Green supplier selection using an AHP-Entropy-TOPSIS framework

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Abstract

Purpose – This paper aims to focus on development of a green supplier selection model using an index system based on a combination of traditional supplier and environmental supplier selection criteria. Strategies that balance economic and environmental performance are increasingly sought after as enterprises that increasingly focus on the sustainability of their operations. Green supply chain management (GSCM) in particular, enables the integration of environmentally friendly suppliers into the supply chain to be systematised to fit with specific environmental regulations and policies. More persuasively, GSCM allows enterprises to improve profits whilst lowering impacts on the global environment.

Design/methodology/approach – A two-phase survey approach was adopted for the research. For the first phase, semi-structured interviews with senior management representatives of the case company – a Chinese-based electronic machinery manufacturer – were used to determine green supplier selection criteria. For the second phase, a two-part questionnaire survey was undertaken, the first part providing the data for an analytic hierarchy process (AHP) analysis of the first-phase criteria and the second with collecting data for an Entropy weight analysis. The resultant AHP and Entropy weights were then combined to form compromised weights – which, using technique for order preference by similarity to the ideal solution (TOPSIS) methodology, were translated into preferential rankings of suppliers.

Findings – Senior managers were found to rank traditional criteria more highly than environmental alternatives – the implication being that for the company, concerned, it may take some time before environmental awareness is fully assimilated into GSCM practice.

Originality/value – The paper moves us a significant step closer to the application more widely, of innovative AHP-Entropy/TOPSIS methodology to real-world SCM problems.

Keywords Green issues, Analytical hierarchy process, Modelling

Paper type Research paper

1. Introduction

Between 1979 and 2010, China's real gross domestic product (GDP) growth averaged over 9.9 per cent per annum and has hardly slackened since. Unfortunately, these remarkable economic results have come at the expense of soaring industrial effluence which Chinese authorities have yet to reverse. This is despite billions of yen of investment resulting from a succession of major government anti-pollution initiatives (Chiou *et al.*, 2008) including, for example, the *Administrative Measure on the Control of Pollution Caused by Electronic Information Products* in March 2007 (Tsai *et al.*, 2013) .

It is estimated that air pollution, on its own, is responsible for an estimated 350,000-500,000 premature deaths in China every year (Chen *et al.*, 2013).

As poisoning of the country's air, water and soil continues to take its toll, it comes as no surprise that young Chinese consumers are increasingly drawn to "green"/environmental measures and alternatives.

Hence, the growing importance of green supply chain management (GSCM), which, in effect, promotes cooperation amongst environmentally friendly suppliers to their long-term trading advantage (Rao, 2002).

Operations research methods have become increasingly prevalent in GSCM-related analysis: in particular, decision support systems and inventory management feature prominently in an e-logistics study by Sarkis *et al.* (2004); analytic network process and portfolio modelling are used by Zhu *et al.* (2010) to evaluate suppliers' relative power and performance and structural equation modelling is exploited by Lee *et al.* (2012) to provide evidence that GSCM practice influences business performance indirectly – through the mediating variables of operational and relational efficiency. Most recently, data envelopment analysis has been used by Bai and Sarkis (2004) to identify key performance indicators (KPI's) influencing suppliers' sustainability performance, whereas resource-based, institutional, stakeholder and social network perspectives have been adopted by Varseyi *et al.* (2014) to assess supplier's sustainability performance. In contrast, Bai *et al.* (2012) provide an assessment of supplier performance using grey-based neighbourhood rough set theory.

Building on this diverse analytical experience, the study now described involves the use of analytic hierarchy process

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(AHP), Entropy and technique for order preference by similarity to the ideal solution (TOPSIS) for optimising green supplier selection (Hu and Hsu, 2006; Seuring and Muller, 2008).To assist with the latter, an index system was developed, which integrated traditional supplier and environmental supplier selection criteria simultaneously.

A case design approach was adopted for the research – data being provided by a People's Republic of China (PRC)-based small and medium-sized enterprise (SME) – see Zhu *et al.* (2005) on unrelated PRC-based GCSM research.

The next section reviews recent literature on GCSM, supplier selection index systems and supplier selection models. Following on, data collection methods are detailed and the case company and analytical approach introduced.

2. Green supply chain management

GSCM can be considered as a composite of SCM and environmental management (Srivastava, 2007). The aim of a green supply chains is to help enterprises achieve a balance between economic and environmental performance, reduce the impact of their products and services on the environment and foster an environmental image (Sarkis, 2001). Ultimately, GSCM is concerned with promoting green products and enhancing market competitiveness (Kumar *et al.*, 2012) Relevant initiatives to this effect are discussed by Chiang *et al.* (2011), Tsireme *et al.* (2012), Payman and Cory (2013), Blome *et al.* (2011), Guo *et al.* (2014).

Like SCM itself, definitions of GSCM vary depending on the goal of the investigator. Adapting a classification by Walton *et al.* (1998) GSCM, here, is taken to cover:
- green purchasing (GP);
- green manufacturing/materials management;
- green distribution/marketing; and
- reverse logistics.

GP takes place at the beginning of a green supply chain and is defined as an environmentally oriented purchasing practice that applies environmental criteria to the selection of products and services. For green programmes to be successful, companies' environmental goals need to be integrated with green purchasing activities – most notably in respect of supplier selection, supplier evaluation, supplier management and relationship management (Galle and Min, 1997). Benefits of GP include reduction in sources of waste, waste minimisation of hazardous materials and recycling and reclamation of purchased materials (Holt and Rao, 2005).

GP strategies can be broadly categorised as **reactive** (where a supplier's environmental performance is evaluated against environmental standards and regulations) or **pro-active** (where suppliers' competency for successfully implementing new environmental programs in the future is assessed). Given the still relatively undeveloped state of GSCM in China, only the reactive strategy was considered in the modelling later.

2.1 Supplier selection

Supplier selection and evaluation (SSE) is a critical consideration in establishing an effective and competitive supply chain (Jabbour and Jabbour, 2009; Noci, 1997), and multiple criteria decision-making (MCDM) methods are widely used for tackling SSE problems (Ho *et al.*, 2010; Jabbour and Jabbour, 2009) (Tahriri *et al.*, 2008).

Various approaches for dealing with SSE have evolved in recent years: in 2005, Chen proposed a two-stage vendor selection process, the first stage was concerned with the minimum level of environmental performance acceptable from suppliers, and the second stage concerned assessment using traditional criteria based on ISO 14000. In contrast, the index system developed by Humphreys *et al.* (2006) used scalable fuzzy membership functions for evaluating suppliers' environmental performance. Subsequently, AHP methods were proposed by Lu *et al.* (2007) and Chiou *et al.* (2008), unlike Tuzkaya *et al.* (2009) who utilized hybrid fuzzy analytic network process methodology.

Supplier selection methods can be conveniently categorised as **qualitative** (Dickson, 1966; Walton *et al.*, 1998) and **quantitative** – quantitative studies being far the more numerous. Following on, four classes of supplier selection model feature prominently in the literature, namely:
1 linear-weighting models/AHP;
2 mathematical programming (MP) models;
3 total cost ownership (TCO) models; and
4 data envelopment analysis (DEA), activity-based cost (ABC) and other models.

Although each has strengths, there are weaknesses also:
- MP models (Humphreys *et al.*, 2007) in particular are only able to cope with quantitative criteria and are often too complex for senior managers to use.
- TCO models (Degraeve *et al.*, 2005) meanwhile – as well as also being over-complex – are notorious for the excessive data demands they make on purchasing managers.
- Other models used in SSE stem from many diverse theoretical sources, e.g. transaction cost theory (Qu and Brocklehurst, 2003), DEA (Talluri *et al.*, 1999), genetic algorithms (Sha and Che, 2006), fuzzy set theoretic analysis (Sarkar and Mohapatra, 2006) and ABC methodology (Roodhooft and Konings, 1996).
- AHP (Saaty, 1980): the focus of this paper is especially popular for dealing with MCDM problems. The downside of AHP however is that it requires data which, reflecting experience, judgement and knowledge, are often of a subjective nature. What is more, if a new criterion is added to the AHP model, the calculation process has to start all over again. To overcome these drawbacks, the Entropy weight method (Shannon, 1948) was used in conjunction with AHP to form a comprehensive index system to allow for both objective and subjective weights simultaneously.

3. Data collection

To determine the green supplier selection criteria needed for the first phase of the analysis, senior management representatives of the company were interviewed using a semi-structured approach. The relevant protocol is described in Appendix 1. Note that semi-structured interviews are useful, particularly in exploratory discussions for stimulating a less forced and more open-ended flow of communication. A traditional Delphi method was used to summarise the data. Note that, in practice, the chosen criteria will be based on the company's green purchasing strategy or business objective and specific procurement requirements.

Representatives for this phase of the data collection included the chief procurement officer and senior management representatives from the procurement department. Not only did these chosen individuals share a deep understanding of their enterprises' business strategy and operation strategy, but they were also familiar with the organization's purchasing strategy, supplier selection process and purchasing performance outcomes.

3.1 Questionnaire survey

For the second phase of the research, a questionnaire survey was undertaken. The questionnaire was divided into two parts – the first part to collect quantitative data by the Modified Delphi Method (Murry and Hammons, 1995) (Appendix 2). Six senior managers from five departments of the company were chosen to make up the expert group and each was required to make a pair-wise comparison of the decision criteria obtained in the first phase, as well as provide relative scores. These results were then aggregated by the expert group "chairman" for use in the AHP analysis.

The second part of the questionnaire (Appendix 3) related to the qualitative data needed to determine the Entropy weights. This was collected using the snowball sampling technique. With snowball sampling an initial respondent is asked to recommend other possible respondents who may also have valuable information for the investigation. The advantage with this approach is that numerous respondents can be selected in a short time without detailed knowledge of the organization concerned. Second, because each respondent has been recommended by another, strong connections can be established with respondents (Etter and Perneger, 2000).

The survey was conducted by email.

The research utilized the Triangulation Paradigm for guaranteeing the efficacy of combining the qualitative and quantitative tools – see Figure 1 for details. The core idea of Triangulation is that confidence in the conclusion is increased by the incorporation of diverse kinds of data (Nigel and Margrit, 2001).

4. The case company and AHP/Entropy weight/ TOPSIS methodology

The case company – an electronic machinery manufacturer – specialises in the design and manufacture of uninterruptible power supply (UPS) machines tailored to individual customer requirements. Recently, it moved to a larger industrial site north of Hangzhou to expand its production. The move

Figure 1 Triangulation of data collection tools

triggered a huge investment in new machinery including high-tech digital control cutting, folding, and punching equipment. At the time, it was also looking to acquire circuit-breaker equipment.

For its existing SSE process, each circuit-breaker supplier would have been recorded and audited by procurement, quality and manufacturing departments. Suppliers would then only have been considered against procurement guidelines if they were:

- able to provide high-quality product or service;
- able to offer low unit cost; and
- a major supplier in the domestic market.

After a first round of screening, five candidate suppliers were identified as being able to meet these requirements.

Correspondingly, 5 dimensions and 16 criteria were identified from a prior procurement and green purchasing strategy assessment – see Table I for details:

1. Cost (A): Cost minimization plays a significant role in company's profit maximization – relevant costs including those associated with communication, transport and purchasing (Min, 1994; Dickson, 1966; Weber *et al.*, 1991).
2. Green competency (B) reflects the supplier's capacity for designing and producing environmentally friendly/low environmental impact products or services (Humphreys *et al.*, 2006; Chiou *et al.*, 2008).
3. Quality (C) is regarded as a very important – if not the most important – criterion for sourcing raw material or components (Dickson, 1966; Weber *et al.*, 1991).
4. Delivery schedule (D): Chiou *et al.* (2008) argue that appropriate suppliers should be able to provide required products or services on time.
5. Environmental management performance is concerned with measuring and analysing a supplier's production process from the "green" or environmental perspective, such as the pollution resulting from equipment, material, etc. (Lamming and Hampson, 1996; Handfield *et al.*,

Table I Green supplier evaluation criteria

First-class criteria	Criteria
Cost (A)	Average market price rate of commodities (A_1)
	Lowest market price rate of commodities (A_2)
Green competency (B)	Green material selection (B_1)
	Green image (B_2)
	Cleaner production technologies (B_3)
	Reduced green packaging (B_4)
Quality (C)	Rejected and returned material ratio (C_1)
	Quality management capacity (C_2)
	Product percentage of pass (C_3)
Delivery schedule (D)	Service performance (D_1)
	On-time delivery rate (D_2)
	On-time delivery quantity rate (D_3)
Environmental management performance (E)	Use of toxic/restricted substances (E_1)
	Waste management (E_2)
	Remanufacturing/reuse activity (E_3)
	ISO-14001 certification (E_4)

2005; Chen, 2005; Chiou *et al.*, 2008; Tuzkaya *et al.*, 2009).

The resultant green supplier selection hierarchy index system consists of three levels as illustrated in Appendix 3:

1 the goal level;
2 the decision level relating to dimensions A-E; and
3 the index level which links to the 16 criteria, $A_1 - E_4$.

The latter hierarchy structure summarises Stage 1 of our proposed green supplier selection model. Stage 2 – see Figure 2 – involves applying straight AHP to the data (Saaty, 2000). For this aspect of the analysis, each set of criteria was processed separately, and the results then pooled to obtain the subjective weights, a_j.

For Stage 3, objective weights, b_j, were obtained using the Entropy method (Mon *et al.*, 1994).

To arrive at the compromised weights for Stage 4, we exploit a formula due to Xu (2006):

$$W_j = (a_j)^{\alpha}(b_j)^{1-\alpha} \Big/ \sum_{j}^{n} (a_j)^{\alpha}(b_j)^{1-\alpha} \quad (j = 1, 2 \ldots, n) \tag{1}$$

Here W_j represents the compromised weight, and α represents the relative importance of the subjective weight over the objective weight – with $\alpha \in [0, 1]$. For the analysis, α was taken as 0.5, green and traditional criteria being regarded as equally important by survey participants. The resultant Wj was then converted into formal preference rankings ("priority weights") using the TOPSIS method of Hwang and Yoon, (1981).

The priority weight details for Stage 5 of the procedure appear in Table II.

Intriguingly, the new AHP–Entropy approach was found to generate much higher criteria weights for traditional than environmental criteria. This suggests that senior managers in the case company still rated product quality, component price and delivery performance to be more important than GSCM-related factors. In the circumstances, this might not

Figure 2 Overview of AHP/Entropy Weight/TOPSIS methodology

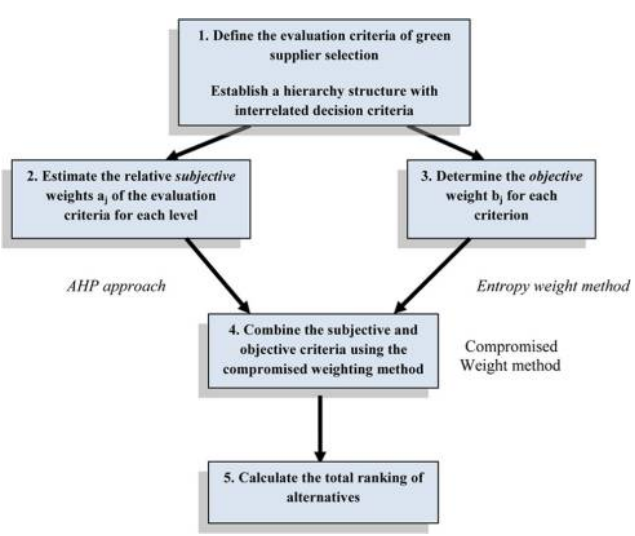

Table II Priority weights of suppliers

Supplier	Priority weight
1	0.76
2	0.8
3	0.77
4	0.25
5	0.24

seem so unrealistic, the view being that until the economic and other benefits of sustainability are better understood, it may take some time before environmental awareness can be fully assimilated into GSCM practice.

From Table I, the priority ranking of the five decision alternatives for Stage 5 is Supplier 2 > Supplier 3 > Supplier 1 > Supplier 4 > Supplier 5. Hence, Supplier 2 is selected as the most appropriate circuit breaker supplier for the case company – closely followed by Suppliers 3 and 1.

For $0 \le \alpha \le 0.8$, Supplier 2 remains the most highly ranked of the five suppliers, suggesting that this choice would be a relatively robust one for the case company. In practice, relevant α values may vary for different companies and careful thought needs to be given on how they might most sensibly be set – or even optimised.

5. Conclusion

The extraordinarily levels of environmental pollution evidenced in China in recent years has led to an urgent response by government and business concerned with balancing greater production and manufacturing with corresponding negative effects on the environment. Although the need for environmental protection and sustainable development is largely accepted in principle, the necessary GCSM tools, skills and knowledge seemingly have yet to be widely adopted.

Within GSCM, green supplier selection is seen as paramount: by embedding "green" initiatives, green suppliers enable manufacturers not only to reduce environmental risk but also to minimise production cost and thus increase their competitiveness.

The paper describes how a systematic and comprehensive GSCM-based methodology was devised to assist a Chinese electric SME in its selection of the most appropriate green suppliers for an imminent parts requirement. The first phase of the study involved in-depth interviews with senior managers to determine the key dimensions (decision areas) and criteria on which potential suppliers were to be evaluated. These enabled a relevant hierarchy index system to be developed. For the second phase of the research, a two-part questionnaire survey was conducted online – the first part providing data for the AHP subjective criteria weight calculations. Correspondingly the second part provided the data for the Entropy weight calculations. Following on, the two sets of weights were combined into a single set of "compromised weights". Finally, the TOPSIS method was used to translate the latter weights into a set of supplier preference rankings.

Particular advantages of the AHP–Entropy model based on the TOPSIS method are that:

- It considers both the qualitative and quantitative criteria available to managers simultaneously and integrates them into a systematic index system.
- By aggregating the AHP subjective and Entropy objective weights into a single compromised weight, manufacturers are able to assess potential suppliers more scientifically and comprehensively.

However, there are limitations also: effective estimation of the parameter, α, which represents the relative importance of the AHP over the Entropy weights in the compromised weight calculations is an issue that warrants further investigation. Similarly, the results obtained for the case company are highly conditioned by the particular green supplier selection index system obtained. Realistically, this may be only one of a number of feasible options available to them. Perhaps a different option might have been "better" in some sense. If so, why, and how could such an option be determined?

Notwithstanding the latter reservations, we believe the experience gained from this research takes us a significant step closer to a more widespread real world use of AHP–Entropy/TOPSIS methodology in the future.

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Appendix 1

Interview protocol

Interview protocol for green supplier selection criteria

1 Objectives:
- To understand which environmental issues (green supplier selection criteria) concern supplier selection in the case company.
- Build a scientific and comprehensive multi-criteria hierarchy system to evaluate and select the most appropriate green supplier by using green supplier chain-based operational methodology.

2 General issues:
- What do you think about the green supply chain?
- Do you think green supply chains are a trend for the future manufacturing industry, and if so, why?
- Why would the company be interested in implementing a green supply chain management strategy?
- In your opinion, which criteria are important for selecting a green supplier?
- Why are they important? What are the potential benefits for the company using these criteria to evaluate a supplier?
- How do environmental criteria impact on supplier selection?
- What is the relationship between company objectives and the green supplier selection criteria?
- What future supplier selection trends are there in manufacturing industry?

Appendix 2

Questionnaire for evaluating the green suppliers

Questionnaire for evaluating the green suppliers

Dear Sir/Madam,

I am currently undertaking a questionnaire survey to evaluate three potential green suppliers according to various qualitative criteria.

I would like to invite you to participate in this research project. A questionnaire that asks you to assign the scores for suppliers is attached in the e-mail. I hope you can look over the questionnaire and thoughtfully make decisions from your practical experience and knowledge. The questionnaire should take you about 5-10 minutes to complete.

In a highly competitive environment, green supplier selection is increasingly recognized as an important area in the supply chain. This is because Ggreen suppliers which embed "green" initiatives enable companies to reduce environmental risk, minimise production costs and increase environment performance. Most importantly, they also help the companies to achieve a sustainable development. Our research will provide a systematic operational methodology to help your company to select the most appropriate suppliers.

I guarantee that your responses will be kept confidential and private. I promise not to share your names, addresses with any other person or organization. Although your participation is voluntary, it will be greatly appreciated if you could complete the questionnaire and return it to the e-mail address provided.

If you require any further assistance or have any questions about finishing the questionnaire or about our research, please contact me by using the details below.

Thank you for your co-operation,

Now, please answer the following questions.

In our survey, questionnaire items are measured using five-point Likert scales.

Please indicate with an X in the box which is appropriate for each supplier's performance.

Figure AI

1. Green material selection (B_1)

	Extremely Good	Very Good	Good	Average	Poor
Supplier 1	☐	☐	☐	☐	☐
Supplier 2	☐	☐	☐	☐	☐
Supplier 3	☐	☐	☐	☐	☐
Supplier 4	☐	☐	☐	☐	☐
Supplier 5	☐	☐	☐	☐	☐

(*continued*)

Figure AI

2. Green image (B_2)

	Extremely Good	Very Good	Good	Average	Poor
Supplier 1					
Supplier 2					
Supplier 3					
Supplier 4					
Supplier 5					

3. Cleaner production technologies (B_3)

	Extremely Good	Very Good	Good	Average	Poor
Supplier 1					
Supplier 2					
Supplier 3					
Supplier 4					
Supplier 5					

4. Reduced green packaging (B_4)

	Extremely Good	Very Good	Good	Average	Poor
Supplier 1					
Supplier 2					
Supplier 3					
Supplier 4					
Supplier 5					

5. Quality management capacity (C_2)

	Extremely Good	Very Good	Good	Average	Poor
Supplier 1					
Supplier 2					
Supplier 3					
Supplier 4					
Supplier 5					

(*continued*)

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Figure AI

6. Service performance (D_1)

	Extremely Good	Very Good	Good	Average	Poor
Supplier 1	☐	☐	☐	☐	☐
Supplier 2	☐	☐	☐	☐	☐
Supplier 3	☐	☐	☐	☐	☐
Supplier 4	☐	☐	☐	☐	☐
Supplier 5	☐	☐	☐	☐	☐

7. Use of toxic/restricted substances (E_1)

	Never use & has an Excellent monitor system	Never use & has a control group	Never use, but no monitor at present process	Do not use	Use
Supplier 1	☐	☐	☐	☐	☐
Supplier 2	☐	☐	☐	☐	☐
Supplier 3	☐	☐	☐	☐	☐
Supplier 4	☐	☐	☐	☐	☐
Supplier 5	☐	☐	☐	☐	☐

8. Waste management (E_2)

	Extremely Good	Very Good	Good	Average	Poor
Supplier 1	☐	☐	☐	☐	☐
Supplier 2	☐	☐	☐	☐	☐
Supplier 3	☐	☐	☐	☐	☐
Supplier 4	☐	☐	☐	☐	☐
Supplier 5	☐	☐	☐	☐	☐

9. Remanufacturing/reuse activity (E_3)

	Extremely Good	Very Good	Good	Average	Poor
Supplier 1	☐	☐	☐	☐	☐
Supplier 2	☐	☐	☐	☐	☐
Supplier 3	☐	☐	☐	☐	☐
Supplier 4	☐	☐	☐	☐	☐
Supplier 5	☐	☐	☐	☐	☐

(*continued*)

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Figure AI

10. ISO-14001 certification (E_4)

	Has and has a excellent environment management system	Has and has environmental management group	Has and has no environmental management organization	Applied	No
Supplier 1	☐	☐	☐	☐	☐
Supplier 2	☐	☐	☐	☐	☐
Supplier 3	☐	☐	☐	☐	☐
Supplier 4	☐	☐	☐	☐	☐
Supplier 5	☐	☐	☐	☐	☐

Appendix 3

Questionnaire for assigning the weights of green supplier selection index system

Questionnaire for assigning the weights of green supplier selection index system

Dear Sir/Madam,

I'm currently undertaking a questionnaire survey of assigning the weights for each criterion in the hierarch index system. The weights assignment plays a significant role in our study and has a direct impact to the final results.

I am very glad to invite you to participate in this research project. A questionnaire that asks you to assign the weights for criteria is attached in the e-mail. I hope you can look over the questionnaire and thoughtfully make the decision under your practical experience and knowledge. The questionnaire should take you about 10-15 minutes to compete, and you may be required to make the compassion decision again if inconsistency happens in the evaluation process.

I guarantee that your responses will only be accessed by research people in order to keep confidential and private. I promise not to share your names, address and other personal/organization details that identify you with anyone outside the research staff. Although your participation is voluntary, it will be greatly appreciated if you could complete the questionnaire and return it according the following e-mail address.

If you have any further assistance or question about finishing the questionnaire and our research, please contact me by using the details below.

Thank you for your co-operation.

Figure AII

1. Measurement scale for pair-wise comparisons

Preference	Numerical rating
Equally preferred	1
Moderately preferred	3
Strongly preferred	5
Very strongly preferred	7
Extremely preferred	9
2, 4, 6, 8 represent intermediate preferences	
Source: Saaty (2000)	

(*continued*)

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Figure AII

2. Illustrated example

The following table shows that: (1) Both A and B are equally preferred, so A/B=1; (2) B is moderately preferred to C, so B/C=3; (3) D is strongly preferred to C, so D/C=5 and C/D is therefore 1/5.

A	B	C	D	
A	1	1		
B	——	1	3	
C	——	——	1	1/5
D	——	——	——	1

1. Green supplier selection hierarchy index system

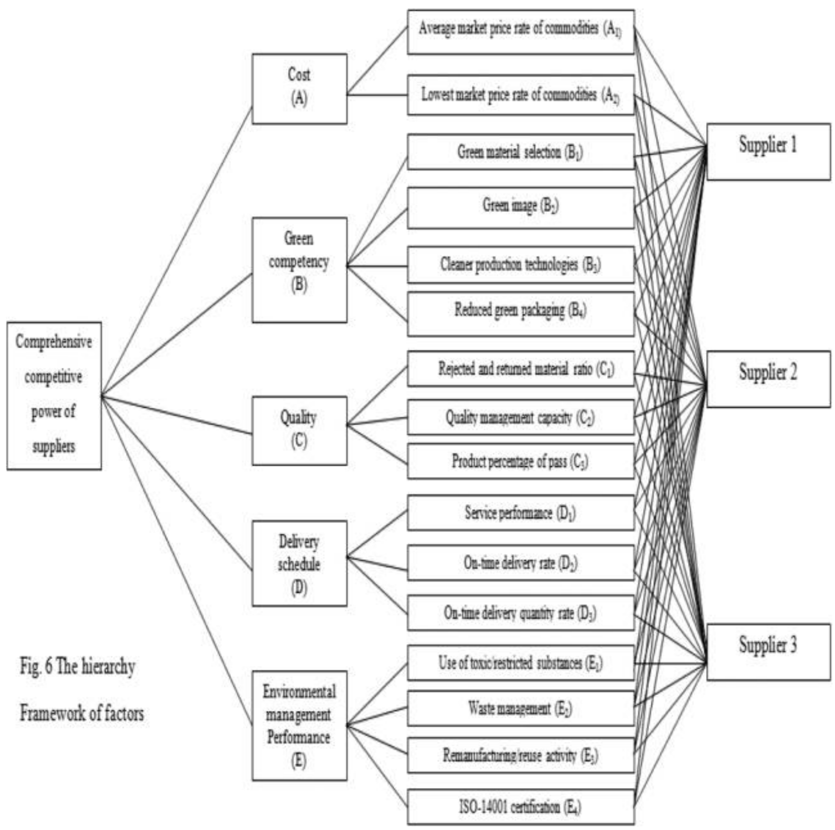

Fig. 6 The hierarchy Framework of factors

Now, please make the comparisondecision based on the above information.

(*continued*)

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Figure AII

First class criteria

1. "Comprehensive competitive power of suppliers"------pair-wise comparison of first class criteria' relevant importance

Cost	Green competency (A)	(B) Quality	Delivery schedule (C)	(D)	Environmental performance management (E)
Cost(A)	1				
Green Competency (B)	——	1			
Quality (C)	——	——	1		
Delivery Schedule (D)	——	——	——	1	
Environmental Performance Management (E)	——	——	——	——	1

Second class criteria

2. "Cost (A)"-----Pair-wise comparison of sub-criteria under the Cost (A) factor

	Average market price rate of commodities (A_1)	Lowest market price rate of commodities (A_2)
Average market price rate of commodities (A_1)		
Lowest market price rate of commodities (A_2)	——	1

(*continued*)

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Figure AII

3. "Green competency (B)"------Pair-wise comparison of sub-criteria under the Green competency (B) factor

	Green material selection (B_1)	Green image (B_2)	Cleaner production technologies (B_3)	Reduced green packaging (B_4)
Green material Selection (B_1)	1			
Green image (B_2)	____	1		
Cleaner production Technologies (B_3)	____	____	1	
Reduced green packaging ((B_1)	____	____	____	1

4. "Quality (C)"------ Pair-wise comparison of sub-criteria under the Quality (C) factor

	Rejected and returned material ratio (C_1)	Quality management capacity (C_2)	Product percentage of pass (C_3)
Rejected and returned material ratio (C_1)	1		
Quality management capacity (C_2)	____	1	
Product percentage of pass (C_3)	____	____	1

(*continued*)

Figure AII

5. "Delivery schedule (D)"------ Pair-wise comparison of sub-criteria under the Delivery schedule (D) factor

	Service performance (D_1)	On-time delivery rate (D_2)	On-time delivery quantity rate (D_3)
Service performance (D_1)	1		
On-time delivery rate (D_2)	——	1	
On-time delivery quantity rate (D_3)	——	——	1

6. "Environmental management performance (E)-----Pair-wise comparison of sub-criteria under the Environmental ma nagement performance (E) factor

	Use of toxic/restricted substances (E_1)	WasteRemanufacturing/reuse management (E_2)	ISO-14001 activity (E_3)	certification (E_4)
Use of toxic/restricted substances (E_1)	1			
Waste management (E_2)	——	1		
Remanufacturing /reuse activity (E_3)	——	——	1	
ISO-14001 Certification (E_4)	——	——	——	1

About the authors

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