survey (M6) to prepare supply chain design (Young and Kielkiewicz-Young, 2001; Hu and Hsu, 2010; Lippmann, 1999). The suppliers are asked to do a self-assessment of their environmental awareness and abilities to meet the environmental requirements. This information can help the chemical companies to choose the best suppliers that offer the high-grade raw materials or products. This information can also be stored in the corporate environmental information system to aide future decisions on supplier selection.

In addition, establishing communication platform (M7) can facilitate the inter-communication with high efficiency, effectiveness and clarity not only within the company but also between the company and its suppliers and partners in the supply chain (Lippmann, 1999). The communication platform within the company helps the top executives to convey the GSCM goals within the corporate hierarchy, and helps the practitioners and employees inside the organisation to build understandings on how the set corporate objectives relate to their functions in the company. Moreover, the platform could assist the chemical companies in communicating environmental issues with their suppliers.

Since it has been commonly believed that GSCM is a complex system engineering that involve complicated issues which is difficult for a traditional function team with a lack of cutting-edge knowledge to properly handle, chemical companies need to arrange training and education programmes (M8) regarding GSCM and develop cross-functional team (M9) to work towards the common goal (Evans and Johnson, 2005; Rao, 2002; Young and Kielkiewicz-Young, 2001). Members gathered from departments as diverse as the sustainability department, sales department, operational department, purchasing department and others need to be well trained and experienced in developing GSCM-oriented strategies which requires a great scope of information and knowledge.

### 2.2.3. Environment

One of the main reasons for some chemical companies fail to develop GSCM practices is the lack of top management support (M10) (Lozano, 2013, 2015, 2013; Tseng et al., 2018; Lin et al., 2014). Top managers should formulate the corporate culture beyond a short-sighted focus on economic profits, and incorporate the goal of improving environmental and sustainability performance into their supply chain management. Product testing (M11) and environmental auditing (M12) are effective tools for measuring the effects of the products and manufacturing activities on the environment against set standards (Islam et al., 2018; Zhu et al., 2005; Rostamzadeh et al., 2015). Chemical companies need to accomplish product testing and environmental auditing to identify and assess hazards, prevent pollution, and protect and promote safety and health. Besides, managers need to manage the environmental risks along the whole supply chain (M13) (Garengo and Biazzo, 2012; Tseng et al., 2018). This requires chemical companies to set up risk management systems to capture, analyse and screen hazardous materials and equipment that could lead to environmental problems faced by stakeholders. Also, when making the choice of material input, chemical companies can also use a “cradle to grave” approach, the life cycle assessment (M14), for green product design and analysing the environmental characters of the materials by systematically evaluating the products’ environmental impacts throughout their whole life cycle (Su et al., 2015; Shi et al., 2017; Lin et al., 2014).

It is also key to develop GSCM by efficiently collecting information and practices of each department, the operational flow of each manufacturing process, information of the products and materials, documents and reports provided by the suppliers (Shi et al., 2017; Evans and Johnson, 2005). Thus, building up an environmental information system (M15) can be an essential measure to assist companies to support decision-making processes in GSCM. Besides, chemical companies should set environmental policies for GSCM (M16) to the suppliers and customers to enhance the environmental awareness among the employees in the companies as well as other stakeholders in the supply chain (Young and Kielkiewicz-Young, 2001; Hu and Hsu, 2010). The companies should convey their policies with the corporate goals and future trends about GSCM to their stakeholders. One company in the supply chain setting up policies for its upstream suppliers could push them to implement GSCM practices and encourage them to draw up environmental policies as well.

Improving material recycling and recovery to build circular economy

**Table 2**
Preference scale for pair-wise comparisons.

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 2 | Moderate importance of one over another | Experience and judgement slightly favor one activity over another. |
| 3 | Essential/Strong importance | Experience and judgement strongly favor one activity over another. |
| 4 | Very strong importance | Experience and judgement very strongly favor one over the other. |
| 5 | Absolute importance | The evidence favoring one over the other is of the highest possible validity. |

has also become a key target for GSCM in the chemical industry. Therein, reverse logistics (M17) is an important recycling measure (Tseng et al., 2019; Shi et al., 2017). Through the companies' logistics networks, the wastes can be collected from the former users and the resource recovery practices and sales of the recovered materials can be operated together with other companies involved. Besides, companies using recycling technologies (M18) are able to return the post-use resources to their basic chemical building blocks through purification, decomposition, and conversion for developing a variety of new products (Hu and Hsu, 2010; Rostamzadeh et al., 2015). Applying these technologies can contribute to a circular economy in which resources can be repurposed instead of being disposed and the inherent value of them can be efficiently utilized. Moreover, since companies undertaking the recovery of the used resources on their own can be extremely inefficient, they may join the local organisations for collaborative recycling (M19) to recycle similar products or materials, through which the recycling cost of each company shouldered can be greatly reduced, especially when taking back products from overseas customers (Rao, 2002).

Ensuring safe, efficient and eco-friendly transport of goods is of key importance for GSCM (Islam et al., 2018; Rostamzadeh et al., 2015). The chemical companies ought to implement green transportation (M20) to measure and manage the transport emissions they have generated to assess and improve their operations. They should also ensure that they comply with the regulations for the transport of hazardous goods. Sometimes, designing green transportation could also require the close collaboration with the transport industry to promote excellence in the green supply chain operations and identify new opportunities to make further enhancements.

Therefore, a decision structure consisted of 20 GSCM practices is proposed, as demonstrated in Table 1 below. There could be an underlying hierarchical structure behind the 20 practices, which can provide conceptual insights into GSCM if clearly identified. Therefore, this paper aims to first attempt to discover the inherent hierarchical framework, and then develop and apply a mixed decision-making approach to identify key dimensions and practices for GSCM.

### 2.3. Proposed method

Lozano (2008) emphasized the hierarchical framework hidden behind the proposed indicators should be identified to support the decision-making processes, because they can provide more conceptual understandings for strategic planning. EFA, a statistical method in multivariate statistics, has been widely used to and reveal the underlying structure of a given set of factors (Wu et al., 2019b). For instance, Wu et al. (2019b) proposed EFA to filter the potential attributes and thereby obtain a hierarchical structure to guide small and medium enterprises to improve corporate sustainable development performance. Tseng et al. (2019) integrated EFA, fuzzy synthetic method and decision-making trial and evaluation laboratory method to assess corporate sustainability performance. Given that EFA is capable of (a) shortening data scale without information loss, and (b) explaining the relationship among a set of latent variables, and (c) translating these relationships into theoretical constructs, this paper decides to utilize EFA to uncover the underlying framework for the proposed twenty GSCM practices and then further identify the key factors.

In the existing GSCM literature, many statistical methods have been designed and applied. For example, Wu et al. (2012) empirically investigated the relationship between GSCM drivers and GSCM practice through regression analysis. Shahzad et al. (2020) applied the partial least square-structural equation modelling to identify the influence of organizational compatibilities on GSCM efforts and estimate their influence on organizational performance. However, these statistical models are based on independence, linearity and correlation (Liu et al., 2019), while the selecting decisive components in a GSCM framework has been characterised with complicated hierarchical features, which makes many widely-used statistical methods inappropriate in this paper's context (Sari, 2017; Mastrocinque et al., 2020). Thus, to meet the objectives of this research, it is required to employ structured and systematic decision-making methods versed in tackling hierarchical relationships.

The analytic hierarchy process (AHP) method, invented by Saaty in 1977, is broadly applied to rank alternatives and layers in decision-making processes. It is well-known not only for its flexibility to integrate diverse assessment data (e.g. experts' evaluation, social media information), but also for its ability and simplicity to classify factors. Therefore, many studies strived to resolve GSCM-related issues with the assistance of AHP. For instance, Sari (2017) proposed a hybrid model that incorporates AHP into Monte Carlo simulation for evaluating GSCM practices. Mastrocinque et al. (2020) developed a hierarchical decision-making framework concerning GSCM based on AHP and the triple bottom line concept. In these cases, AHP provides robust solutions to deal with hierarchical decision-making issues without complex modelling (Sarkis and Sundarraj, 2000), and thus this paper adopts it to address the hierarchical relationships among GSCM practices. Nevertheless, these studies only considered qualitative assessment as the main data source for decision analysis, while the qualitative judgement of experts can be sometimes subjective or even arbitrary (Xia et al., 2020). In order to tackle this dilemma, corporate website information is considered to be integrated with qualitative assessment data for improving the accuracy of decision analysis and simultaneously reducing judgement bias. To enable the merge, official website information needs to be translated into entropy weight.

Owing to the information revolution, corporate websites become an indispensable channel for companies to deliver key information concerning their environmental and sustainable development targets and commitments to the public. The China's chemical companies have also drawn on official websites to facilitate the communication with their supply chain partners and other stakeholders with regard to GSCM practices. For example, the official website of Jinyuyuan Chemical Group conveys the footsteps towards developing the principle of circular economy in its industries and promoting the effectiveness of GSCM for cleaner production. Though fruitful useful information on these pages, it is not possible to effectively learn from this knowledge and experience without a hybrid decision method to process the website information. Thus, to analyse the contents of the official websites of five leading chemical companies for a benchmarking analysis, this paper employs a web crawler programmed by Python to scrap and accumulate the frequency of occurrence of each keyword to understand the key practices in the leading companies. Since these frequencies scraping from the websites contain grey and uncertain information, it thus needs to be transformed into entropy weight for further calculation (Wu et al., 2019b).

Entropy was originally considered as a thermodynamic concept, while Shannon (2001) firstly applied entropy in the field of information communication. The entropy value indicates the degree of chaos in a system. Xia et al. (2020) underlined that the degree of system disorder can be well demonstrated by entropy weight. In the literature, EWM has been widely employed in the application of decision-making approaches

**Table 3**
Results of exploratory factor analysis.

| | Criteria | | GSCM Practices | Factor Loading | Cronbach's Alpha |
|---|---|---|---|---|---|
| A1 | Economic initiatives | P1 | Environmental requirements for purchasing | 0.825 | 0.873 |
| | | P2 | Collaborative R&D | 0.810 | |
| | | P3 | Selecting green suppliers | 0.769 | |
| | | P4 | Environmentally preferable purchasing | 0.755 | |
| A2 | Environmental management | P5 | Managing environmental risks | 0.853 | 0.907 |
| | | P6 | Environmental policy regarding GSCM | 0.808 | |
| | | P7 | Top management support | 0.773 | |
| | | P8 | Environmental auditing | 0.762 | |
| | | P9 | Product testing report | 0.759 | |
| A3 | Resource recycling | P10 | Integrating reverse logistics | 0.846 | 0.852 |
| | | P11 | Advancing recycling technologies | 0.841 | |
| | | P12 | Joining local organisations for collaborative recycling | 0.825 | |
| A4 | Eco-design | P13 | Green transportation | 0.853 | 0.895 |
| | | P14 | Performing life cycle assessment | 0.806 | |
| | | P15 | Environmental information systems | 0.751 | |
| A5 | Stakeholder & employee | P16 | Supplier meeting | 0.846 | 0.913 |
| | | P17 | Supplier survey | 0.839 | |
| | | P18 | Establishing communication platform | 0.824 | |
| | | P19 | Cross-functional team | 0.811 | |
| | | P20 | Training and education | 0.788 | |

and has been validated as a useful and accurate approach for determining objective weights. For instance, Wang and Lee (2009) calculated the distances to both ideal and negative-ideal solutions to determine the ranking order of alternatives with regard to the Shannon's entropy theory. Khan et al. (2018) used fuzzy Shannon entropy to obtain the sustainability weight so as to evaluate and select suppliers. Xia et al. (2020) proposed a hybrid method that integrates vague set theory with the technique for order preference by similarity to ideal solution method associated with entropy weights. Moreover, the importance and quantity of information can be measured based on the dataset itself through EWM. Therefore, this paper employs this method to purify these ambiguous data originated from the corporate websites, as well as provide an appropriate objective weighted approach to modify the traditional AHP.

In summary, this paper utilizes EFA to uncover the underlying hierarchical framework of the proposed 20 practices. Then, AHP is employed to address the hierarchical relations contained in this framework and identifies the key GSCM factors in the proposed structure by adopting an EWM-AHP method incorporating corporate official website information with qualitative assessment data.

## 3. Methodology

### 3.1. Industrial background and benchmarking

The chemical industry, one of China's main manufacturing industries, is central to China's economy. Currently, China is the largest chemical manufacturer in the world. With the support by the Chinese government, the industry has made great efforts to fight the environmental problems including industrial wastes and pollution. From the beginning of this century, one of the actions of the China's chemical

**Table 5**
Statistics for Overall Weights using AHP Method.

| | Weight | MAX | MIN | Standard Deviation | 95% Confidence Interval |
|---|---|---|---|---|---|
| A1 | 0.0286 | 0.0160 | 0.0793 | 0.0159 | [0.0599, −0.0026] |
| A2 | 0.0535 | 0.0257 | 0.1007 | 0.0236 | [0.0996, 0.0073] |
| A3 | 0.0388 | 0.0138 | 0.0560 | 0.0131 | [0.0645, 0.0131] |
| A4 | 0.0504 | 0.0326 | 0.0951 | 0.0154 | [0.0806, 0.0201] |
| A5 | 0.0245 | 0.0065 | 0.0530 | 0.0140 | [0.0519, −0.0029] |
| P1 | 0.0060 | 0.0040 | 0.0079 | 0.0009 | [0.0078, 0.0041] |
| P2 | 0.0050 | 0.0033 | 0.0060 | 0.0007 | [0.0064, 0.0036] |
| P3 | 0.0060 | 0.0044 | 0.0077 | 0.0009 | [0.0078, 0.0041] |
| P4 | 0.0107 | 0.0084 | 0.0132 | 0.0014 | [0.0135, 0.0079] |
| P5 | 0.0182 | 0.0144 | 0.0216 | 0.0025 | [0.0230, 0.0134] |
| P6 | 0.0107 | 0.0096 | 0.0131 | 0.0008 | [0.0122, 0.0092] |
| P7 | 0.0251 | 0.0217 | 0.0323 | 0.0030 | [0.0309, 0.0193] |
| P8 | 0.0092 | 0.0073 | 0.0138 | 0.0014 | [0.0120, 0.0064] |
| P9 | 0.0095 | 0.0066 | 0.0125 | 0.0016 | [0.0126, 0.0064] |
| P10 | 0.0137 | 0.0102 | 0.0154 | 0.0014 | [0.0165, 0.0109] |
| P11 | 0.0167 | 0.0131 | 0.0231 | 0.0028 | [0.0222, 0.0113] |
| P12 | 0.0072 | 0.0059 | 0.0084 | 0.0005 | [0.0082, 0.0061] |
| P13 | 0.0093 | 0.0077 | 0.0131 | 0.0013 | [0.0119, 0.0068] |
| P14 | 0.0245 | 0.0201 | 0.0323 | 0.0031 | [0.0306, 0.0185] |
| P15 | 0.0094 | 0.0073 | 0.0153 | 0.0019 | [0.0132, 0.0056] |
| P16 | 0.0035 | 0.0029 | 0.0048 | 0.0005 | [0.0045, 0.0025] |
| P17 | 0.0038 | 0.0029 | 0.0048 | 0.0006 | [0.0049, 0.0027] |
| P18 | 0.0052 | 0.0043 | 0.0088 | 0.0009 | [0.0070, 0.0033] |
| P19 | 0.0047 | 0.0031 | 0.0071 | 0.0009 | [0.0063, 0.0030] |
| P20 | 0.0063 | 0.0049 | 0.0079 | 0.0010 | [0.0082, 0.0043] |

**Table 4**
A sample of six pair-wise comparison matrixes of aspects.

| | A1 | A2 | A3 | A4 | A5 | | A1 | A2 | A3 | A4 | A5 | | A1 | A2 | A3 | A4 | A5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 1.00 | 0.25 | 0.20 | 0.33 | 1.00 | A1 | 1.00 | 0.50 | 0.33 | 0.33 | 0.50 | A1 | 1.00 | 0.33 | 0.50 | 0.50 | 2.00 |
| A2 | 4.00 | 1.00 | 1.00 | 4.00 | 5.00 | A2 | 2.00 | 1.00 | 1.00 | 1.00 | 1.00 | A2 | 3.00 | 1.00 | 4.00 | 1.00 | 2.00 |
| A3 | 5.00 | 1.00 | 1.00 | 4.00 | 5.00 | A3 | 3.00 | 1.00 | 1.00 | 2.00 | 2.00 | A3 | 2.00 | 0.25 | 1.00 | 1.00 | 2.00 |
| A4 | 3.00 | 0.25 | 0.25 | 1.00 | 5.00 | A4 | 3.00 | 1.00 | 0.50 | 1.00 | 1.00 | A4 | 2.00 | 1.00 | 1.00 | 1.00 | 2.00 |
| A5 | 1.00 | 0.20 | 0.20 | 0.20 | 1.00 | A5 | 2.00 | 1.00 | 0.50 | 1.00 | 1.00 | A5 | 0.50 | 0.50 | 0.50 | 0.50 | 1.00 |
| | A1 | A2 | A3 | A4 | A5 | | A1 | A2 | A3 | A4 | A5 | | A1 | A2 | A3 | A4 | A5 |
| A1 | 1.00 | 2.00 | 3.00 | 0.25 | 0.33 | A1 | 1.00 | 0.33 | 0.25 | 0.50 | 0.25 | A1 | 1.00 | 0.33 | 0.25 | 0.20 | 1.00 |
| A2 | 0.50 | 1.00 | 1.00 | 0.50 | 0.33 | A2 | 3.00 | 1.00 | 0.50 | 0.50 | 1.00 | A2 | 3.00 | 1.00 | 0.50 | 0.33 | 4.00 |
| A3 | 0.33 | 1.00 | 1.00 | 0.33 | 0.33 | A3 | 4.00 | 2.00 | 1.00 | 3.00 | 1.00 | A3 | 4.00 | 2.00 | 1.00 | 1.00 | 4.00 |
| A4 | 4.00 | 2.00 | 3.00 | 1.00 | 0.33 | A4 | 2.00 | 2.00 | 0.33 | 1.00 | 2.00 | A4 | 5.00 | 3.00 | 1.00 | 1.00 | 5.00 |
| A5 | 3.00 | 3.00 | 3.00 | 3.00 | 1.00 | A5 | 4.00 | 1.00 | 1.00 | 0.50 | 1.00 | A5 | 1.00 | 0.25 | 0.25 | 0.20 | 1.00 |

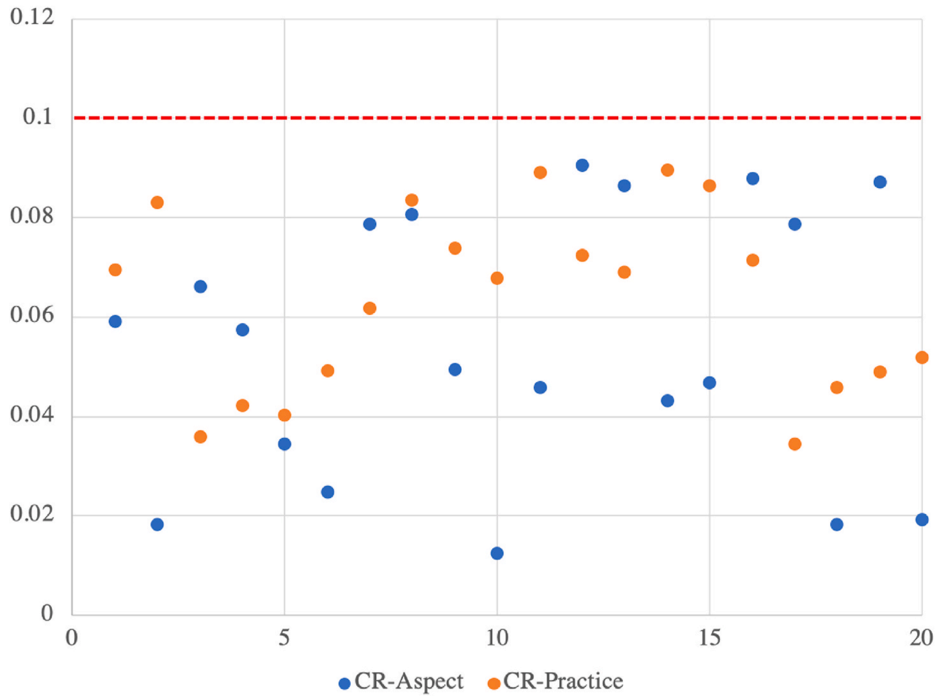


**Fig. 1.** Consistency test: Results of CR values.

**Table 6**
Collected frequencies using web crawler.

| Company Web Address | http://www.jihenggroup.com | http://www.nx-jyy.com | http://www.xj-tianye.com | http://www.lubei.com.cn | http://www.ybty.com | Total |
|---|---|---|---|---|---|---|
| Number of Web Pages | 42 | 651 | 206 | 1048 | 206 | 2153 |
| Economic initiatives | 49 | 322 | 45 | 4299 | 49 | 4764 |
| Environmental management | 4 | 242 | 89 | 5999 | 33 | 6367 |
| Resource recycling | 24 | 1418 | 19 | 1403 | 46 | 2910 |
| Eco-design | 30 | 1571 | 30 | 5592 | 17 | 7240 |
| Stakeholder & employee | 4 | 94 | 240 | 619 | 12 | 969 |

**Table 7**
Results of entropy weight method.

| | Criteria | Frequency | Entropy | Degree of Divergence | Entropy Weight |
|---|---|---|---|---|---|
| A1 | Economic initiatives | 4764 | 0.257 | 0.743 | 0.239 |
| A2 | Environmental management | 6367 | 0.169 | 0.831 | 0.268 |
| A3 | Resource recycling | 2910 | 0.522 | 0.478 | 0.154 |
| A4 | Eco-design | 7240 | 0.367 | 0.633 | 0.204 |
| A5 | Stakeholder & employee | 969 | 0.581 | 0.419 | 0.135 |

industry to combat environmental issues is to develop and apply greener technologies. For instance, many companies in China have used more sustainable fuels to produce chemical products; while some have used carbon dioxide and others naturally occurring chemical elements to produce chemical products, fuels, and other substances. In order to promote sustainable development of the industry, chemical companies in China have also been increasingly endeavouring to include sustainability in their corporate strategies to meet the governmental requirements, and to manage the corporate social reputation. Yet, the management of many environment-related issues, including the joint management of environment and supply chain, still falls behind western countries.

To carry out a benchmarking analysis, studies need to first identify and select the companies with the good performance in the industry, and then explore how their targets have been well achieved through their business practices. Therefore, in order to benchmark GSCM practices in the China's chemical sector, five China's chemical companies are selected from the pilot companies in the first batch of circular economy project.[1] This project was launched and developed by the Chinese National Development and Reform Commission and the Chinese State Environmental Protection Administration in October 2005. The selected five China's chemical companies have well developed their circular business models for sustainable development and are good companies to be selected for deeply understanding the GSCM practices they have taken. The chemical companies on the list developed by the national project include: (1) Tianye Group, Xinjiang Province; (2) Jinyuyuan Chemical Group, Ningxia Province; (3) Ji Heng Group, Hebei Province (4) Yibin Tian Yuan Group, Sichuan Province and (5) Lubei Enterprise Group, Shandong Province.

The practices of these benchmarking companies can be captured on their official websites. Their websites contain much information about their plans, strategies, and actions related to GSCM, which could be useful to guide other companies in the industry to make improvements.

[1] In 2005, the Chinese government launched the first batch of pilot companies in its national circular economy project: https://www.ndrc.gov.cn/fggz/hjyzy/fzxhjj/200510/t20051031_1203265.html.

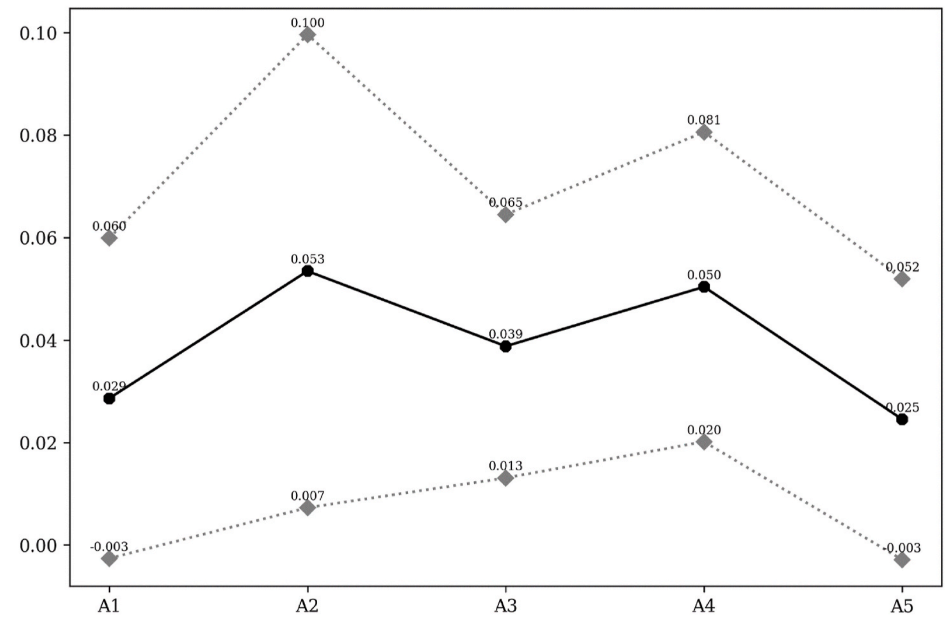


**Fig. 2.** The overall weights of aspects (with 95% confidence interval).

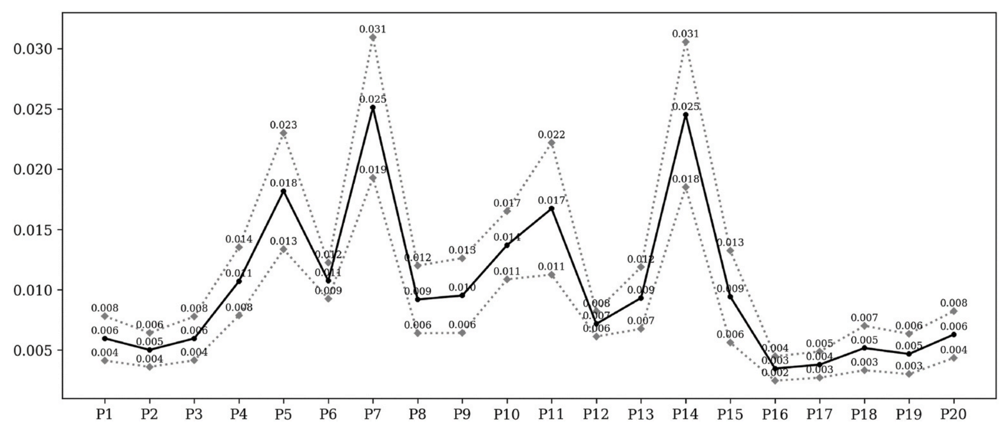


**Fig. 3.** The overall weights of practices (with 95% confidence interval).

Therefore, this research plans to use a web crawler to obtain the frequencies of some keywords in the proposed decision framework and use them to weigh the decision matrixes in order to identify the key GSCM practices. Besides this website information from the chosen companies, qualitative assessment data are also aggregated to weigh and rank each proposed GSCM attribute and practice in the framework. The rest parts of this section will present the hybrid decision making tool this paper applies to provide GSCM decision aids in an effective and cost-effective way.

### 3.2. Exploratory factor analysis

EFA is used to identify the relationships that are reflected by the correlation matrix or the covariance matrix (Wu et al., 2019b). This process is repeated until the criteria are categorised into a few aspects that reflect intrinsic relationships. This paper employs Kaiser–Meyer–Olkin measure and Bartlett test of sphericity for examining the correlation.

Principle components analysis is used to standardize these relations. The factor loading matrix F is generated by computing the eigen values $e_x$ and corresponding standard orthogonal eigen vectors $\varepsilon_{xy}$, x = 1, 2, ⋯, *a*., y = 1, 2, ⋯, b.

$$f_{xy} = \sqrt{e_x}\varepsilon_{xy} \tag{1}$$

$$F = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1b} \\ f_{21} & f_{22} & & f_{2b} \\ \vdots & & \ddots & \vdots \\ f_{a1} & f_{a2} & \cdots & f_{ab} \end{bmatrix} = \begin{bmatrix} \sqrt{e_1}\varepsilon_{11} & \sqrt{e_2}\varepsilon_{12} & \cdots & \sqrt{e_b}\varepsilon_{1b} \\ \sqrt{e_1}\varepsilon_{21} & \sqrt{e_2}\varepsilon_{22} & & \sqrt{e_b}\varepsilon_{2b} \\ \vdots & & \ddots & \vdots \\ \sqrt{e_1}\varepsilon_{a1} & \sqrt{e_2}\varepsilon_{a2} & \cdots & \sqrt{e_b}\varepsilon_{ab} \end{bmatrix} \tag{2}$$

The variance $v_{xy}$ of $f_{xy}$ can be calculated by:

$$v_{xy}^2 = \sum_{x=1}^{a} f_{xy}^2 \tag{3}$$

Assume $g_{xy}^2 = \frac{f_{xy}}{v_x}$, $\widetilde{g}_y = \frac{1}{a}\sum_{x=1}^{a} h_{xy}^2$,

$$V(F) = \sum_{y=1}^{b} V_y \sum_{x=1}^{a} \left(g_{xy}^2 - \widetilde{g}_y\right)^2 \tag{4}$$

Then, this paper uses the maximum variance method for the original rotation. Original rotation matrix $\theta$ is chosen to facilitate the maximization of $V(F\vartheta)$. When b = 2, $\theta$ can be proposed by:

$$F = \begin{bmatrix} \cos\vartheta & -\sin\vartheta \\ \sin\vartheta & \cos\vartheta \end{bmatrix} \tag{5}$$

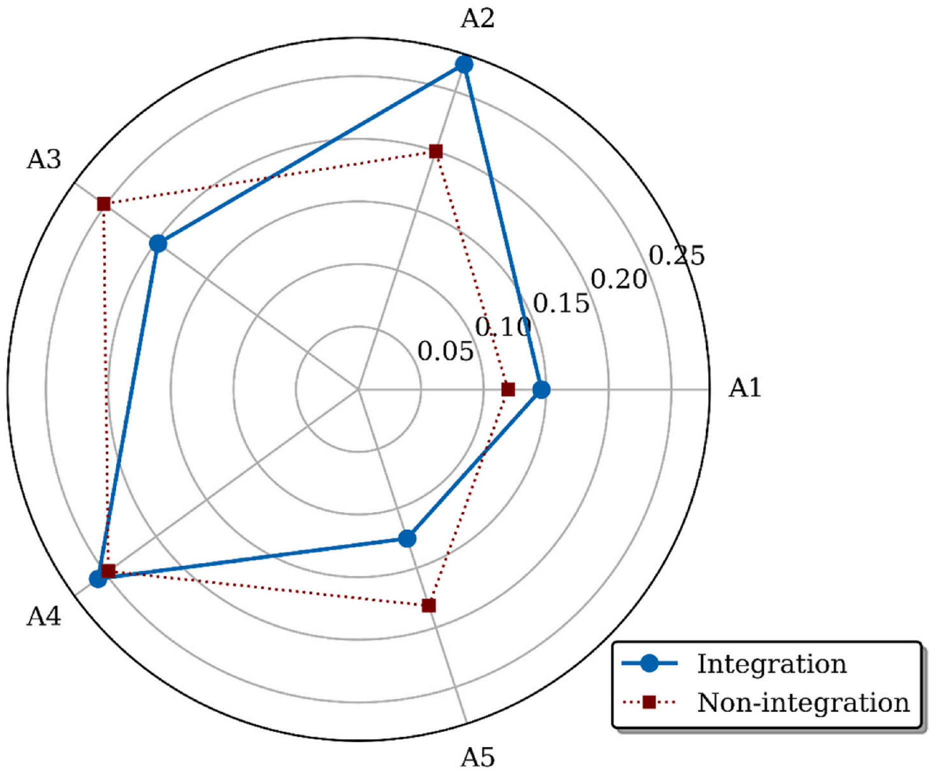


**Fig. 4.** A comparative analysis of weights of aspects calculated with and without official website information.

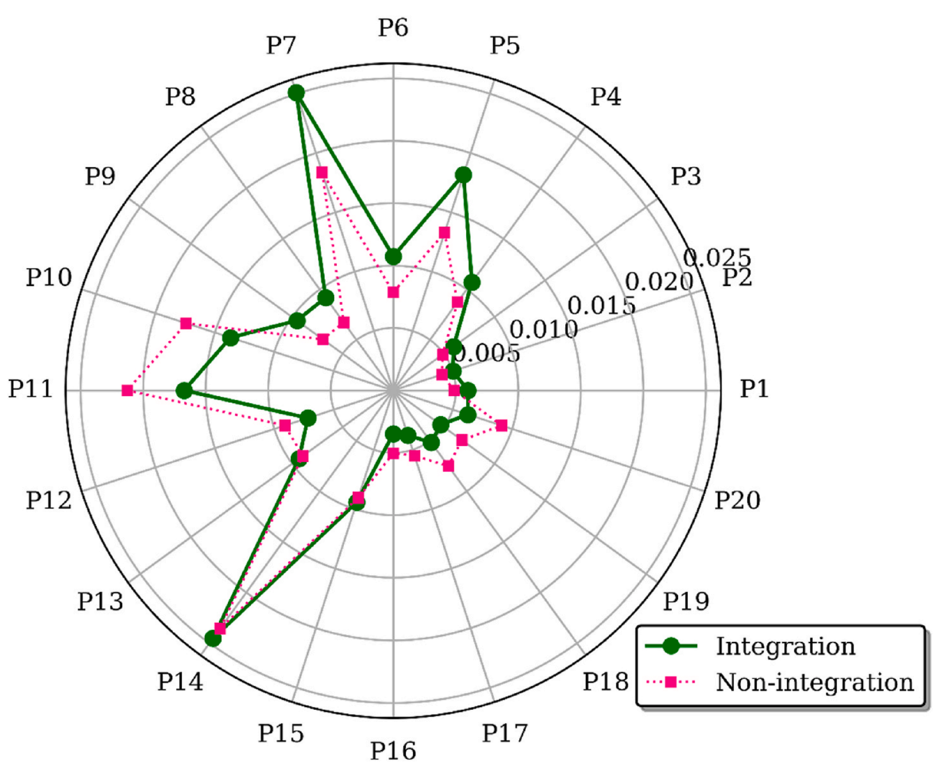


**Fig. 5.** A comparative analysis of weights of practices calculated with and without official website information.

Once $\vartheta$ is chosen for the rotation, $F\vartheta$ is maximized. When b > 2, the successive rotation of two criterion can be reached. Criteria are repeated to be rotated until the total variance reaches convergence.

### 3.3. Analytic hierarchy process

AHP has been broadly used to estimate relative weights of the elements in a decision system. Once defining the context and constructing the decision framework, experts' opinions need to be collected through

**Table 8**
Rankings of aspects and practices.

| | AHP only | Ranking | EWM-AHP | Ranking |
|---|---|---|---|---|
| A1 | 0.1195 | 5 | 0.1462 | 4 |
| A2 | 0.1997 | 3 | 0.2730 | 1 |
| A3 | 0.2519 | 1 | 0.1981 | 3 |
| A4 | 0.2471 | 2 | 0.2573 | 2 |
| A5 | 0.1818 | 4 | 0.1253 | 5 |
| P1 | 0.0245 | 18 | 0.0292 | 14 |
| P2 | 0.0206 | 20 | 0.0245 | 17 |
| P3 | 0.0245 | 19 | 0.0291 | 15 |
| P4 | 0.0439 | 10 | 0.0523 | 7 |
| P5 | 0.0668 | 5 | 0.0888 | 3 |
| P6 | 0.0395 | 11 | 0.0525 | 6 |
| P7 | 0.0923 | 3 | 0.1227 | 1 |
| P8 | 0.0338 | 15 | 0.0449 | 11 |
| P9 | 0.0350 | 13 | 0.0465 | 8 |
| P10 | 0.0874 | 4 | 0.0669 | 5 |
| P11 | 0.1068 | 2 | 0.0817 | 4 |
| P12 | 0.0458 | 7 | 0.0350 | 12 |
| P13 | 0.0449 | 9 | 0.0455 | 10 |
| P14 | 0.1183 | 1 | 0.1199 | 2 |
| P15 | 0.0454 | 8 | 0.0460 | 9 |
| P16 | 0.0253 | 17 | 0.0170 | 20 |
| P17 | 0.0276 | 16 | 0.0185 | 19 |
| P18 | 0.0377 | 12 | 0.0253 | 16 |
| P19 | 0.0341 | 14 | 0.0229 | 18 |
| P20 | 0.0458 | 6 | 0.0307 | 13 |

pare-wise comparison. This paper collects their opinions using the preference scale presented as below.When n criteria or practices within one level are assessed against each other, a pair-wise comparison matrix can be generated:

$$C = \left[c_{ij}\right]_{n\times n} = \begin{bmatrix} 1 & c_{12} & c_{13} & & c_{1n-1} & c_{1n} \\ 1/c_{12} & 1 & c_{23} & \cdots & c_{2n-1} & c_{2n} \\ 1/c_{13} & 1/c_{23} & 1 & & c_{3n-1} & c_{3n} \\ \vdots & & & \ddots & \vdots & \\ 1/c_{1n-1} & 1/c_{2n-1} & 1/c_{3n-1} & \cdots & 1 & c_{n-1n} \\ 1/c_{n2} & 1/c_{2n} & 1/c_{3n} & \cdots & 1/c_{n-1n} & 1 \end{bmatrix} \tag{6}$$

Then, the eigenvector of each of the pair-wise comparison matrix can be expressed as $W = (w_1, w_2, \ldots, w_n)^T$, and is computed by the following equation:

$$CW = \lambda_{max} W \tag{7}$$

where $\lambda_{max}$ denotes the maximum eigenvalue of the pair-wise comparison matrix $C$.

In order to check the consistency of the experts' judgements, the following equation can be used to calculate the consistency index (CI), and further obtain the consistency ratio (CR).

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{8}$$

$$CR = \frac{CI}{RI} \tag{9}$$

where RI is the average random consistency index which varies with the size of assessment matrix (i.e. $n$), as shown in Appendix A.

Furthermore, two conditions may occur where depend on the value of $CR$:

**Condition 1.** If $CR \leq 0.1$, the consistency of assessment matrix is acceptable.

**Condition 2.** If $CR \geq 0.1$, the consistency of assessment matrix is rejected, which means that another round of assessment by experts needs to be performed until the **Condition 1** is satisfied.

### 3.4. Entropy weight method (EWM)

Assuming there are $\tau$ aspects and $\omega_m$ denotes the frequencies scrapped from official website, additionally, $m = 1, 2, \cdots, \tau$. These frequencies $\omega_m$ have to be normalized through the following equation:

$$\overline{\omega}_m = \frac{\omega_m}{\sum_{m=1}^{\tau} \omega_m} \tag{10}$$

Subsequently, entropy associated with each item can be calculated by means of the following equation.

$$\omega_{\mathrm{m}}^E = -\omega_0 \times \left[\sum_{m=1}^{\tau} \overline{\omega}_m \ln\left(\overline{\omega}_m\right)\right] \tag{11}$$

Where $\omega_o$ represent the constant of entropy and was proved equal to $(\ln \tau)^{-1}$.

Next, the degree of discriminability can be attained through applying the following equation:

$$d_m^E = 1 - \omega_{\mathrm{m}}^E \tag{12}$$

Once obtaining the entropy and the degree of discriminability, the following equation can be used to determine the entropy weight $\widetilde{\omega}_m^E$ for each aspect.

$$\widetilde{\omega}_m^E = \frac{d_m^E}{\tau - \sum_{m=1}^{\tau} \omega_{\mathrm{m}}^E} \tag{13}$$

Then, the entropy weight stemmed from official website needs to be considered to weigh each eigenvector to acquire the more accurate relative weights of each practice or criterion through the following equation:

$$W^E = \left[\widetilde{\omega}_m^E\right] \times W = \left[w_i^e\right]^T, \ i = 1, 2, 3, n \tag{14}$$

Lastly, the result of relative weights of each practice should be normalized by the equation as below:

$$w_i' = \frac{w_i^e}{\sum_{i=1}^{n} w_i^e}, \ i = 1, 2, 3, n \tag{15}$$

## 4. Results

In this section, the analytical procedures and the corresponding results are presented step by step.

Step 1. After selecting 20 GSCM practices from previous literature, the first-round survey is conducted to check the validity of selected measures among 20 industrial and academic experts. All of them have been worked or studied in the field of theory or/and practice of corporate sustainable development and environmental management for over 5 years. These experts have conducted academic research in the China's chemical industry or have worked in the industry. Then, EFA is utilized by adopting Equations (1)–(5) to demonstrate the internal structure among the twenty GSCM practices, and thereby generate the hierarchical framework for the second-round assessment. The result of EFA was presented in Table 3, therein, the factor loading for each practice ranges between 0.751 and 0.853, indicating that the 0.5 threshold is satisfied (Wu et al., 2019b). In addition, the Cronbach's Alpha also meet the requirement of greater than 0.6, which has been used to measure the internal consistency.

Step 2. Once high content reliability and validity is ensured, the AHP is performed to evaluate the factors in the generated decision framework. A second-round survey is carried out and experts' opinion is obtained through pair-wise comparison using the preference scale presented in Table 2. Then, the pair-wise comparison matrix can be generated using Equation (6). A sample of six pair-wise comparison matrixes of aspects are presented in Table 4.

Step 3. Equation (7) can be adopted to calculate the eigenvector of each matrix. Table 5 presents the weights of each aspect and practice. This paper also calculates the maximum values, minimum values,

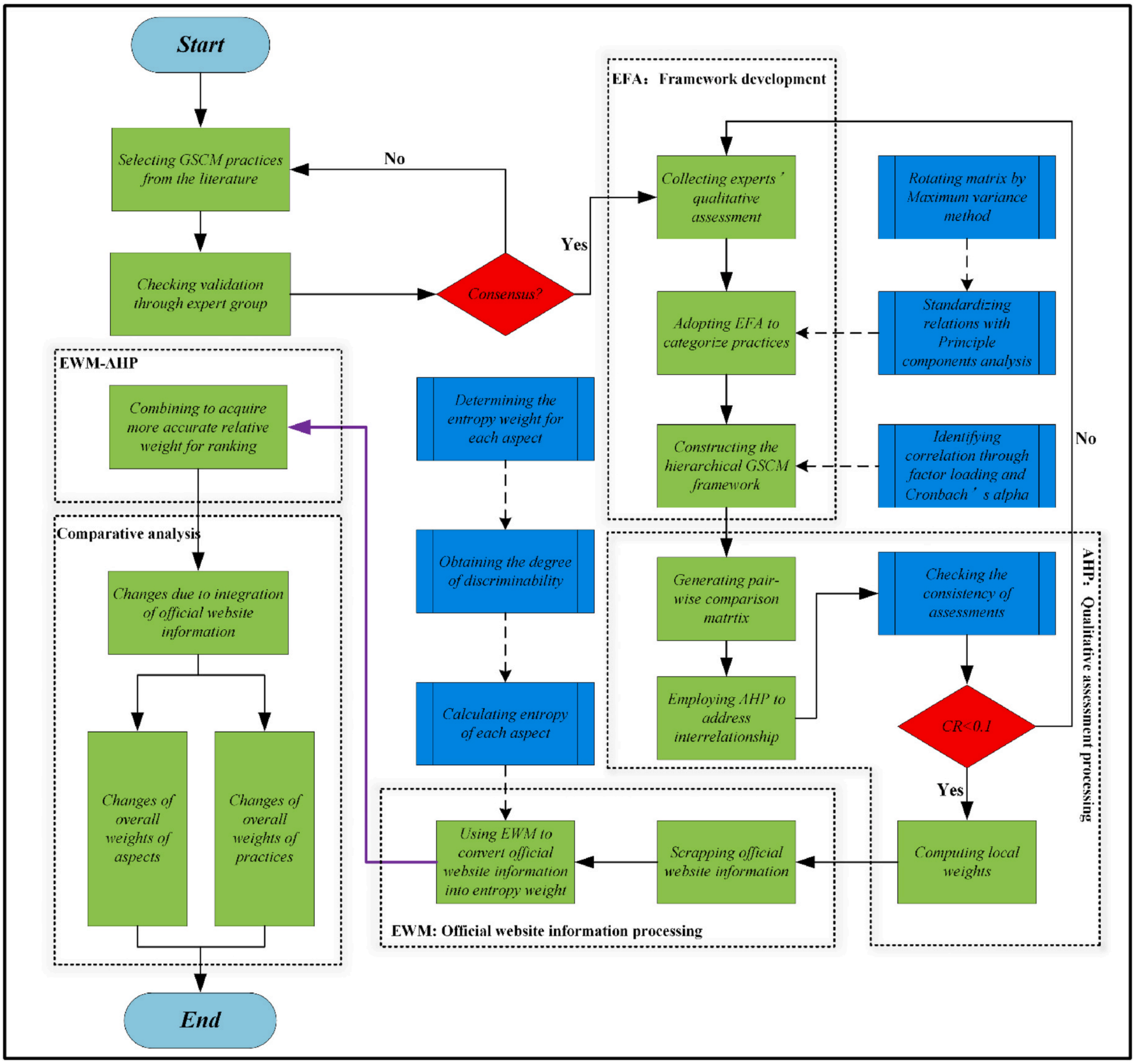


**Fig. 6.** Research flow chart of proposed hybrid method.

standard deviation and 95% confidence levels. In order to check the consistency of the respondents' evaluations, CR must be computed through Equations (8) and (9), and the result was shown in Fig. 1. It is demonstrated that all the CRs are less than 0.1, indicating high consistency of the pair-wise matrixes.

Step 4. A Python scraping tool is programmed and employed to scrap the corporate website information from the official websites of the five chosen companies for benchmarking analysis. Table 6 shows the scrapped frequencies of the keywords (i.e. each aspect in the framework) using the web crawler. Subsequently, these frequencies for each criterion were normalized using Equation (10). Afterwards, the entropy, degree of divergence and entropy weight can be calculated by means of Equation (11)-(13), and the corresponding results are shown in Table 7.

Step 5. Equation (14) and (15) are then used to weigh the eigenvector with the obtained entropy weights, so as to acquire more accurate relative weights of each factor. The overall weights of the aspects and practices generated from EWM-AHP are presented in Fig. 2 and Fig. 3.

Step 6. This paper conducts two comparative analyses to compare the results of integration or non-integration of corporate website information into decision analysis, which are shown in Fig. 4 and Fig. 5. The figures indicate that corporate website information provides some modifications (Xia et al., 2020). Table 8 presented the rankings of the factors within the two levels of the framework. Specifically, the ranking result of EWM-AHP can be demonstrated as P7 > P14 > P5 > P11 > P10 > P6 > P4 > P11 > P15 > P13 > P8 > P12 > P20 > P1 > P3 > P18 > P2 > P19 > P17 > P16 and A2 > A4 > A3 > A1 > A5. Overall, the research flowchart is displayed in Fig. 6 to more intuitively understand the decision-making instrument.

## 5. Implications

### 5.1. Conceptual implications

In order to provide some conceptual implications for GSCM implementation, EFA is utilized to cluster the proposed GSCM practices. As shown in Table 3, the EFA results demonstrate that managers launching GSCM requires to consider five key aspects, including economic initiatives, environmental management, eco-design, resource recycling, and stakeholder and employee. The five perspectives function to improve the GSCM performance from different angles. As demonstrated in Fig. 2, the results of EWM-AHP show the aspects of environmental management (A2), eco-design (A4) and resource recycling (A3) are the most important GSCM themes. It is also worth mentioning that considering website information can help modify the decision system by reducing the subjective information bias (Figs. 4 and 5). As presented in Fig. 4, the comparative analysis shows that integrating corporate website information increases the weight of environmental management (A2) whose ranking rises from the third to the first, while decreases the weight of resource recycling (A3) whose ranking drop to the third from the first place. Similarly, the weight of eco-design (A4) and economic initiatives (A1) also see a growth after integration despite of the varied ascending degree, conversely, the weight of stakeholder and employee (A5) drop markedly due to the integration. Likewise, Fig. 5 shows that the integrating weight of P10, P11, P12, P16, P17, P18, P19 and P20 declines and that of P1, P2, P3, P4, P5, P6, P7, P8, P9, P13, P14 and P15 increases.

This paper shows that environmental management is the most important aspect among the all five to promote GSCM in the China's chemical industry. This aspect indicates the companies in the industry should adopt environmental strategies and manage the operations aiming at reducing the negative environmental impacts and risks (Bowen et al., 2001; Rao, 2002), in order to boost the implementation of environmental practices collaboratively, especially the collaboration and cooperation with other companies in the supply chain (Geffen and Rothenberg, 2000; Vachon and Klassen, 2006). To perform productive GSCM also needs the support from the top executives. Only if the top-level managers make commitments to GSCM, the mid-level managers could lead the practitioners and engineers in different units to practically perform GSCM. Moreover, the framework also demonstrates environmental management could contribute to meet the GSCM goals through facilitating the action of environmental programs and enhance the environmental performance of the products.

The eco-design aspect ranks second. The purpose of eco-design is to minimise the products' life cycle environmental impacts throughout the supply chain (Lifset and Graedel, 2002). During the pre-control process before chemical production, it could reduce the consumption of environmentally unfriendly materials and resources, minimise the adverse effects on the environment and society at the design stage. Eco-design is a critical factor that can influence GSCM practices internally and externally. It can contribute to higher productivity, reduce toxicity and improve recyclability to promote sustainability. In turn, the costs and risks decrease but the quality improves. The regulatory burden that company shoulders can also be lessened. Furthermore, through eco-design in a collaborative way, value throughout the entire life cycle can be further added with the help of different companies and stakeholders to jointly identify opportunities to introduce GSCM actions, such as applying other input alternatives.

Resource recycling refers to taking full advantage of every piece of resource input that has been fed into the production process. This aspect emphasizes the circulation in the economy, whose final purpose is to reach a closed industrial system with zero emission and zero waste. Resource recycling can reduce the environmental damages through managing the wastes and in full measure putting them back into the production to improve the resource efficiency. Chemical companies in China can introduce recycling actions not only internally through exploiting the wastes generated from their own production, but also externally through integrating reverse flow to recycle the fuels and materials from other companies (Sellitto, 2018). In addition, resource recycling could also boost the corporate sales for sustainable economic development, which means a win-win might emerge. This is because recycling actions can trigger positive response from the customers and the wider public attributed to the corporate social reputation enhancement (Zhang et al., 2018; Sellitto, 2018).

### 5.2. Practical implications

The AHP and EWM approaches are combined and utilized to identify the key GSCM practices as well. Different from some previous studies that prioritise purchasing and procurement in GSCM practices (Islam et al., 2018; Tseng et al., 2020), the results in this paper demonstrate that the China's chemical industry should focus more on the management of the environmental issues, and the evaluation, selection, and efficiency promotion of the resources and materials for developing chemical products. The reason for this could be, different from other industries, the chemical industry normally is the upstream supplier for other industries, such as the electronics and electrical industry. Therefore, as demonstrated in Fig. 3, the top five GSCM practices includes top management support (P7), performing life cycle assessment (P14), managing environmental risks (P5), advancing recycling technologies (P11) and integrating reverse logistics (P10).

Top management support (P7) and managing environmental risks (P5) are the most important practices in the aspect of environmental management. This indicates the top executives' value and support is essential to the success of GSCM employment. Top management can strongly promote the cooperation among departments and units and settle the complexity and difficulty of the extensive tasks in GSCM. For example, with the strong support of the top executives in the Tian Yuan Group on the promotion of advanced, green and circular supply chains, and the strategic planning of renewable energy and eco-friendly materials, the company is leading the green and high-quality growth in the chemical industry in Sichuan Province, China. Once top managers commit, risk management adopter can expand the risks identification from merely economic and profit-related risks to environmental and social ones. For instance, top managers in Jinyuyuan Group enact close inspections to assess and manage the safety and environmental risks on the hazardous chemical storage sites.

Performing life cycle assessment (P14) must be enacted to complete eco-design. With LCA, the cumulative environmental impacts of the resources, materials, and energies in the production processes are assessed all the way through manufacturing, distribution, use, disposal, and recycling. In the focal companies, Jinyuyuan Chemical Group actively launched LCA in order to release the public concern regarding the toxic and hazardous chemicals. The managers have been striving to reduce potential waste and possible detriment through optimising the means of controlling operational risks, improving the basic management of the whole process, and improving operational efficiency. Furthermore, in the design of life cycle assessment in the Tianye Group, the company highlights the optimal utilisation of the resources, maximization of the recovery rate, and transportation manners, in order to achieve green supply chains with the resources running efficiently in the system. Besides, as a co-benefit, the published LCA report that announce the corporate social and environmental responsibilities can form a signal in supply chain end-users the public that can better the corporate social image and stimulate product sales (Zhang et al., 2018).

In the perspective of resource recycling, advancing recycling technologies (P11) and integrating reverse logistics (P10) are the most important GSCM practices. Though investment in the applications of novel technologies can cause huge cost burden in the short run, the following recycling costs could be significantly reduced, and efficiency of recycling could be largely promoted, leading to corporate long-term development. Moreover, the reverse flow in the chemical industry requires the collaborations of other companies to build circular industrial chains. The focal companies have also implemented these practices. Lubei Enterprise Group, with the goal of the kinetic energy conversion, industrial transformation and the application of technological innovations, makes good use of seawater, develops new materials and renewable energy for lithium batteries, explores and develops new industries such as graphene, and forms a business strategy to employ green innovations through vertical connections and developing green supply chains through horizontal connections. Tianye Group has developed a circular industry chain at the end of the products' life cycle by using patented technology to produce high value-added calcium carbonate products with carbon dioxide tail gas emitted from industrial parks as raw materials, with reducing the cost of water-saving products.

## 6. Conclusions

The China's chemical industry has been endeavouring to promote sustainability. Researchers are trying to incorporate sustainability concept into supply chain management in the chemical industries in order to effectively improve corporate environmental performance and develop sustainable business models. This paper establishes a multi-criteria decision framework with a set of GSCM practices that could be implemented by chemical companies. In order to develop some conceptual understandings for GSCM, the EFA is used to cluster the proposed practices, which demonstrates that five aspects, including economic initiatives, environmental management, eco-design, resource recycling, and stakeholder and employee, constitutes the underlying conceptual structure of GSCM.

A mixed technique for decision analysis combining EWM and AHP is developed and applied to identify key factors in the proposed framework. Instead of entirely using experts' opinions to inform decision-making as many previous studies did, the novel method developed by this paper aggregates qualitative assessment and corporate website data to reduce the information bias and inaccuracy of subjective judgements. The web crawler programmed by Python is applied to analyse the website contents of five leading companies listed in the national circular economy project, all of which demonstrate good environmental performance in the China's chemical industry. The results demonstrate that for the companies in the industry that are eager to develop GSCM, the integration of the aspects of environmental management, eco-design and resource recycling should be considered priorities. More specifically, the top five GSCM practices are top management support, performing life cycle assessment, managing environmental risks, advancing recycling technologies and integrating reverse logistics.

The contribution of this paper is threefold: (1) this paper proposes a framework with five aspects and twenty practices for GSCM, which could be used by executives to develop business strategies and operations; (2) this paper uses a hierarchical model with considering corporate official website information to identify the important factors that required to be enacted by the Chinese chemical companies for GSCM; (3) this paper combines and applies a mixed decision making tool which can be reapplied to rank factors in many contexts not limited to GSCM. Yet, this paper still has some limitations. Firstly, although this research proposes a systematic framework which has been verified, future studies can discuss other aspects or practices that this framework fails to cover, or revise some of the factors in the proposed framework with reliable evidence to improve its effectiveness. Secondly, it only focuses on the China's chemical industry. Many companies in other industries inside or outside China are still lack of precise guidance as to how to employ GSCM. Future studies could assist those companies in picking out decisive factors to help them effectively and efficiently enact GSCM.

## CRediT authorship contribution statement

**Shuo Gao:** Conceptualization, Methodology, Data collection. **Renlu Qiao:** Data collection, Software. **Ming Kim Lim:** Methodology, Writing – review & editing. **Chentao Li:** Writing – review & editing. **Yang Qu:** Writing – review & editing. **Li Xia:** Methodology, Formal analysis, Writing – original draft, Preparation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledges

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## Appendix A. Average random consistency index

| Size | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *RI* | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.46 | 1.49 | 1.52 | 1.55 | 1.57 | 1.58 |

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