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The best vendor selection for conducting the recycled material based on a hybrid MCDM model combining DANP with VIKOR

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ABSTRACT

Environmentally conscious manufacturing and product recovery (ECMPRO) has become an obligation of manufacturers, and it has been extended to be the policy and strategy of businesses. Producing recyclable products and using recycled materials are optimal strategies for ECMPRO. Vendor selection (VS) is one of the multiple criteria decision-making (MCDM) problems in strategic supply chain management. The purpose of this article is to propose how the best selection to conduct the recycled materials can be implemented for enhancing and increasing the efficiency of using resources in the manufacturing process through recycled materials VS. Aluminum composite panel (ACP) is a global product, and ACP companies in Taiwan use recycled materials in more than 80% for their products on a quantity basis. Therefore, we selected the ACP industry of Taiwan as an empirical model to study VS and to reveal methods of improving gaps in each criterion for achieving the aspired levels of performance. We use the MCDM model combining DEMATEL-based on ANP (called DANP) with VIKOR to solve the recycled materials VS problems of multiple dimensions and criteria that are interdependent, instead of the independent assumption of an analytic hierarchy process, for mimicking the real-world scenario.

1. Introduction

Environmentally conscious manufacturing is concerned with developing methods for manufacturing new products from conceptual design to final delivery and ultimately to the end-of-life (EOL) disposal such that environmental standards and requirements are satisfied. Conversely, product recovery aims to minimize the amount of waste sent to landfills by recovering materials and parts from old or outdated products through recycling and remanufacturing (including reuse of parts and products) (Gungor and Gupta, 1999).

The increasing interest in product reuse originates not only from the reinforcement of environmental awareness legislation but also from the fact that the engagement in reuse activities has been proven profitable in many industries (Kannan et al., 2009). So, suppliers face increasing pressure from their customers to improve their environmental performance (Delmas and Montiel, 2009). Mena et al. (2011) identified the main root causes of food waste in the supplier-retailer interface and compared practices in the UK and Spain. Zhang et al. (2012) analyzed the demands, possibilities, difficulties and suggestions for waste cooking oil recycling in China. For these reasons, green manufacturing, that is, making environmentally sound products through efficient processes, can be good for business and is a current trend in business around the world (Melnyk et al., 2001; Venus, 2011).

In the automotive industry, most companies are putting the ability to recycle parts on the same level as safety, fuel economy, and costs when they design new vehicles. The 15-nation European Union is considering a rule that would require 85% of a car by weight to be recycled or remanufactured. This would increase to 95% by 2015. The source of recycled material is post consumer waste (PCW), of which paper, metal, glass, and plastics are the largest categories (Field and Sroufe, 2007). Olugu et al. (2011) developed a set of measures for evaluating the performance of the automobile green supply chain.

According to a long-term study in the US during 1960 to 1996, the amount of plastics consumed annually have been growing steadily from 0.5% to 12.3%, by weight of municipal solid waste (Subramanian, 2000). And the polyethylene, including high density polyethylene and low density polyethylene, forms the largest fraction of plastics in municipal solid waste about 49%. For example, aluminum composite panel (ACP) is a multi-layer sheet that is

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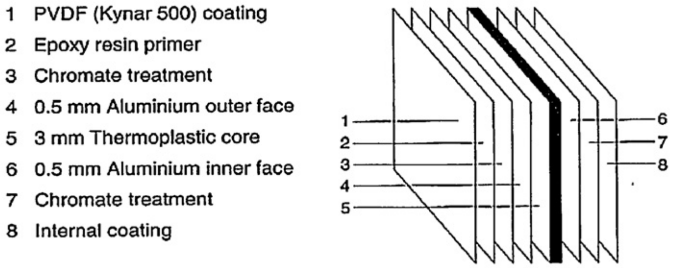

Fig. 1. The composition structure of ACP.

produced by laminating two pre-treated and coated aluminum with a fire resistant mineral-filled or polyethylene (PE) core under a continuous high pressure and heat process (Fig. 1). ACP is a construction material that has been applied to the decoration of buildings both inside and outside of the wall. ACP can be 100% recycled for both aluminum and plastic materials at its EOL.

To introduce the ACP recycling loop, we modified the product life cycle, recycling states and activities figure of Chen et al. (1993). Fig. 2 shows the general stages and the associated activities of ACP recycling. Although the primary recyclable ACP components include aluminum and plastics, this study focus on recycled plastics, such as, low-density PE (LDPE) and high-density of PE (HDPE).

As we know, one of the competencies essential to supply chain success is an effective purchasing function (Cakravastia and Takahashi, 2004; Giunipero and Brand, 1996). Vendor selection (VS), the first step of purchasing function, has a very important role in the supply chain of manufacturing companies Therefore, the purpose of this article is to enhance and increase the efficiency of using resources in the manufacturing process through recycled materials vendor selection (VS). As the demand for environmentally friendly products has grown, the technology for converting PCW into new products has improved, and more recycling programs have been implemented. As a result, the demand for recycled materials and the availability and variety of products with recycled content continues to increase (Field and Sroufe, 2007). For example, according to production records of Taiwan's aluminum composite panel (ACP) manufactures' they used recycled plastics in their products has grown from 0% to 80% on a quantity basis in the past 10 years. Chinese ACP manufacturers use an even higher ratio of recycled plastics. Moreover, this tendency will continue to increase following improvements in environmental management systems and recycling technology in the future.

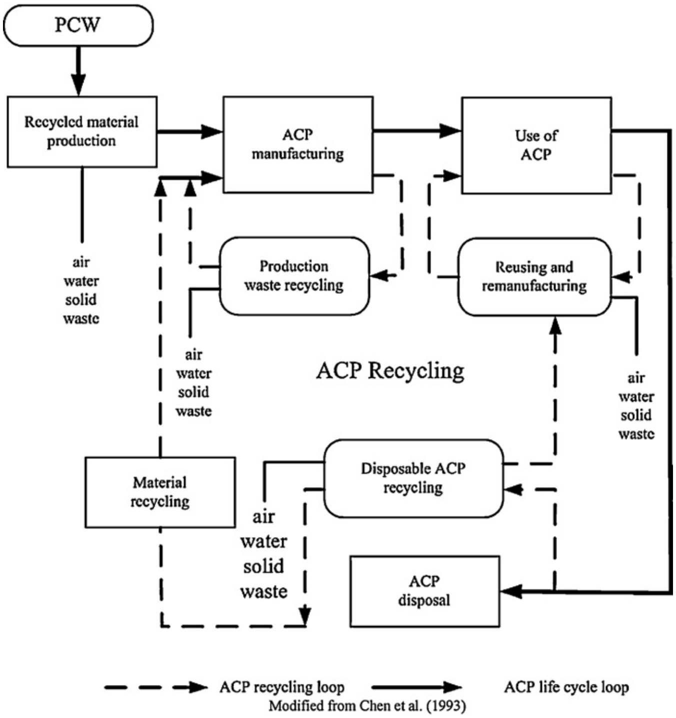

Fig. 2. ACP life cycle recycling stages and activities.

This is the essential reason for our focus on VS, as regarding recycled materials in the ACP industry expect to support acquisition by companies of environmentally friendly materials with stable quality and quantity, reasonable cost, on-time delivery, and good service. As VS is a type of multiple criteria decision-making (MCDM) problem, we propose a hybrid MCDM model combining a decision-making trial and evaluation laboratory (DEMATEL) method with an analytic network process (ANP) and 'VIseKriterijumska Optimizacija I Kompromisno Resenje' (VIKOR; translates into multicriteria optimization and compromise solution) method in this study.

The DEMATEL method (Fontela and Gabus, 1976) was designed to determine the degree of influence of the VS criteria and apply them to normalize the unweighted supermatrix in the ANP. The ANP is an extension of the analytic hierarchy process (AHP); indeed, it is the general form of the AHP. The ANP handles dependence within a cluster (inner dependence) and among different clusters (outer dependence). The ANP is a nonlinear structure, whereas the AHP is hierarchical and linear with goals at the top and alternatives at lower levels (Saaty, 1999). The ANP has been used successfully in many practical decision-making problems, such as the project selection, supply chain management, and optimal scheduling problems (Lee and Kim, 2000; Meade and Presley, 2002; Momoh and Zhu, 2003; Sarkis, 2003).

A hybrid model combining DEMATEL and ANP (we call this model DEMATEL-based ANP; DANP) has been widely applied to solve a variety of applications in solving MCDM problems, such as e-learning evaluations (Tzeng et al., 2007), airline safety measurements (Liou et al., 2007), and innovation policy portfolios for Taiwan's silicon/semiconductor intellectual property (SIP) Mall (Huang et al., 2007). Strategic management decisions influence the relative importance of the various criteria in the VS process (Weber et al., 2000). The majority of VS models in existing publications ignored the fact that evaluation criteria must be aligned with a firm's environmental strategies (Chou et al., 2007).

As mentioned in the previous paragraph, this work is different from previously research in three ways. First, we aligned the criteria with the firm's strategy of environmentally conscious green manufacturing to use recycled materials with VS dimensions and criteria. Second, we adopted a hybrid MCDM model of DANP to evaluate and improve the performance of vendor's dimensions and criteria, which are interdependent for achieving the best alternative in VS. Finally, we combined DANP with VIKOR to evaluate/improve the aspired level of vendor performance based on the network relation map (NRM) by the DEMATEL technique. The best vendor selection for conducting the recycled materials can be achieved.

The rest of this research is organized as follows. In the next section, the relevant literature about vendor selection criteria is reviewed. A hybrid MCDM model for solution methodology is developed in Section 3. In Section 4, an empirical case is illustrated to calculate and show the proposed hybrid MCDM model. In Section 5, we use the results of Section 4 to discuss and highlight the managerial implications based on the case analysis. Finally, conclusions are drawn in Section 6.

2. Vendor selection criteria

VS has a very important role in the supply chain of manufacturing companies. Regarding VS in SCM, many published studies described their evaluation criteria and methods (Chan and Kumar, 2007; Chou et al., 2007; Foster and Ogden, 2008; Ghodsypour and O'Brien, 1998, 2001; Govindan et al., 2010; Masella and Rangone, 2000; Shen and Yu, 2009; Yang et al., 2008). But we did not come across any papers discussing VS for conducting the recycled materials in the literature. VS decisions are complicated by the fact that various criteria must be considered in the decision-making process. The criteria used may vary across different product categories and purchase situations (Shen and Yu, 2009). There may not be a generalized consensus on how to identify suitable criteria because these decisions are highly firm-and situation-specific (Chou et al., 2007; Liu and Hai, 2005; Schmitz and Platts, 2004).

With reference to past literature, it can be observed that there has only been limited discussion of virgin material VS dimensions and criteria, which in fact is insufficient for VS for conducting the recycled materials. To align the company strategy of environmentally conscious green manufacturing with the use of recycled materials, we must consider critical criteria that are connected with green manufacturing in our study.

Vachon (2007) described the concept of green supply chain practices as two sets of related yet independent environmental activities: environmental collaboration and environmental monitoring. Environmental collaboration can be defined as the planning and development of environmental activities and projects that require direct involvement of an organization, whether with its suppliers or its customers, to jointly develop environmental solutions (Geffen and Rothenberg, 2000; Rao, 2002).

According to the above VS criteria review, we modified Chan and Kumar's (2007) VS dimensions which included the overall cost of the product, quality of the product, service performance of supplier, supply risk, delivery, as well as consideration of green supply chain practices for environmental collaboration. The problem we studied here has four levels of hierarchy, and different decision dimensions and criteria will be further discussed in Table 1. The overall objective is selecting the best recycled materials vendor for an ACP manufacturing company.

We denote above dimensions, criteria, and alternatives by D_i ($i = 1, 2, \ldots, 6$), C_j ($j = 1, 2, \ldots, 17$), and V_k ($k = 1, 2, \ldots, n$) to form a hierarchy of vendor selection in recycled materials in Fig. 3.

Based on the literature review, we found the following methods are using recently for evaluation or development suppliers in supply chain management: (1) linear weighting models (Barbarosoglu and Yazgaç, 1997); (2) mathematical programming models (Weber et al., 1991); (3) statistical models (Ronen and Trietsch, 1988; Soukup, 1987); (4) artificial intelligence models (Albino and Gravel, 1998); (5) fuzzy extended AHP (analytic hierarchy process) approach (Chan and Kumar, 2007; Chou et al., 2007; Shen and Yu, 2009); (6) ISM and TOPSIS (Kannan et al., 2009); (7) ISM and fuzzy integral (Yang et al., 2008).

It is quite clear that few articles were carried out on the selection of recycled material vendors using the hybrid MCDM model combining with DANP and VIKOR. Therefore, we proposed to use DEMATEL combine ANP to determine the degrees of influence among the criteria and VIKOR method for calculating the compromise ranking and gap of the alternatives for alternative improvement.

3. Development of solution methodology

VS is one of MCDM problems, as any criterion may be inter-influenced, the DEMATEL technique permits us to know the influence structure between the criteria and try to find problems that can be improved. DEMATEL technique combined with the ANP method to find the most important criterion that will help to improve VS performance. To understand the gap of each criterion and to rank the first important strategy to implement, the VIKOR method will be leveraged for calculating the compromise ranking and gap of the alternatives for alternative improvement. In short, the framework of evaluation contains three main phases: (1) constructing the NRM among criteria by the DEMATEL technique, (2) calculating the weights of each criterion by combining the ANP based on the NRM, and (3) ranking and improving the priorities of alternative vendors through the VIKOR. The process of this hybrid MCDM model is briefly illustrated in Fig. 4.

3.1. *The DEMATEL technique for developing NRM*

The DEMATEL technique has been successfully applied in many situations, such as marketing strategies, e-learning evaluations, control systems and safety problems (Chiu et al., 2006), information security (Ou Yang et al., 2009), financial stock investment (Lee et al., 2009), water resources and environment (Chen et al., 2010), industry technology (Lin and Tzeng, 2009; Lin et al., 2010a–c), and portfolio selection based on CAPM (Ho et al., 2011). The methodology can confirm interdependence among variables/criteria and restrict the relationships that reflect characteristics within an essential systemic and developmental trend. The method can be summarized as follows (Liou et al., 2007, 2008):

Step 1: *Calculate the initial average matrix by scores*. In this step, respondents are asked to indicate the degree of direct influence each factor/element i exerts on each factor/element j, as indicated by a_{ij}, using an integer scale ranging from 0 to 4 (going from "no influence (0)", to "very high influence (4)"). From any group of direct matrices of respondents, it is possible for experts to derive an average matrix $\boldsymbol{A} = [a_{ij}]_{n\times n}$, with each element being the mean of the same elements in the various direct matrices of the respondents.

The average matrix $\boldsymbol{A}$ is represented as shown in Eq. (1).

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

Step 2: *Calculate the initial influence matrix*. The initial influence matrix $\mathbf{X} = [x_{ij}]_{n\times n}$ is obtained by normalizing the average matrix $\boldsymbol{A}$ (shown by degree, i.e., shown by membership and $0 \le x_{ij} < 1$, also called the "fuzzy cognitive matrix"), in which all principal diagonal elements equal zero. Based on $\boldsymbol{X}$, the initial effect that an element exerts and receives from another is shown. The map portrays a contextual relationship among the elements of a system, in which the numeral represents the strength of influence (affected degree).

Table 1
The influence dimensions and criteria of comprehensive VS in recycled materials.

Dimensions	Influence criteria	Statements of influence criteria
Quality of the product (D_1)	Ingredient consistency (C_1)	The ingredient consistency indicates that the source of recycled materials should be one type of PCW
	Process capability (C_2)	Process capability describes the remanufacturing capability of the vendor's production line
	Yield rate (C_3)	The yield rate of products means the fraction of good products used in the recycled materials in production line
Delivery schedule (D_2)	Shortest lead time (C_4)	Lead time is the prepare time, include delivery time, for the vendor to supply recycled materials to their purchasers
	Delivery on time rate (C_5)	The fraction of the vendor's on time delivery of the total shipments in last one year
	Serious delivery delay rate (C_6)	A long time delays that affect the manufacturer's ability to deliver products to customers in a timely advantage
Supply risk (D_3)	Geographical location (C_7)	Increasing distance between a vendor and a purchaser increase the risk of delivery delay, as there is an increased risk of issue with long distance transportation
	Political stability (C_8)	For example, a strike by workers in public utilities and transportation will cause major supply risks for the vendor and purchaser
	Equipment capacity change (C_9)	Equipment capacity change indicates that a vendor has sufficient equipment capacity to meet any change in supply situation change
Overall cost of the product (D_4)	Recycled material price (C_{10})	The bulk of the cost of ACP is recycled material price, which depends on the ingredient consistency of the recycled materials
	Handling cost (C_{11})	The handling cost includes the replenishment costs per unit time and the costs of carrying inventory over a unit time period
	Process loss cost (C_{12})	In processing recycled materials, the quality of the material affects the process loss cost much more than the aforementioned causes
Services (D_5)	Response to demand (C_{13})	The fast and effective response to change in demand by the vendor is very important
	Information acquisition (C_{14})	Recycled materials users require the marketing information about recycled materials and the situations of their competitors, when devising materials purchasing and products sales strategies
	After- sales service (C_{15})	There are frequent quality issues regarding recycled plastics materials. Therefore, vendor's warranties and claim polices for after-sales service are important criteria for VS
Environmental collaboration (D_6)	Technology for recycling products and process (C_{16})	A qualified vendor for recycled materials should have the proper technology for recycling products and process, as more recycling technology will stabilize product quality and decrease resource waste in manufacturing
	Green manufacturing policy (C_{17})	A green manufacturing policy is making environmentally friendly products at the design stage and through efficient processes

***Step* 3**: *Derive the full direct/indirect influence matrix*. A continuous decrease of the indirect effects of problems can be determined along the powers of $\boldsymbol{X}$, e.g., $\boldsymbol{X}^2$, $\boldsymbol{X}^3$, ..., $\boldsymbol{X}^h$ and $\lim_{h\to\infty}\boldsymbol{X}^h=[0]_{n\times n}$, where $\boldsymbol{X}=[x_{ij}]_{n\times n}$, $0\le x_{ij}<1$ and $0\le\sum_i x_{ij}\le 1$ or $0\le\sum_j x_{ij}\le 1$ and at least one column or one row of summation, but not all, equals one. If the (i,j) element of matrix $\boldsymbol{A}$ is denoted by a_{ij}, the matrix $\boldsymbol{X}$ can be obtained through Eqs. (2) and (3), in which all principal diagonal elements are equal to zero.

$$\boldsymbol{X}=z\times\boldsymbol{A} \tag{2}$$

where
$$z=\min\left\{\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n}a_{ij}},\frac{1}{\max_{1\le i\le n}\sum_{i=1}^{n}a_{ij}}\right\} \tag{3}$$

and

$$\lim_{h\to\infty}\mathbf{X}^h=[0]_{n\times n},\ 0\le x_{ij}\le 1$$

Step 4: *Attainning the total-influence matrix* $\boldsymbol{T}$. The total-influence matrix can be obtained through Eq. (4), in which $\boldsymbol{I}$ denotes the identity matrix.

$$\boldsymbol{T}=\boldsymbol{X}+\boldsymbol{X}^2+\cdots+\boldsymbol{X}^h=\quad\boldsymbol{X}(\boldsymbol{I}-\boldsymbol{X})^{-1}\quad\text{when}\lim_{h\to\infty}\boldsymbol{X}^h=[0]_{n\times n}. \tag{4}$$

Explanation

$$\begin{aligned}\boldsymbol{T}&=\boldsymbol{X}+\boldsymbol{X}^2+\cdots+\boldsymbol{X}^h=\boldsymbol{X}(\boldsymbol{I}+\boldsymbol{X}+\boldsymbol{X}^2+\cdots+\boldsymbol{X}^{h-1})(\boldsymbol{I}-\boldsymbol{X})(\boldsymbol{I}-\boldsymbol{X})^{-1}\\&=\boldsymbol{X}(\boldsymbol{I}-\boldsymbol{X}^h)(\boldsymbol{I}-\boldsymbol{X})^{-1}\end{aligned}$$

then,

$$\mathbf{T}=\boldsymbol{X}(\boldsymbol{I}-\boldsymbol{X})^{-1},\quad\text{when}\,h\to\infty.$$

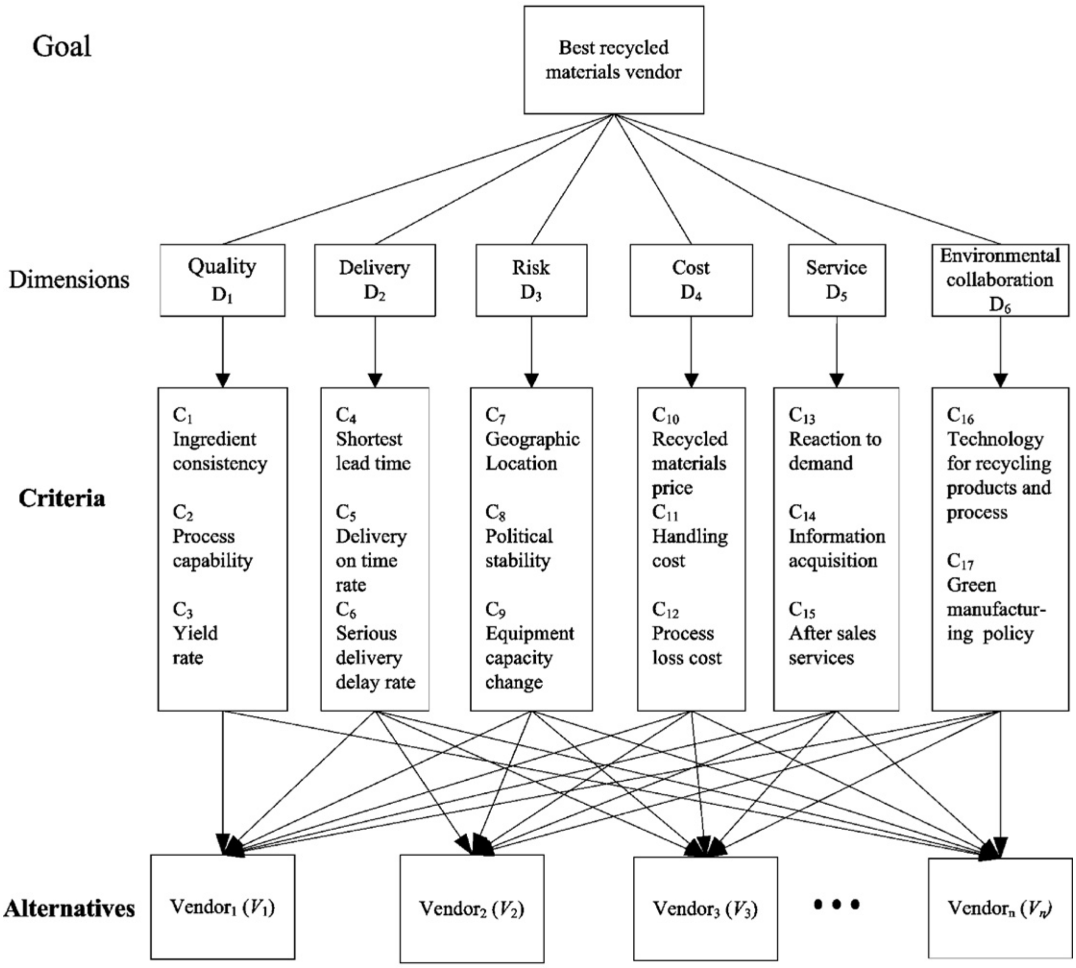

Fig. 3. The hierarchy of vendor selection in recycled materials.

If we define the sum of the rows and the sum of the columns separately expressed as vector $\boldsymbol{r}$ and vector $\boldsymbol{s}$ within the total-influence matrix $\boldsymbol{T}$ through Eqs. (5)–(6) then

$$\boldsymbol{T} = [t_{ij}], \quad i, j = 1, 2, \ldots, n, \tag{5}$$

$$\boldsymbol{r} = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, \quad \boldsymbol{s} = [s_j]_{n\times 1} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} \tag{6}$$

where the superscript denotes transpose.

If r_i denotes the row sum of the ith row in matrix $\boldsymbol{T}$, then r_i shows the sum of direct and indirect effects of factor i on the other factors/criteria. If s_j denotes the column sum of the jth column of matrix $\boldsymbol{T}$, then s_j shows the sum of direct and indirect effects that factor j has received from the other factors. Furthermore, when $j = i$ (i.e. the sum of the row and column aggregates), $(r_i + s_i)$ provides an index of the strength of influences given and received, that is, $(r_i + s_i)$ shows the degree that the factor i plays in the problem. In addition, the difference $(r_i - s_i)$ shows the net effect that factor i contribute to the problem. If $(r_i - s_i)$ is positive, then factor i is affecting other factors, and if $(r_i - s_i)$

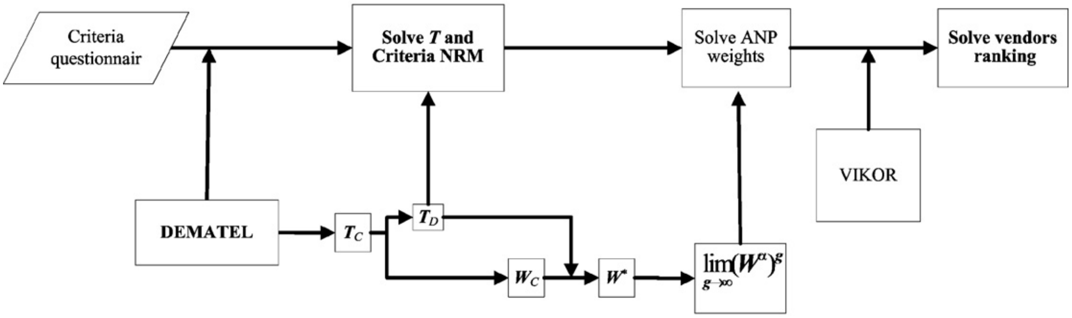

Fig. 4. The process of a hybrid MCDM model combined DANP and VIKOR.

is negative, then factor i is being influenced by other factors (Tzeng et al., 2007).

3.2. Combining DEMATEL and ANP to find the evaluation weights

ANP was published by Saaty (1999); its purpose was to solve the problems of interdependence and feedback between criteria and alternatives in the real world. ANP is a mathematical theory that can systematically overcome all types of dependences. In ANP procedures, the initial step is to compare the criteria in the entire system to form an unweighted supermatrix by pairwise comparisons. Then, the weighted supermatrix is derived by transforming each column to sum exactly to unity (1.00). Each element in a column is divided by the number of clusters, and thus each column will sum to unity exactly. However, using the assumption of equal weight for each cluster to obtain the weighted supermatrix appears irrational because there are different degrees of influence among the criteria (Ou Yang et al., 2008). Thus, we adopted the DEMATEL technique to determine the degrees of influence of these criteria and apply these to normalize the unweighted supermatrix in the ANP to mimic the situation in the real world. We named this improved ANP as DANP. The improved ANP is divided into the steps as follows:

Step 1: *Develop an unweighted supermatrix.* The total-influenced matrix will be obtained from DEMATEL. Each column will sum for normalization. We call the total-influenced matrix $\boldsymbol{T}_c = [t_{ij}]_{n\times n}$ obtained by criteria and $\boldsymbol{T}_D = [t_{ij}^D]_{m\times m}$ obtained by dimensions (clusters) from $\boldsymbol{T}_c$. Then, we normalize the supermatrix $\boldsymbol{T}_c$ for the ANP weights of dimensions (clusters) by using influence matrix $\boldsymbol{T}_D$. Each column will sum for normalization.

$$\boldsymbol{T}_c = \begin{array}{cc|ccccc|}
 & & D_1 & & D_j & & D_n \\
 & & c_{11}\ldots c_{1m_1} & \cdots & c_{j1}\ldots c_{jm_j} & \cdots & c_{n1}\ldots c_{nm_n} \\
\hline
D_1 & \begin{smallmatrix} c_{11}\\ c_{12}\\ \vdots \\ c_{1m_1} \end{smallmatrix} & \boldsymbol{T}_c^{11} & \cdots & \boldsymbol{T}_c^{1j} & \cdots & \boldsymbol{T}_c^{1n} \\
\vdots & \vdots & \vdots & & \vdots & & \vdots \\
D_i & \begin{smallmatrix} c_{i1}\\ c_{i2}\\ \vdots \\ c_{im_i} \end{smallmatrix} & \boldsymbol{T}_c^{i1} & \cdots & \boldsymbol{T}_c^{ij} & \cdots & \boldsymbol{T}_c^{in} \\
\vdots & \vdots & \vdots & & \vdots & & \vdots \\
D_n & \begin{smallmatrix} c_{n1}\\ c_{n2}\\ \vdots \\ c_{nm_n} \end{smallmatrix} & \boldsymbol{T}_c^{n1} & \cdots & \boldsymbol{T}_c^{nj} & \cdots & \boldsymbol{T}_c^{nn} \\
\hline
\end{array} \tag{7}$$

After normalizing the total-influence matrix T_c by dimensions (clusters), we will obtain a new matrix $\boldsymbol{T}_c^{\alpha}$ as shown as Eq. (8).

$$\boldsymbol{T}_c^{\alpha} = \begin{array}{cc|ccccc|}
 & & D_1 & & D_j & & D_n \\
 & & c_{11}\ldots c_{1m_1} & & c_{j1}\ldots c_{jm_j} & \cdots & c_{n1}\ldots c_{nm_n} \\
\hline
D_1 & \begin{smallmatrix} c_{11}\\ c_{12}\\ \vdots \\ c_{1m_1} \end{smallmatrix} & \boldsymbol{T}_c^{\alpha 11} & \cdots & \boldsymbol{T}_c^{\alpha 1j} & \cdots & \boldsymbol{T}_c^{\alpha 1n} \\
\vdots & \vdots & \vdots & & \vdots & & \vdots \\
D_i & \begin{smallmatrix} c_{i1}\\ c_{i2}\\ \vdots \\ c_{im_i} \end{smallmatrix} & \boldsymbol{T}_c^{\alpha i1} & \cdots & \boldsymbol{T}_c^{\alpha ij} & \cdots & \boldsymbol{T}_c^{\alpha in} \\
\vdots & \vdots & \vdots & & \vdots & & \vdots \\
D_n & \begin{smallmatrix} c_{n1}\\ c_{n2}\\ \vdots \\ c_{nm_n} \end{smallmatrix} & \boldsymbol{T}_c^{\alpha n1} & \cdots & \boldsymbol{T}_c^{\alpha nj} & \cdots & \boldsymbol{T}_c^{\alpha nn} \\
\hline
\end{array} \tag{8}$$

In addition, an explanation for the normalization $\boldsymbol{T}_c^{\alpha 11}$ is shown as Eqs. (9)–(10), and other $\boldsymbol{T}_c^{\alpha nm}$ values are as above.

$$d_{ci}^{11} = \sum_{j=1}^{m_1} t_{cij}^{11}, \quad i = 1, 2, \ldots, m_1 \tag{9}$$

$$\boldsymbol{T}_c{}^{\alpha 11} = \begin{bmatrix} t_{c11}^{11}/d_{c1}^{11} & \cdots & t_{c1j}^{11}/d_{c1}^{11} & \cdots & t_{c1m_1}^{11}/d_{c1}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{11}/d_{ci}^{11} & \cdots & t_{cij}^{11}/d_{ci}^{11} & \cdots & t_{cim_1}^{11}/d_{ci}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{cm_1 1}^{11}/d_{cm_1}^{11} & \cdots & t_{cm_1 j}^{11}/d_{cm_1}^{11} & \cdots & t_{cm_1 m_1}^{11}/d_{cm_1}^{11} \end{bmatrix} = \begin{bmatrix} t_{c11}^{\alpha 11} & \cdots & t_{c1j}^{\alpha 11} & \cdots & t_{c1m_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{\alpha 11} & \cdots & t_{cij}^{\alpha 11} & \cdots & t_{cim_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{cm_1 1}^{\alpha 11} & \cdots & t_{cm_1 j}^{\alpha 11} & \cdots & t_{cm_1 m_1}^{\alpha 11} \end{bmatrix} \tag{10}$$

Let the total-influence matrix match and fill into the interdependence clusters. It will be called an unweighted supermatrix as shown as Eq. (11), which is based on transposing the normalized influence matrix $\boldsymbol{T}_c^{\alpha}$ by dimensions (clusters), i.e. $W = (T_c^{\alpha})'$.

$$\boldsymbol{W} = (\boldsymbol{T}_c{}^{\alpha})' = \begin{array}{cc|ccccc|}
 & & D_1 & & D_i & & D_n \\
 & & c_{11}\ldots c_{1m_1} & & c_{i1}\ldots c_{im_i} & \cdots & c_{n1}\ldots c_{nm_n} \\
\hline
D_1 & \begin{smallmatrix} c_{11}\\ c_{12}\\ \vdots \\ c_{1m_1} \end{smallmatrix} & \boldsymbol{W}^{11} & \cdots & \boldsymbol{W}^{i1} & \cdots & \boldsymbol{W}^{n1} \\
\vdots & \vdots & \vdots & & \vdots & & \vdots \\
D_j & \begin{smallmatrix} c_{j1}\\ c_{j2}\\ \vdots \\ c_{jm_i} \end{smallmatrix} & \boldsymbol{W}^{1j} & \cdots & \boldsymbol{W}^{ij} & \cdots & \boldsymbol{W}^{nj} \\
\vdots & \vdots & \vdots & & \vdots & & \vdots \\
D_n & \begin{smallmatrix} c_{n1}\\ c_{n2}\\ \vdots \\ c_{nm_n} \end{smallmatrix} & \boldsymbol{W}^{1n} & \cdots & \boldsymbol{W}^{in} & \cdots & \boldsymbol{W}^{nn} \\
\hline
\end{array} \tag{11}$$

If the matrix W^{11} is blank or 0 as shown as Eq. (12), this means that the matrix between the clusters or criteria is independent and with no interdependence, and the other $\boldsymbol{W}^{nn}$ value are as above.

$$W^{11} = \begin{array}{c|ccccc|}
 & c_{11} & \cdots & c_{1i} & \cdots & c_{1m_1} \\
\hline
c_{11} & t_{c11}^{\alpha 11} & \cdots & t_{ci1}^{\alpha 11} & \cdots & t_{cm_1 1}^{\alpha 11} \\
\vdots & \vdots & & \vdots & & \vdots \\
c_{1j} & t_c & \cdots & t_{cij}^{\alpha 11} & \cdots & t_{cm_1 j}^{\alpha 11} \\
\vdots & \vdots & & \vdots & & \vdots \\
c_{1m_1} & t_{c1m_1}^{\alpha 11} & \cdots & t_{cim_1}^{\alpha 11} & \cdots & t_{cm_1 m_1}^{\alpha 11} \\
\hline
\end{array} \tag{12}$$

Step 2 *For obtaining the* weighted supermatrix, each column will sum for normalization as show in Eq. (13).

$$\boldsymbol{T}_D = \begin{bmatrix} t_D^{11} & \cdots & t_D^{1j} & \cdots & t_D^{1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{i1} & \cdots & t_D^{ij} & \cdots & t_D^{in} \\ \vdots & & \vdots & & \vdots \\ t_D^{n1} & \cdots & t_D^{nj} & \cdots & t_D^{nn} \end{bmatrix} \tag{13}$$

We normalized the total-influence matrix T_D, and obtained a new matrix $\boldsymbol{T}_D^{\alpha}$, as shown as Eq. (14) (where $t_D^{\alpha ij} = t_D^{ij}/d_i$).

$$\boldsymbol{T}_D^{\alpha} = \begin{bmatrix} t_D^{11}/d_1 & \cdots & t_D^{1j}/d_1 & \cdots & t_D^{1n}/d_1 \\ \vdots & & \vdots & & \vdots \\ t_D^{i1}/d_i & \cdots & t_D^{ij}/d_i & \cdots & t_D^{in}/d_i \\ \vdots & & \vdots & & \vdots \\ t_D^{n1}/d_n & \cdots & t_D^{nj}/d_n & \cdots & t_D^{nn}/d_n \end{bmatrix} = \begin{bmatrix} t_D^{\alpha 11} & \cdots & t_D^{\alpha 1j} & \cdots & t_D^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha i1} & \cdots & t_D^{\alpha ij} & \cdots & t_D^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha n1} & \cdots & t_D^{\alpha nj} & \cdots & t_D^{\alpha nn} \end{bmatrix} \tag{14}$$

Let the normalized total-influence matrix T_D^{α} fill into the unweighted supermatrix to obtain the weighted supermatrix.

$$\boldsymbol{W}^{\alpha} = \boldsymbol{T}_D^{\alpha} \times \boldsymbol{W} = \begin{bmatrix} t_D^{\alpha 11} \times \boldsymbol{W}^{11} & \cdots & t_D^{\alpha i1} \times \boldsymbol{W}^{i1} & \cdots & t_D^{\alpha n1} \times \boldsymbol{W}^{n1} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1j} \times \boldsymbol{W}^{1j} & \cdots & t_D^{\alpha ij} \times \boldsymbol{W}^{ij} & \cdots & t_D^{\alpha nj} \times \boldsymbol{W}^{nj} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1n} \times \boldsymbol{W}^{1n} & \cdots & t_D^{\alpha in} \times \boldsymbol{W}^{in} & \cdots & t_D^{\alpha nn} \times \boldsymbol{W}^{nn} \end{bmatrix} \tag{15}$$

Step 3 *Limit the weighted supermatrix.* Limit the weighted supermatrix by raising it to a sufficiently large power k, until the supermatrix has converged and become a long-term stable supermatrix to obtain the global priority vectors, called DANP (DEMATEL-based ANP) influential weights, such as $\lim_{g \to \infty} (\boldsymbol{W}^{\alpha})^g$, where g represents any number of power.

In brief, the overall weights are calculated by using the above steps to derive a stable limiting supermatrix. Therefore, a hybrid model combining the DEMATEL method with ANP methods can deal with the problems of interdependence and feedback.

3.3. *The VIKOR method for ranking and improving the alternatives*

Opricovic and Tzeng (2004) proposed the compromise ranking method (VIKOR) as one applicable technique to implement within MCDM. Suppose that the feasible alternatives are represented by $V_1, V_2, \ldots, V_k, \ldots, V_m$. The performance scores of alternative V_k and the jth criterion is denoted by f_{kj}; w_j is the influential weight (relative importance) of the jth criterion, where $j = 1, 2, \ldots, n$, and n is the number of criteria. Development of the VIKOR method began with the following form of L_p-metric (Ho et al., 2011):

$$L_k^p = \left\{ \sum_{j=1}^{n} \left[\frac{w_j(\left|f_j^* - f_{kj}\right|)}{(\left|f_j^* - f_j^-\right|)} \right] \right\}^{1/p} \tag{16}$$

where $1 \le p \le \infty$; $k = 1, 2, \ldots, m$ and influential weight w_j is derived from the ANP. To formulate the ranking and gap measure $L_k^{p=1}$ (as S_k) and $L_k^{p=\infty}$ (as Q_k) are used by VIKOR (Tzeng et al., 2002, 2005; Opricovic and Tzeng, 2002, 2004, 2007).

$$S_k = L_k^{p=1} = \sum_{j=1}^{n} \left[\frac{w_j(|f_j^* - f_{kj}|)}{(|f_j^* - f_j^-|)} \right] \tag{17}$$

$$Q_k = L_k^{p=\infty} = \max_j \left\{ \frac{(|f_j^* - f_{kj}|)}{(|f_j^* - f_j^-|)} j = 1, 2, \ldots, n \right\} \tag{18}$$

The compromise solution $\min_k L_k^p$ showed the synthesized gap to be minimized, and it will be selected so that its value will be the closest to the aspired level. In addition, the group utility is emphasized when p is small (such as $p = 1$); on the contrary, if p tends to become infinite, the individual maximal regrets/gaps obtain more importance in prior improvement (Freimer and Yu, 1976) in each dimension/criterion. Consequently, $\min_k S_k$ stresses the maximum group utility; however, $\min_k Q_k$ accents on the selecting the minimum from the maximum individual regrets/gaps for shown priority improvement. The compromise-ranking algorithm VIKOR has four steps according to the above mentioned factors:

Step 1: *Obtain an aspired or tolerable level.* We calculated the best f_j^* values (aspired level) and the worst f_j^- values (tolerable level) of all criterion functions, $j = 1, 2, \ldots, n$. Suppose the jth function denotes benefits: $f_j^* = \max_k f_{kj}$ and $f_j^- = \min_k f_{kj}$ or these values can be set by decision makers (i.e. f_j^* is the aspired level and f_j^- is the worst value). Furthermore, an original rating matrix can be converted into a normalized weight-rating matrix by using the equation

$$r_{kj} = \frac{(\left|f_j^* - f_{kj}\right|)}{(\left|f_j^* - f_j^-\right|)} \tag{19}$$

Step 2 *Calculate the mean of group utility and maximal regret.* The values can be computed by $S_k = \sum_{j=1}^{n} w_j r_{kj}$ (the synthesized gap for all criteria) and $Q_k = \max_j \left\{ r_{kj} \middle| j = 1, 2, \ldots, n \right\}$ (the maximal gap in k criterion for priority improvement), respectively.

Step 3 *Calculate the index value.* The value can be counted by $R_k = v(S_k - S^*)/(S^- - S^*) + (1 - v)(Q_k - Q^*)/(Q^- - Q^*)$, where $k = 1, 2, \ldots m$, $S^* = \min_i S_i$ or $S^* = 0$ (when all criteria have been achieved to the aspired level) and $S^- = \max_i S_i$ or $S^- = 1$ (when the worst situation); $Q^* = \min_i Q_i$ or setting $Q^* = 0$ and $Q^- = \max_i Q_i$ or setting $Q^- = 1$, and $\boldsymbol{v}$ is presented as the weight of the strategy of the maximum group utility. Conversely, $1 - v$ is the weight of individual regret. Therefore, we also can re-write $R_k = vS_k + (1 - v)Q_k$, when $S^* = 0$, $S^- = 1$, $Q^* = 0$ and $Q^- = 1$.

Step 4 Rank or *improve the alternatives for a compromise solution*. Order *alternatives* decreasingly by the values of S_k, Q_k and R_k. Propose as a compromise solution the alternatives $V^{(1)}$, $V^{(2)}, \ldots, V^{(M)}$.

The compromise-ranking method (VIKOR) is applied to determine the compromise solution and the solution is adaptable for decision-makers in that it offers a maximum group utility of the majority (shown by min S), and a maximal regret of minimum individuals of the opponent (shown by min Q). This model utilizes the DEMATEL and ANP processes in Sections 3.1 and 3.2 to obtain the influential weights of criteria with dependence and feedback and employs the VIKOR method to acquire the compromise solution.

4. Application of the model to empirical case

In this section, an empirical study is displayed to illustrate the application of the proposed model to evaluate and find the best vendor for conducting the recycled materials in real world case.

4.1. Background and problem descriptions

As an example case, Corporation G has dedicated its efforts since 1966 to develop ACP products for exterior and interior decoration in Taiwan. Corporation G is one of the pioneers of ACP manufacturing in Asia. The products of Corporation G include fire resistant exterior cladding solution and embossed interior ACP cladding solution.

To reduce the cost of its products and to be environmentally friendly, Corporation G changed its production line process to use recycled materials instead of virgin raw materials in 1998. Because recycled materials suppliers and vendors could not manage or control the quality of their products consistently and deliver materials on schedule, Corporation G faced critical problems regarding the inconsistent quality of its products and overwhelmed process capability. Three alternatives vendors, V_1, V_2, and V_3, could supply the recycled materials to Corporation G. We evaluated and improved these vendors and then selected the best one by using the hybrid MCDM model combining DANP with VIKOR as follows.

4.2. Data collection

To assess the inter-influence of VS criteria for the DEMETEL calculation, we designed a questionnaire to collect data from experts in the ACP industry (see Appendices A and B). These experts were the vice president, corporation general manager, plant assistant general manager, R&D manager, purchase manager, vice plant manager, and section managers.

4.3. Measuring relationships among dimensions and criteria by DEMATEL

In this study, we adopted a DEMATEL decision-making structure and analyzed 6 dimensions of 17 criteria as well as the impact of mutual relationships. The ACP experts were thus asked to determine the influential importance of the relationships among the dimensions and criteria. The averaged initial direct-relationship 17 × 17 matrix $\boldsymbol{A}$ (Table 2) was obtained by pairwise comparisons in terms of influences and directions between criteria. As matrix $\boldsymbol{A}$ shows, the normalized direct-influence matrix $\boldsymbol{X}$ (Table 3) was calculated from Eqs. (1)–(3). Then, using Eq. (4), the total influence $\boldsymbol{T}_c$ (Table 4) and $\boldsymbol{T}_D$ (Table 5) were derived, and by using Eq. (6), the NRM was constructed by the $\boldsymbol{r}$ and $\boldsymbol{s}$ in the total direct-influence matrix $\boldsymbol{T}_c$ and $\boldsymbol{T}_D$ (Table 6) as shown in Figs. 5 and 6.

4.4. Weighting of each criterion by combining the DEMATEL methods with ANP methods (DANP Technique)

In this research, we combined the DEMATEL technique with the ANP method to solve VS problem, and this combination was used to obtain the normalized matrix $\boldsymbol{T}_c$ We first normalized the total-influence matrix $\boldsymbol{T}$. By calculating the limiting power of the weighted supermatrix, $\lim_{g\to\infty}(\boldsymbol{W}^{\alpha})^{g}$ is applied until a steady-state condition is reached (Tables 7–11).

By evaluating the VS criteria of Corporation G according to the DEMATEL process, we obtained dynamic relationships between the construction of an important degree of influence-unweighted supermatrix (Table 8), and in accordance with the extent of the impact of various criteria, we achieved a weighted supermatrix (Table 10). Finally, the limit of the supermatrix (Table 11) to confirm the supermatrix has been converged and become a long-term stable supermatrix and to obtain the global and local weights of all criteria and their ranks, as shown in Table 12.

Table 2
The initial influence matrix $\boldsymbol{A}$ for criteria.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	Sum
C_1	0	3.375	3.375	2	2.625	2.75	1.5	1.25	3.125	2.75	2.25	3.5	2.125	2.625	2.125	3.125	3	42
C_2	3.5	0	3.375	2.25	3	2.875	1.375	1.25	3.25	2.25	2.375	3.5	2.375	2.75	2	2.5	2.5	41
C_3	3.125	3.125	0	2.125	2.875	2.375	1.125	1	3.25	2.125	2.25	3.5	2.25	2.5	1.875	2.625	2.375	39
C_4	1.75	1.875	2.375	0	3.375	3.125	2.75	2	2.875	2.125	2	2	2.5	2.375	1.75	1.375	1.5	36
C_5	1.75	2.25	2.75	2.75	0	2.625	2.75	1.875	2.75	2	2.125	2	2.5	2.375	2.125	1.75	1.125	36
C_6	2	2.125	2.875	2.25	3.625	0	2.625	2.375	2.625	1.875	2	2.5	2.625	2.5	2.5	2.125	1.875	39
C_7	1	0.75	0.625	2.375	3.125	3	0	2.75	1.125	2.125	2.125	1.875	2.625	1.625	2.25	1.875	1.875	31
C_8	0.625	0.5	0.5	2.25	2.625	2.875	3.125	0	1.25	2	1.625	1.75	1.5	1.25	2.125	1.25	1.125	26
C_9	2.5	2.75	3	2.5	3	2.625	1.25	1.125	0	2.25	1.75	2.5	3	2.75	2.125	2.375	2	38
C_{10}	3.25	3.125	2.5	2.375	2	2.25	2.375	1.75	2	0	3	2.5	2.375	1.75	1.625	2.375	1.75	37
C_{11}	2	2.125	1.875	2.125	1.625	2.25	1.625	1.375	1.625	2.625	0	2.125	1.875	1.5	1.75	2.25	2	31
C_{12}	2.625	2.375	2.125	2	1.625	1.75	1.375	0.75	1.75	2.875	2.125	0	1.75	1.75	2	2.25	2	31
C_{13}	1.75	2.125	2.125	2	2.125	2.375	1.875	1.25	2.125	1.875	1.875	2	0	2.125	2.25	1.875	1.375	31
C_{14}	2.25	2.625	2.875	2.875	3	3.125	0.875	0.875	2.5	2.375	1.875	2	2.25	0	2.625	2.375	1.5	36
C_{15}	2.375	2.25	2.625	2.25	2.375	2.25	1.625	1.125	1.75	1.875	1.875	2.375	2.875	2.5	0	1.875	1.75	34
C_{16}	2.75	2.875	2.25	1.25	1.75	1.625	1.5	1.125	2.5	1.875	2	2	2.375	1.875	2.625	0	3	33
C_{17}	2.5	2.75	1.375	1.25	1.375	1.125	1.5	1.125	1.5	2.125	1.875	1.75	2	1.25	1.625	2	0	27
Sum	35.75	37	36.63	34.63	40.13	39	29.25	23	36	35.13	33.13	37.88	37	33.5	33.38	34	30.75	42

Table 3
The normalized direct-influence matrix $\boldsymbol{X}$ for criteria.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
C_1	0	0.081	0.081	0	0.063	0.066	0.036	0.03	0.075	0.066	0.054	0.084	0.051	0.063	0.051	0.075	0.072
C_2	0.084	0	0.081	0.054	0.072	0.069	0.033	0.03	0.078	0.054	0.057	0.084	0.057	0.066	0.048	0.06	0.06
C_3	0.075	0.075	0	0.051	0.069	0.057	0.027	0.024	0.078	0.051	0.054	0.084	0.054	0.06	0.045	0.063	0.057
C_4	0.042	0.045	0.057	0	0.081	0.075	0.066	0.048	0.069	0.051	0.048	0.048	0.06	0.057	0.042	0.033	0.036
C_5	0.042	0.054	0.066	0.066	0	0.063	0.066	0.045	0.066	0.048	0.051	0.048	0.06	0.057	0.051	0.042	0.027
C_6	0.048	0.051	0.069	0.054	0.087	0	0.063	0.057	0.063	0.045	0.048	0.06	0.063	0.06	0.06	0.051	0.045
C_7	0.024	0.018	0.015	0.057	0.075	0.072	0	0.066	0.027	0.051	0.051	0.045	0.063	0.039	0.054	0.045	0.045
C_8	0.015	0.012	0.012	0.054	0.063	0.069	0.075	0	0.03	0.048	0.039	0.042	0.036	0.03	0.051	0.03	0.027
C_9	0.06	0.066	0.072	0.06	0.072	0.063	0.03	0.027	0	0.054	0.042	0.06	0.072	0.066	0.051	0.057	0.048
C_{10}	0.078	0.075	0.06	0.057	0.048	0.054	0.057	0.042	0.048	0	0.072	0.06	0.057	0.042	0.039	0.057	0.042
C_{11}	0.048	0.051	0.045	0.051	0.039	0.054	0.039	0.033	0.039	0.063	0	0.051	0.045	0.036	0.042	0.054	0.048
C_{12}	0.063	0.057	0.051	0.048	0.039	0.042	0.033	0.018	0.042	0.069	0.051	0	0.042	0.042	0.048	0.054	0.048
C_{13}	0.042	0.051	0.051	0.048	0.051	0.057	0.045	0.03	0.051	0.045	0.045	0.048	0	0.051	0.054	0.045	0.033
C_{14}	0.054	0.063	0.069	0.069	0.072	0.075	0.021	0.021	0.06	0.057	0.045	0.048	0.054	0	0.063	0.057	0.036
C_{15}	0.057	0.054	0.063	0.054	0.057	0.054	0.039	0.027	0.042	0.045	0.045	0.057	0.069	0.06	0	0.045	0.042
C_{16}	0.066	0.069	0.054	0.03	0.042	0.039	0.036	0.027	0.06	0.045	0.048	0.048	0.057	0.045	0.063	0	0.072
C_{17}	0.06	0.066	0.033	0.03	0.033	0.027	0.036	0.027	0.036	0.051	0.045	0.042	0.048	0.03	0.039	0.048	0

Table 4
The total influence matrix $\boldsymbol{T}_c$ for criteria.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	r
C_1	0.325	0.411	0.410	0.352	0.411	0.402	0.291	0.233	0.396	0.373	0.347	0.417	0.377	0.361	0.344	0.375	0.344	1.145
C_2	0.400	0.333	0.408	0.356	0.418	0.404	0.287	0.232	0.397	0.361	0.347	0.415	0.380	0.363	0.340	0.360	0.331	1.141
C_3	0.373	0.384	0.313	0.335	0.394	0.373	0.266	0.214	0.378	0.340	0.327	0.395	0.358	0.340	0.320	0.345	0.313	1.070
C_4	0.316	0.329	0.340	0.266	0.381	0.366	0.286	0.225	0.344	0.316	0.300	0.336	0.340	0.314	0.296	0.294	0.271	1.013
C_5	0.315	0.336	0.347	0.326	0.304	0.354	0.284	0.220	0.341	0.312	0.301	0.335	0.339	0.313	0.303	0.301	0.262	0.985
C_6	0.341	0.354	0.370	0.335	0.406	0.315	0.298	0.244	0.358	0.329	0.317	0.367	0.362	0.334	0.329	0.328	0.295	1.056
C_7	0.257	0.261	0.258	0.280	0.330	0.320	0.194	0.216	0.263	0.277	0.265	0.289	0.301	0.258	0.270	0.265	0.243	0.673
C_8	0.215	0.220	0.220	0.246	0.283	0.282	0.237	0.133	0.232	0.241	0.224	0.251	0.243	0.219	0.236	0.219	0.198	0.602
C_9	0.351	0.367	0.372	0.336	0.389	0.371	0.264	0.213	0.297	0.334	0.309	0.365	0.367	0.338	0.318	0.332	0.297	0.774
C_{10}	0.361	0.368	0.354	0.328	0.361	0.357	0.284	0.224	0.336	0.278	0.332	0.360	0.347	0.310	0.302	0.327	0.288	0.970
C_{11}	0.287	0.298	0.291	0.277	0.301	0.306	0.231	0.186	0.280	0.292	0.221	0.301	0.288	0.260	0.261	0.279	0.252	0.813
C_{12}	0.307	0.310	0.303	0.279	0.306	0.301	0.228	0.174	0.289	0.302	0.274	0.258	0.291	0.271	0.271	0.284	0.257	0.835
C_{13}	0.285	0.301	0.301	0.279	0.317	0.314	0.239	0.185	0.295	0.279	0.267	0.302	0.249	0.278	0.276	0.274	0.241	0.803
C_{14}	0.337	0.355	0.361	0.336	0.380	0.372	0.249	0.202	0.345	0.328	0.304	0.345	0.342	0.268	0.320	0.323	0.278	0.930
C_{15}	0.318	0.325	0.333	0.303	0.344	0.332	0.249	0.195	0.308	0.298	0.285	0.331	0.334	0.305	0.243	0.293	0.266	0.881
C_{16}	0.324	0.336	0.321	0.277	0.325	0.313	0.242	0.191	0.320	0.295	0.285	0.320	0.320	0.288	0.299	0.247	0.292	0.539
C_{17}	0.272	0.285	0.254	0.233	0.266	0.254	0.206	0.163	0.251	0.256	0.240	0.266	0.264	0.230	0.234	0.249	0.184	0.433
s	1.098	1.128	1.131	0.927	1.092	1.036	0.694	0.562	0.793	0.873	0.827	0.919	0.925	0.851	0.839	0.496	0.476	–

Table 5
The total influences matrix $\boldsymbol{T}_D$ and influences given/received for dimensions.

Dimensions		D_1	D_2	D_3	D_4	D_5	D_6	r_i	Dimensions	r_i	s_i	r_i+s_i	r_i-s_i
D_1	Quality	0.373	0.383	0.299	0.369	0.354	0.345	2.123	D_1	2.123	1.935	4.06	0.19
D_2	Delivery	0.339	0.339	0.289	0.324	0.326	0.292	1.908	D_2	1.908	1.959	3.87	−0.05
D_3	Risk	0.28	0.315	0.228	0.284	0.283	0.259	1.649	D_3	1.649	1.544	3.19	0.11
D_4	Cost	0.32	0.313	0.248	0.291	0.289	0.281	1.742	D_4	1.742	1.849	3.59	−0.11
D_5	Service	0.324	0.331	0.252	0.304	0.291	0.279	1.781	D_5	1.781	1.814	3.59	−0.03
D_6	Environmental collaboration	0.299	0.278	0.229	0.277	0.272	0.243	1.597	D_6	1.597	1.699	3.30	−0.10
s_j		1.935	1.959	1.544	1.849	1.814	1.699	–	–	–	–	–	–

Note: Let $i=j$ be r_i+s_i and $r_i-s_{i.}$

As shown in Tables 7–11, we used the DANP method to obtain the weights and priority of dimensions and criteria of the empirical case of Corporation G. According to Table 12, we found that the priority in global weight of the first dimension is delivery (D_2), followed by quality (D_1), cost (D_4), service (D_5), environmental collaboration (D_6), and risk (D_3), in that order.

In addition, we extended the priority of criteria in each dimension from the local weights in Table 12. For example, delivery (D_2) is the first priority in dimensions of a global weight; when extended to local weight, however, we know that the delivery on-time rate (C_5) will be the first priority of delivery (D_2). All these local and global weights will be helpful in selecting the best alternatives in MCDM problems with VIKOR.

4.5. Using a VIKOR model to calculate the performance value and to select the best alternative vendor for the case corporation

There are three vendors to supply plastic recycled materials for the corporation G. According to the aforementioned 6 dimensions and 17 criteria, we evaluated the performance of each vendor

Table 6
The sum of influences given and received on criteria.

Criteria		r_i	s_i	r_i+s_i	r_i-s_i
Ingredient consistency	C_1	1.145	1.098	2.243	0.047
Process capability	C_2	1.141	1.128	2.270	0.013
Yield rate	C_3	1.070	1.131	2.201	–0.061
Shortest lead time	C_4	1.013	0.927	1.940	0.086
Delivery on time rate	C_5	0.985	1.092	2.077	–0.107
Serious delivery delay rate	C_6	1.056	1.036	2.092	0.021
Geographical location	C_7	0.673	0.694	1.367	–0.021
Political stability	C_8	0.602	0.562	1.164	0.040
Equipment capacity change	C_9	0.774	0.793	1.567	–0.018
Recycled material price	C_{10}	0.970	0.873	1.842	0.097
Handling cost	C_{11}	0.813	0.827	1.640	–0.014
Process loss cost	C_{12}	0.835	0.919	1.754	–0.083
Response to demand	C_{13}	0.803	0.925	1.728	–0.122
Information acquisition	C_{14}	0.930	0.851	1.780	0.079
After sales service	C_{15}	0.881	0.839	1.721	0.042
Technology for recycling products and process	C_{16}	0.539	0.496	1.035	0.043
Green manufacturing policy	C_{17}	0.433	0.476	0.909	–0.043

Note: Let $i=j$ be r_i+s_i and r_i-s_i.

Table 7
The new matrix T_c^{α} obtained by normalizing matrix T_c in criteria.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
C_1	0.283	0.359	0.358	0.302	0.353	0.345	0.316	0.254	0.430	0.328	0.305	0.367	0.348	0.334	0.318	0.522	0.478
C_2	0.350	0.292	0.358	0.302	0.355	0.343	0.313	0.253	0.433	0.321	0.309	0.369	0.351	0.335	0.314	0.521	0.479
C_3	0.349	0.359	0.293	0.304	0.357	0.338	0.310	0.250	0.440	0.320	0.308	0.372	0.352	0.334	0.314	0.525	0.475
C_4	0.321	0.334	0.345	0.262	0.376	0.361	0.335	0.263	0.403	0.332	0.315	0.353	0.358	0.331	0.311	0.520	0.480
C_5	0.316	0.336	0.348	0.331	0.309	0.360	0.336	0.261	0.403	0.329	0.318	0.353	0.355	0.328	0.317	0.534	0.466
C_6	0.320	0.332	0.348	0.317	0.385	0.299	0.331	0.271	0.398	0.325	0.313	0.362	0.353	0.326	0.321	0.526	0.474
C_7	0.332	0.336	0.332	0.302	0.355	0.344	0.288	0.321	0.391	0.333	0.319	0.348	0.363	0.312	0.325	0.521	0.479
C_8	0.329	0.335	0.336	0.303	0.349	0.347	0.394	0.221	0.385	0.337	0.312	0.350	0.348	0.314	0.338	0.525	0.475
C_9	0.322	0.337	0.341	0.307	0.355	0.338	0.341	0.275	0.384	0.332	0.307	0.362	0.358	0.331	0.311	0.528	0.472
C_{10}	0.333	0.340	0.327	0.313	0.345	0.341	0.337	0.265	0.398	0.287	0.342	0.371	0.362	0.323	0.315	0.532	0.468
C_{11}	0.328	0.334	0.333	0.314	0.340	0.346	0.331	0.267	0.402	0.359	0.271	0.370	0.356	0.321	0.323	0.525	0.475
C_{12}	0.333	0.337	0.330	0.315	0.345	0.339	0.330	0.252	0.418	0.362	0.329	0.309	0.349	0.325	0.326	0.525	0.475
C_{13}	0.321	0.339	0.340	0.307	0.348	0.345	0.332	0.258	0.410	0.329	0.315	0.356	0.310	0.346	0.344	0.532	0.468
C_{14}	0.320	0.337	0.343	0.309	0.349	0.342	0.312	0.254	0.434	0.336	0.311	0.353	0.367	0.288	0.345	0.537	0.463
C_{15}	0.326	0.333	0.341	0.310	0.351	0.339	0.331	0.259	0.410	0.326	0.312	0.362	0.379	0.346	0.275	0.524	0.476
C_{16}	0.330	0.342	0.327	0.303	0.355	0.342	0.321	0.254	0.425	0.328	0.316	0.356	0.353	0.317	0.330	0.458	0.542
C_{17}	0.336	0.351	0.313	0.310	0.353	0.337	0.332	0.263	0.405	0.336	0.315	0.349	0.362	0.316	0.322	0.575	0.425

Table 8
The unweighted supermatrix ***W***.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
C_1	0.283	0.350	0.349	0.321	0.316	0.320	0.332	0.329	0.322	0.333	0.328	0.333	0.321	0.320	0.326	0.330	0.336
C_2	0.359	0.292	0.359	0.334	0.336	0.332	0.336	0.335	0.337	0.34	0.34	0.337	0.339	0.337	0.333	0.342	0.351
C_3	0.358	0.358	0.293	0.345	0.348	0.348	0.332	0.336	0.341	0.327	0.333	0.33	0.34	0.343	0.341	0.327	0.313
C_4	0.302	0.302	0.304	0.262	0.331	0.317	0.302	0.303	0.307	0.313	0.314	0.315	0.307	0.309	0.31	0.303	0.31
C_5	0.353	0.355	0.357	0.376	0.309	0.385	0.355	0.349	0.355	0.345	0.34	0.345	0.348	0.349	0.351	0.355	0.353
C_6	0.345	0.343	0.338	0.361	0.36	0.299	0.344	0.347	0.338	0.341	0.346	0.339	0.345	0.342	0.339	0.342	0.337
C_7	0.316	0.313	0.31	0.335	0.336	0.331	0.288	0.394	0.341	0.337	0.331	0.33	0.332	0.312	0.331	0.321	0.332
C_8	0.254	0.253	0.25	0.263	0.261	0.271	0.321	0.221	0.275	0.265	0.267	0.252	0.258	0.254	0.259	0.254	0.263
C_9	0.43	0.433	0.44	0.403	0.403	0.398	0.391	0.385	0.384	0.398	0.402	0.418	0.41	0.434	0.41	0.425	0.405
C_{10}	0.328	0.321	0.32	0.332	0.329	0.325	0.333	0.337	0.332	0.287	0.359	0.362	0.329	0.336	0.326	0.328	0.336
C_{11}	0.305	0.309	0.308	0.315	0.318	0.313	0.319	0.312	0.307	0.342	0.271	0.329	0.315	0.311	0.312	0.316	0.315
C_{12}	0.367	0.369	0.372	0.353	0.353	0.362	0.348	0.35	0.362	0.371	0.37	0.309	0.356	0.353	0.362	0.356	0.349
C_{13}	0.348	0.351	0.352	0.358	0.355	0.353	0.363	0.348	0.358	0.362	0.356	0.349	0.31	0.367	0.379	0.353	0.362
C_{14}	0.334	0.335	0.334	0.331	0.328	0.326	0.312	0.314	0.331	0.323	0.321	0.325	0.346	0.288	0.346	0.318	0.316
C_{15}	0.318	0.314	0.314	0.311	0.317	0.321	0.325	0.338	0.311	0.315	0.323	0.326	0.344	0.345	0.275	0.33	0.322
C_{16}	0.522	0.521	0.525	0.52	0.534	0.526	0.521	0.525	0.528	0.532	0.525	0.525	0.532	0.537	0.524	0.458	0.575
C_{17}	0.478	0.479	0.475	0.48	0.466	0.474	0.479	0.475	0.472	0.468	0.475	0.475	0.468	0.463	0.476	0.542	0.425
	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

Note: $\boldsymbol{W} = (\boldsymbol{T}_c^{\alpha})'$.

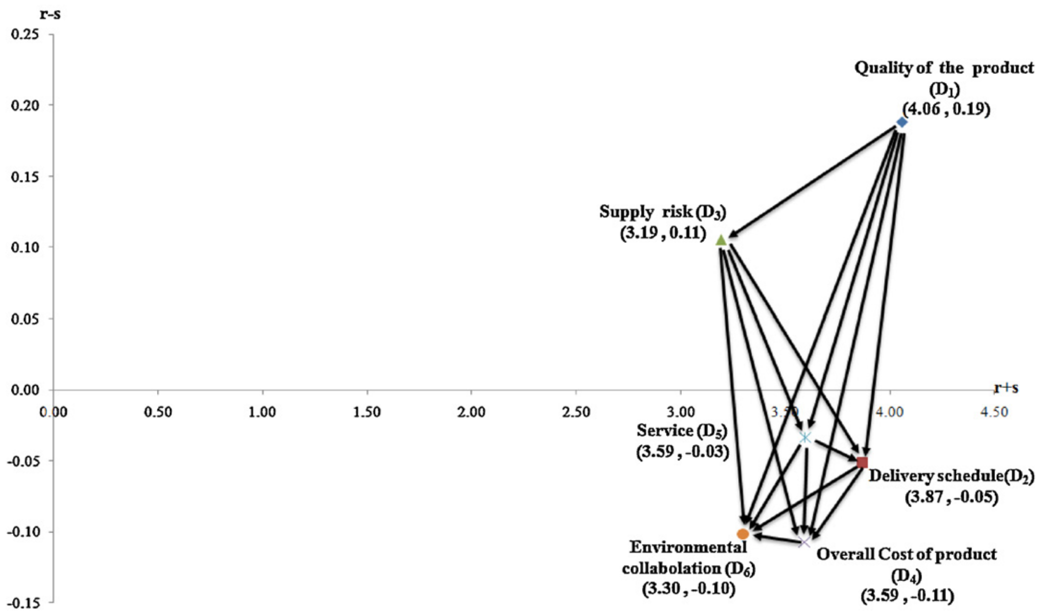

Fig. 5. The influential NRM of relation within dimensions.

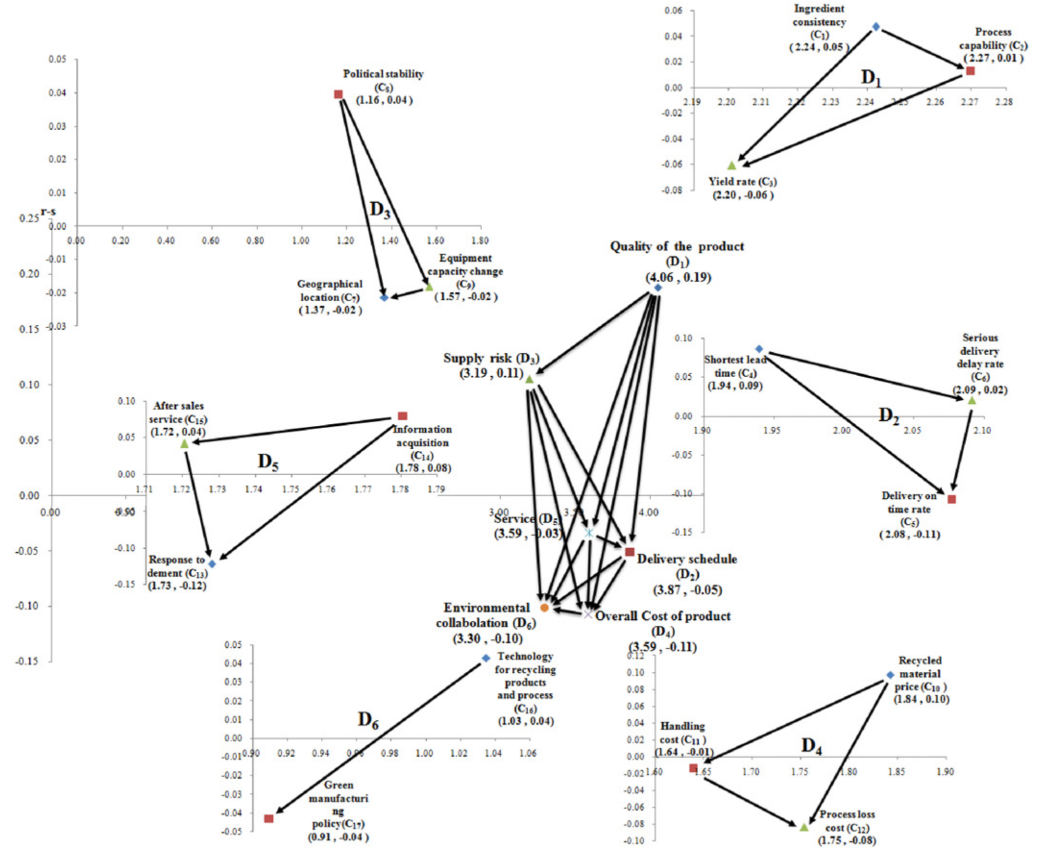

Fig. 6. The influential NRM of 17 criteria within 6 dimensions.

according to the opinions of eight experts in ACP manufacturing. We evaluated performance on a scale of 0–4, with 0 indicating very bad and 4 indicating the best. Then, we used the average performance scores of each vendor and applied the VIKOR model to obtain the performance and aspired level gaps of alternative vendors, as shown in Table 12.

5. Results and discussion

According to the empirical study in Section 4, our proposed hybrid MCDM model could provide more relevant results. For instance, the interdependent and feedback relationship of VS dimensions and criteria can be used as the performance of

Table 9
The new matrix $\boldsymbol{T}_D^{\alpha}$ obtained by matrix $\boldsymbol{T}_D$.

Dimensions		D_1	D_2	D_3	D_4	D_5	D_6
D_1	Quality	0.176	0.177	0.170	0.184	0.182	0.187
D_2	Delivery	0.180	0.178	0.191	0.180	0.186	0.174
D_3	Risk	0.141	0.151	0.138	0.142	0.141	0.143
D_4	Cost	0.174	0.170	0.172	0.167	0.171	0.173
D_5	Service	0.167	0.171	0.172	0.166	0.163	0.170
D_6	Environmental collaboration	0.162	0.153	0.157	0.161	0.157	0.152

Table 10
Weighting the unweighted supermatrix based on total-influence normalized matrix $\boldsymbol{W}^{\alpha}$.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
C_1	0.05	0.062	0.061	0.057	0.056	0.057	0.056	0.056	0.055	0.061	0.06	0.061	0.058	0.058	0.059	0.062	0.063
C_2	0.063	0.051	0.063	0.059	0.06	0.059	0.057	0.057	0.057	0.062	0.062	0.062	0.062	0.061	0.061	0.064	0.066
C_3	0.063	0.063	0.051	0.061	0.062	0.062	0.056	0.057	0.058	0.06	0.061	0.061	0.062	0.062	0.062	0.061	0.059
C_4	0.054	0.055	0.055	0.047	0.059	0.056	0.058	0.058	0.059	0.056	0.056	0.057	0.057	0.057	0.058	0.053	0.054
C_5	0.064	0.064	0.064	0.067	0.055	0.068	0.068	0.067	0.068	0.062	0.061	0.062	0.065	0.065	0.065	0.062	0.061
C_6	0.062	0.062	0.061	0.064	0.064	0.053	0.066	0.066	0.065	0.061	0.062	0.061	0.064	0.064	0.063	0.06	0.059
C_7	0.045	0.044	0.044	0.051	0.051	0.05	0.04	0.054	0.047	0.048	0.047	0.047	0.047	0.044	0.047	0.046	0.048
C_8	0.036	0.036	0.035	0.04	0.039	0.041	0.044	0.03	0.038	0.038	0.038	0.036	0.036	0.036	0.037	0.036	0.038
C_9	0.061	0.061	0.062	0.061	0.061	0.06	0.054	0.053	0.053	0.057	0.057	0.059	0.058	0.061	0.058	0.061	0.058
C_{10}	0.057	0.056	0.056	0.056	0.056	0.055	0.057	0.058	0.057	0.048	0.06	0.06	0.056	0.057	0.056	0.057	0.058
C_{11}	0.053	0.054	0.054	0.053	0.054	0.053	0.055	0.054	0.053	0.057	0.045	0.055	0.054	0.053	0.053	0.055	0.055
C_{12}	0.064	0.064	0.065	0.06	0.06	0.061	0.06	0.06	0.062	0.062	0.062	0.052	0.061	0.06	0.062	0.062	0.06
C_{13}	0.058	0.058	0.059	0.061	0.061	0.06	0.062	0.06	0.062	0.06	0.059	0.058	0.051	0.06	0.062	0.06	0.062
C_{14}	0.056	0.056	0.056	0.056	0.056	0.056	0.054	0.054	0.057	0.054	0.053	0.054	0.056	0.047	0.056	0.054	0.054
C_{15}	0.053	0.052	0.052	0.053	0.054	0.055	0.056	0.058	0.053	0.052	0.054	0.054	0.056	0.056	0.045	0.056	0.055
C_{16}	0.085	0.085	0.085	0.08	0.082	0.08	0.082	0.082	0.083	0.086	0.085	0.085	0.083	0.084	0.082	0.07	0.087
C_{17}	0.078	0.078	0.077	0.073	0.071	0.072	0.075	0.075	0.074	0.076	0.077	0.077	0.073	0.073	0.075	0.082	0.065
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Note: $\boldsymbol{W}^{\alpha} = \boldsymbol{T}_D^{\alpha} \times \boldsymbol{W}$.

recycled material vendors. Also, the results can be used to obtain the aspired level gaps of criteria for improvement. Some findings are given as follows:

(1) From DEMENTAL model in Fig. 5, we can easily understand that six dimensions are influenced each other such as quality of the product (D_1) will influence delivery schedule (D_2), supply risk (D_3), overall cost of product (D_4), service (D_5), and environmental collaboration (D_6); supply risk (D_3) will influence delivery schedule (D_2), service (D_5), overall cost of the product (D_4), and environmental collaboration (D_6). These influential relations will help managers to do the decision-making. In order to reduce the overall cost of product, managers should request their vendors to improve product quality first. Then, managers can refer D_1 from Fig. 6 to advise their vendors to improve the ingredient consistency of product for upgrading their product quality.

(2) According to the results of DANP with VIKOR (see Table 12), we found that the total performance of three vendors (V_1–V_3) are 2.294, 2.192, and 2.018 respectively. That is, we can treat vendor V_1 as the best vendor to conduct the recycled material. In addition, we found that vendor V_1 has very good performance on the quality of the product (D_1) with 2.752 score and environmental collaboration (D_6) with 2.434 score. These two scores of vendor V_1 are larger than those of other two vendors.

(3) The traditional VS approaches are only used to select the best vendor. Our proposed hybrid MCDM model can be used to select the best vendor and to analyze the gaps of aspired level for

Table 11
The stable matrix of ANP when power $\lim_{g \to \infty} (W^{\alpha})^g$.

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
C_1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_2	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_3	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_4	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_5	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_6	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_7	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C_8	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
C_9	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_{10}	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_{11}	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C_{12}	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_{13}	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_{14}	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C_{15}	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
C_{16}	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
C_{17}	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Table 12
The performance and aspired level gaps of alternative vendors.

Dimensions and criteria	Local weight (base on DANP)	Global weight (base on DANP)	Performance			Gap of aspired level		
			Vendor V_1	Vendor V_2	Vendor V_3	Vendor V_1	Vendor V_2	Vendor V_3
Quality of the product (D_1)	**0.179(2)**		**2.752**	**2.25**	**1.542**	**0.312**	**0.438**	**0.614**
Ingredient consistency (C_1)	0.327(3)	0.059	2.625	2.250	1.500	0.344	0.438	0.625
Process capability (C_2)	0.338(1)	0.061	3.000	2.250	1.625	0.250	0.438	0.594
Yield rate (C_3)	0.335(2)	0.060	2.625	2.250	1.500	0.344	0.438	0.625
Delivery schedule (D_2)	**0.181(1)**		**2.131**	**2.331**	**2.243**	**0.467**	**0.417**	**0.439**
Shortest lead time (C_4)	0.307(3)	0.056	2.000	2.500	2.500	0.500	0.375	0.375
Delivery on time rate (C_5)	0.352(1)	0.064	2.250	2.625	2.375	0.438	0.344	0.406
Serious delivery delay rate (C_6)	0.341(2)	0.062	2.125	1.875	1.875	0.469	0.531	0.531
Supply risk (D_3)	**0.143(6)**		**1.959**	**2.226**	**2.597**	**0.51**	**0.444**	**0.351**
Geographical location (C_7)	0.328(2)	0.047	1.875	2.375	3.125	0.531	0.406	0.219
Political stability C_8	0.261(3)	0.037	2.000	2.000	2.875	0.500	0.500	0.281
Equipment capacity change (C_9)	0.411(1)	0.059	2.000	2.250	2.000	0.500	0.438	0.500
Overall cost of product (D_4)	**0.171(3)**		**2.136**	**2.036**	**1.856**	**0.466**	**0.491**	**0.536**
Recycled material price (C_{10})	0.330(2)	0.057	2.125	2.125	1.750	0.469	0.469	0.563
Handling cost (C_{11})	0.313(3)	0.054	1.875	2.125	2.375	0.531	0.469	0.406
Process loss cost (C_{12})	0.357(1)	0.061	2.375	1.875	1.500	0.406	0.531	0.625
Service (D_5)	**0.168(4)**		**2.294**	**2.286**	**2.083**	**0.426**	**0.428**	**0.479**
Response to dement (C_{13})	0.354(1)	0.060	2.375	2.125	2.000	0.406	0.469	0.500
Information acquisition (C_{14})	0.325(2)	0.055	2.250	2.375	2.500	0.438	0.406	0.375
After sales service (C_{15})	0.320(3)	0.054	2.250	2.375	1.750	0.438	0.406	0.563
Environmental collaboration (D_6)	**0.157(5)**		**2.434**	**2.006**	**1.881**	**0.391**	**0.498**	**0.53**
Technology for recycling production and process (C_{16})	0.525(1)	0.082	2.375	2.125	2.000	0.406	0.469	0.500
Green manufacturing policy (C_{17})	0.475(2)	0.075	2.500	1.875	1.750	0.375	0.531	0.563
Total performance			**2.294**(1)	**2.192**(2)	**2.018**(3)			
Total gap						**0.427**(1)	**0.452**(2)	**0.496**(3)

Note: The numbers in the ( ) denotes the ranks of local weights in dimensions and criteria.

each vendor's performance. For example, vendor V_1 is the best vendor of recycled material in the present situation, but the gap of its aspired level is 0.427. In order to minimize the gap of its aspired, we can propose an improvement suggestion for vendor V_1 such as the three largest gaps of aspired level are 0.51 (supply risk D_3), 0.467 (delivery schedule D_2) and 0.466 (overall cost of product D_4), respectively. That is, vendor V_1 should focus on supply performance and reduce the gaps of aspired level.

6. Conclusions

Vendor selection is an important issue in the supply chain management. The decision of VS is a complicated process that various criteria are uncertainty and may vary across the different product categories and purchase situations. In this study, we developed the dimensions and criteria that align with the collaboration of environmentally for the ACP industry in Taiwan. An empirical study was used to demonstrate the application of a hybrid MCDM model combining DANP with VIKOR. We can not only select the best vendor but also find how to improve the gaps of aspired level of each dimension and criterion for vendor's performance. Therefore, this study can contribute to enhance and increase the efficiency of using resources and obtain the objective of environmentally conscious manufacturing for any industries.

One of the limitations of this study is that the survey conducted was only an expert evaluation exercise rather than a full industrial survey. It is recommended that the scale of the surveyed samples should be enough large. In addition, resources are limited in most companies. In order to reduce the gaps of aspired level for optimal or suitable areas, the MCDM model with a dominance-based rough set approach (DRSA) or a new approach could be investigated in future works.

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Appendix A. Survey questionnaire used in this study

Good day! This is an academic research about "The best vendor selection for conducting the recycled materials based on a hybrid MCDM model combining DANP with VIKOR". The purpose is to explore recycled material vendor's dimension of performance evaluation, evaluation index, and key factors related to performance evaluation. As we are greatly impressed by your company's outstanding achievement in this field, if we could have the honor of obtaining your precious opinions, the result and credibility of this research will be tremendously benefited. All the information provided will be used for academic statistical analysis only, and will not be separately announced to the outside or transferred to other applications. Therefore, please feel at ease in filling out the answers. Your support will be very crucial to the successful completion of this research. We sincerely hope that you would spend some time to express your opinions to be taken as reference for this research. Please accept our most sincere appreciation. Thank you and wish you all the best.

(1) Instructions for filling out the questionnaire

This questionnaire is divided into six parts: (1) instructions for filling out; (2) dimensions and criteria description; (3) method for filling out; (4) comparison of the impact of the six dimensions; (5) comparison of the impact of the 17 criteria; (6) personal data.

(2) Descriptions of dimensions and criteria

All decision dimensions and criteria are shown in Table 1.

(3) Method for filling out

Filling factors influence level: 0. No influence; 1. Minor influence; 2. Middle influence; 3. High influence; 4. Extreme influence

Fore example: The influence degree of A to B is extreme influence, then filling 4 under B column.

Criteria	*A*	*B*	*C*	*D*	*E*
A	■	4			
B		■			
		■			

Examples:

(1) The influence degree of ingredient consistency to process capability is extreme then filing 4 into the cross blank of C_1 and C_2.

(2) The influence degree of process capability to ingredient consistency is minor then filing 1 into the cross blank of C_2 and C_1.

Criteria	C_1 Ingredient consistency	C_2. Process capability	C_3. Yield rate	C_4	C_5.	C_6	C_7	C_8.	C_9.	C_{10}	C_{11}.	C_{12}	C_{13}	C_{14}	C_{15}.	C_{16}	C_{17}
C_1.Ingredient consistency	■	**4**															
C_2. Process capability	**1**	■															

(4) The evaluation of influence relationship for 17 criteria

Criteria	C_1. Ingredient consistency	C_2. Process capability	C_3. Yield rate	C_4. Shortest lead time	C_5. Delivery on time rate	C_6 Serious delivery delay rate	C_7 Geographical location	C_8 Political stability	C_9. Equipment capacity change	C_{10}. Recycled material price	C_{11} Handling cost	C_{12} Process loss cost	C_{13}. Response to dement	C_{14} Information acquisition	C_{15}. After sales service	C_{16} Technology for recycling products and process	C_{17} Green manufacturing policy
C_1. Ingredient consistency	■																
C_2. Process capability		■															
C_3. Yield rate			■														
C_4. Shortest lead time				■													
C_5. Delivery on time rate					■												
C_6.Serious delivery delay rate						■											
C_7.Geographical location							■										
$C8$. Political stability								■									
C_9.Equipment capacity change									■								
C_{10}.Recycled material price										■							
$C_{11.}$ Handling cost											■						
C_{12}. Process loss cost												■					
C_{13} Response to dement													■				
C_{14}.Information acquisition														■			
C_{15}. After sales service															■		
C_{16}. Technology for recycling products and process																■	
C_{17}.Green manufacturing policy																	■

(5) To evaluate the performance of present plastics recycled material vendors

According to the following 17 criteria to evaluate your present plastics recycled material vendors (represent by V_1, V_2, V_3,. . .).The performance scores are 0–4 (very bad ←0,1,2,3,4→very good).

Performance degree of dimension (scores between 0~4)	Vendor V_1	Vendor V_2	Vendor V_3	Vendor V_4				
C_1. Ingredient consistency								
C_2. Process capability								
C_3. Yield rate								
C_4 .Shortest lead time								
C_5. Delivery on time rat								
C_6. Serious delivery delay rate								
C_7 .Geographical location								
C_8. Political stability								
C_9.Equipmentcapacity change								
C_{10}.Recycled material price								
C_{11} Handling cost								
C_{12} Process loss cost								
C_{13}. Response to dement								
C_{14} Information acquisition								
$C_{15.}$ After sales service								
C_{16}.Technolo for recycling products and process								
C_{17}.Green manufacturing policy								

(6) Basic personal data

1. Gender: ☐ Male ☐ Female
2. Education Level: ☐ College ☐ University ☐ Master ☐ PhD
3. Service Unit:
4. Service Dept.:
5. Job Title:
6. Age: ☐ Under 30 years old (including) ☐ 30–35 years old (including) ☐ 35–40 years old (including) ☐ 40–50 years old (including) ☐ Over 50 years old

Appendix B.

The MCDM model based on DEMATEL and ANP combining with VIKOR calculation steps with empirical case data. The calculations of all tables are shown in excel file which is available from the first author.

References

Albino V, Gravel AC. A neural network application to subcontractor rating in construction firms. International Journal of Project Management 1998;16(1):9–14.

Barbarosoglu G, Yazgaç T. An application of the analytic hierarchy process to the supplier selection problem. Production and Inventory Management Journal 1997;First Quarter:14–21.

Cakravastia A, Takahashi K. Integrated model for supplier selection and negotiation in a make-to-order environment. International Journal of Production Research 2004;42(21):4457–74.

Chan FTS, Kumar N. Global supplier development considering risk factors using fuzzy extended AHP-based approach. The International Journal of management Science (Omega) 2007;35(4):417–31.

Chen RW, Navin-Chandra D, Prinz FB. Product design for recyclability: a cost benefit analysis and its application. In: Proceedings of the IEEE international symposium on May 10–12; 1993. p. 178–83.

Chen YC, Lien HP, Tzeng GH. Measures and evaluation for environment watershed plans using a novel hybrid MCDM model. Expert Systems with Applications 2010;37(2):926–38.

Chiu YJ, Chen HC, Tzeng GH, Shyu JZ. Marketing strategy based on customer behavior for the LCD-TV. International Journal of Management and Decision Making 2006;7(2/3):143–65.

Chou SY, Shen CY, Chang YH. Vendor selection in a modified re-buy situation using a strategy-aligned fuzzy approach. International Journal of Production Research 2007;45(14):3113–33.

Delmas M, Montiel IG. The supply chain: When is customer pressure effective? Journal of Economics & Management Strategy 2009;18(1):171–201.

Field JM, Sroufe RP. The use of recycled materials in manufacturing: implications for supply chain management and operations strategy. International Journal of Production Research 2007;45(18/19):4439–63.

Fontela E, Gabus A. The DEMATEL observe. Geneva Research Center: Battelle Institute; 1976.

Foster ST, Ogden J. On differences in how operations and supply chain managers approach quality management. International Journal of Production Research 2008;46(24):6945–61.

Freimer M, Yu PL. Some new results on compromise solutions for group decision problems. Management Science 1976;2(6):688–93.

Geffen CA, Rothenberg S. Suppliers and environmental innovation: the automotive paint process. International Journal of Operations and Production Management 2000;20(20):166–86.

Ghodsypour SH, O'Brien C. A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming. International Journal of Production Economics 1998;56–57(1):199–212.

Ghodsypour SH, O'Brien C. The total cost of logistics in supplier selection: under conditions of multiple sourcing, multiple criteria and capacity constraint. International Journal of Production Economics 2001;73(1):15–27.

Giunipero LC, Brand RR. Purchasing's role in supply chain management. International Journal of Logistics Management 1996;7(1):29–38.

Govindan K, Devika K, Haq AN. Analyzing supplier development criteria for an automobile industry. Industrial Management and Data Systems 2010;110(1):43–62.

Gungor A, Gupta SM. Issues in environmentally conscious manufacturing and product recovery: a survey. Computers & Industrial Engineering 1999;36(4):811–53.

Ho CL, Tsai CL, Tzeng GH, Fang SK. Combined DEMATEL technique with a novel MCDM model for exploring portfolio selection based on CAPM. Expert Systems with Applications 2011;38(1):16–25.

Huang CY, Shyu JZ, Tzeng GH. Reconfiguring the innovation portfolios for Taiwan's SIP mall industry. Technovation 2007;27(12):744–65.

Kannan G, Pokharel S, Kumar PS. A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider. Resources, Conservation and Recycling 2009;54(1):28–36.

Lee JW, Kim SH. Using analytic network process and goal programming for interdependent information system project selection. Computers & Operations Research 2000;27(4):367–82.

Lee WS, Tzeng GH, Hsu CY, Huan JM. Combined MCDM techniques for exploring stock selection based on Gordon model. Expert Systems with Applications 2009;36(3):6421–30.

Lin CL, Tzeng GH. A value-created system of science (technology) park by using DEMATEL. Expert Systems with Applications 2009;36(6):9683–97.

Lin CL, Chen CW, Tzeng GH. Planning the development strategy for the mobile communication package based on consumers' choice preferences. Expert Systems with Applications 2010a;37(7):4749–60.

Lin CL, Hsieh MS, Tzeng GH. Evaluating vehicle telematics system by using a novel MCDM techniques with dependence and feedback. Expert Systems with Applications 2010b;37(10):6723–36.

Lin YT, Lin L, Yu HC, Tzeng GH. A novel hybrid MCDM approach for outsourcing vendor selection: a case study for a semiconductor company in Taiwan. Expert Systems with Applications 2010c;37(7):4796–804.

Liou JH, Tzeng GH, Chang HC. Airline safety measurement using a hybrid model. Air Transport Management 2007;13(4):243–9.

Liou JH, Yen L, Tzeng GH. Building an effective safety management system for airlines. Journal of Air Transport Management 2008;14(1):20–6.

Liu FHF, Hai HL. The voting analytic hierarchy process method for selecting supplier. International Journal of Production Economics 2005;97(3):308–17.

Masella C, Rangone A. A contingent approach to the design of vendor selection systems for different types of co-operative customer/supplier relationships. International Journal of Operations and Production Management 2000;20(1):70–84.

Meade LM, Presley A. R&D project selection using the analytic network process. IEEE Transactions on Engineering Management 2002;49(1):59–66.

Melnyk SA, Sroufe R, Montabon F. How does management view environmentally responsible manufacturing? Production and Inventory management Journal 2001;42(3–4):55–63.

Mena C, Adenso-Diaz B, Yurt O. The causes of food waste in the supplier–retailer interface: evidences from the UK and Spain. Resources, Conservation and Recycling 2011;55(6):648–58.

Momoh JA, Zhu J. Optimal generation scheduling based on AHP/ANP. IEEE Transactions on Systems, Man and Cybernetics: Part B: Cybernetics 2003;33(3):531–5.

Olugu EU, Wong KY, Shaharoun AM. Development of key performance measures for the automobile green supply chain. Resources, Conservation and Recycling 2011;55(6):648–58.

Opricovic S, Tzeng GH. Multicriteria planning of post-earthquake sustainable reconstruction. Computer-Aide Civil and Infrastructure Engineering 2002;17(3):211–20.

Opricovic S, Tzeng GH. Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS. European Journal of Operational Research 2004;156(2):445–55.

Opricovic S, Tzeng GH. Extended VIKOR method in comparison with outranking methods. European Journal of Research 2007;178(2):514–29.

Ou Yang YP, Shieh HM, Leu JD, Tzeng GH. A novel hybrid MCDM model combined with DEMATEL and ANP with applications. International Journal of Operations Research 2008;5(3):1–9, 160–168.

Ou Yang YP, Shieh HM, Leu JD, Tzeng GH. A VIKOR-based multiple criteria decision method for improving information security risk. International Journal of Information Technology & Decision Making 2009;8(2):267–87.

Rao P. Greening the supply chain: a new initiative in South East Asia. International Journal of Operational Production Management 2002;22(6):632–55.

Ronen B, Trietsch D. A decision support system for purchasing management of large projects. Operations Research 1988;36(6):882–90.

Saaty TL. Fundamentals of the analytic network process. In: Proceedings of the 5th international symposium on the analytic hierarchy process; 1999.

Sarkis J. A strategic decision framework for green supply chain management. Journal of Cleaner Production 2003;11(4):397–409.

Schmitz J, Platts KW. Supplier logistics performance measurement: indication from a study in the automotive industry. International Journal of Production Economics 2004;89(2):231–43.

Shen CY, Yu KY. Enhancing the efficacy of supplier selection decision-making on the initial stage of new product development: a hybrid fuzzy approach considering the strategic and operational factors simultaneously. Expert Systems with Applications 2009;36(12):11271–81.

Subramanian PM. Plastics recycling and waste management in the US. Resource, Conservation and Recycling 2000;28(1):253–63.

Soukup WR. Supplier selection strategies. Journal of Purchasing and Materials Management 1987;23(3):7–12.

Tzeng GH, Chiang CH, Li CW. Evaluating intertwined effects in e-learning programs: a novel hybrid MCDM model based on factor analysis and DEMATEL. Expert Systems with Applications 2007;32(4):1028–44.

Tzeng GH, Lin CW, Opricovic S. Multi-criteria analysis of alternative-fuel buses for public transportation. Energy Policy 2005;33(11):1373–83.

Tzeng GH, Tsaur SH, Laiw YD, Opricovic S. Multicriteria analysis of environmental quality in Taipei: public preferences and improvement strategies. Journal of Environmental Management 2002;65(2):109–20.

Vachon S. Green supply chain practices and the selection of environmental technologies. International Journal of Production Research 2007;45(18/19):4357–79.

Venus LYH. Green management practices and fir performance: a case of container terminal operations. Resources, Conservation and Recycling 2011;55(6):559–66.

Weber CA, Current JR, Benton WC. Vendor selection criteria and methods. European Journal of Operational Research 1991;50(1):2–18.

Weber CA, Current JR, Desai A. An optimization approach to determining the number of vendors to employ. Supply Chain Management: An International Journal 2000;5(2):90–8.

Yang JL, Chiu HN, Tzeng GH, Yeh RH. Vendor selection by integrated fuzzy MCDM technique with independent and interdependent relationships. Information Sciences 2008;178(21):4166–83.

Zhang Y, Bao X, Ren G, Cai X, Li J. Analysing the status: obstacles and recommendations for WCOs of restaurants as biodiesel feedstocks in China from supply chain' perspectives. Resources, Conservation and Recycling 2012;60(1):20–37.