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Article

Developing a Green Supplier Selection Model by Using the DANP with VIKOR

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Abstract: This study proposes a novel hybrid multiple-criteria decision-making (MCDM) method to evaluate green suppliers in an electronics company. Seventeen criteria in two dimensions concerning environmental and management systems were identified under the Code of Conduct of the Electronic Industry Citizenship Coalition (EICC). Following this, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) used the Analytic Network Process (ANP) method (known as DANP) to determine both the importance of evaluation criteria in selecting suppliers and the causal relationships between them. Finally, the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method was used to evaluate the environmental performances of suppliers and to obtain a solution under each evaluation criterion. An illustrative example of an electronics company was presented to demonstrate how to select green suppliers.

Keywords: supplier selection; environmental performance; EICC; DANP; VIKOR

1. Introduction

Given growing environmental concerns during the past decade, a consensus is emerging that environmental pollution issues accompanying industrial development should be addressed along with supply chain management, thus contributing to a green supply chain management (GSCM) system [1]. GSCM is generally understood to involve screening suppliers based on environmental performance and then doing business only with those that meet certain environmental regulations or standards [2]. Supplier selection in GSCM is clearly a critical activity in purchasing management [2,3]; an increasing number of authors have addressed supplier selection issues when these are viewed from an environmental perspective [4–18].

Supplier selection and evaluation is a multi-criteria decision-making (MCDM) approach [19,20] that provides an effective framework for comparing suppliers. By considering the qualitative characteristic of environmental performance as an indicator in green supplier selection, either the weighting model of the analytic hierarchy process (AHP) [5] or the analytic network process (ANP) [10,21–24] can be more effectively used for treating qualitative factors than other models, such as mathematical programming models. Moreover, most studies have assumed that each cluster in the ANP method has equal weight in obtaining a weighted supermatrix [24,25]. To improve upon this shortcoming, a novel combination of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and ANP techniques, known as the DANP, is used to determine the influential weights of criteria based on the DEMATEL network relationship map (NRM). When evaluating a supplier, ANP techniques are used to determine the weights of performance criteria and determine the total performance of the supplier. DEMATEL techniques are used to compute the effects between criteria. Another promising technique for solving MCDM problems in supplier selection is the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [26–28], which focuses on ranking and selecting from a set of alternatives. This determines compromise solutions for a problem with conflicting criteria and helps in arriving at a final decision [29].

Although there has been previous research in the field of supplier selection and evaluation using a hybrid MCDM model, combining the DEMATEL method with an ANP approach (DANP) and VIKOR to propose a hybrid MCDM method in green supplier selection is, to the best of our knowledge, a new, pioneering study. Application of a hybrid MCDM method combining the DANP and VIKOR has previously been investigated in other fields, including e-store business [30], vendor selection of recycled materials [24], the improvement of tourism policy [31], glamour stock selection [32], the evaluation of RFID technology [33], and brand marketing [34]. However, previous research into either traditional or green supplier selection has been limited. Based on the characteristics of the problem and the advantages of the aforementioned two techniques, this study proposes a hybrid MCDM model based on the DANP which is utilized to determine relative weight. The advantage is that the DANP can use one matrix, instead of the DEMATEL with ANP methods that require two types of questionnaire. The DANP method can benefit the company by determining the weighting and causal relationships among criteria without dealing with the complex, huge and time-consuming comparison matrix of the ANP. The VIKOR with DANP weightings is then proposed for evaluating the environmental performance of suppliers by determining performance scores and gaps. The VIKOR is applied to select appropriate green suppliers and to analyze gaps in the desired level of green performance for each supplier. This can help managers devise strategies for supplier development to effectively minimize gaps in the green performance of potential suppliers. Finally, an example using a Taiwanese electronics manufacturer is included in this research to demonstrate the use of the proposed framework to facilitate selection of appropriate green suppliers. The proposed model provides a new way for decision makers to manage and evaluate suppliers' demonstrated competence in environmental management.

2. Literature Review

2.1. Methods to Green Supplier Selection and Evaluation

In selecting both traditional and green suppliers, individual approaches have been found to be more popular than integrated approaches; the top three approaches have been the AHP, the ANP, and data envelopment analysis (DEA) [35,36] as shown in Table 1. In considering most qualitative criteria and the complexities of a real-world decision process for green supplier selection, AHP and ANP methods were integrated for managers to use in selecting appropriate suppliers. Evaluations were based upon the unique advantages of individual techniques, including DEA, rough set theory, PROMETHEE, and VIKOR.

Table 1. Methods for green supplier selection by using AHP and AHP.

Method		References
AHP	AHP, Fuzzy AHP, FEAHP	[5,9,11,37]
Integrated AHP	AHP and artificial neural network	[38]
	AHP and genetic algorithm	[39]
	AHP and data envelopment analysis	[40]
	AHP and grey relational analysis	[41]
	AHP and mathematical programming	[42]
	AHP and fuzzy TOPSIS	[17]
ANP	ANP, Fuzzy ANP	[10,22,43]
Integrated ANP	ANP and data envelopment analysis	[40,44]
	ANP and rough set theory	[12]
	ANP and PROMETHEE	[45]
	ANP and VIKOR	[24]

2.2. Criteria for Green Supplier Selection

According to the literature review from Govindan *et al.* [36], both traditional and environmental criteria are considered in the selection and evaluation of green suppliers, as shown in Table 2. It has been found that environmental management systems have been examined most frequently in evaluating the environmental performance of suppliers, followed by green design, green image, environmental performance, environmental competences, and green collaboration with suppliers. Most companies tend to ask their suppliers to implement ISO14001 since the standard has become a prevalent tool for evaluating environmental aspects and factors in the sustainable supply chain (social, economic and environmental) [43,46].

Ho, Xu and Dey [35] found that 68 research papers (87.18%) considered quality the most popular criterion for decision makers in evaluating and selecting the most appropriate supplier, followed by delivery, price/cost, manufacturing capability, service, management, technology, research and development, finance, flexibility, reputation, relationship, risk, and safety and environment. This is consistent with Govindan *et al.* [36]; consideration of traditional quality has frequently been used in selecting and evaluating green suppliers, followed by price/cost, service and technology. In implementing a green supply chain, managers must consider not only ecological criteria in selecting and evaluating green suppliers, but also the traditional criteria of quality, price/cost, and service. This implies that firms that are more focused on traditional criteria and adopt formalized supplier selection methods still pay little attention to environmental criteria [18]. This notion has been supported by in-depth interviews demonstrating that even some large companies still lack a formalized environmental performance assessment of their suppliers.

Table 2. Top ten criteria for green supplier selection [36].

Criteria	References
Environmental management systems	[6,7,11,13,37–39,41,46–49]
Quality	[11,13,39,40,46,48,49]
Price/cost	[13,39,47,49–51]
Service	[13,39–41,49,52]
Technology	[11,40,41,43]
Green design	[6,7,11,48,53,54]
Green image	[6,7,11,47,48]
Environmental performance	[37,54–56]
Environmental Competences	[6,7,46,47]
Green collaboration with suppliers	[5,10,56]

In 2004, an implementation group representing a collaboration of large global electronics firms created the EICC Code of Conduct [57]. This EICC Code of Conduct reflects how the electronics industry has developed and matured its corporate responsibility systems in the five core elements of labor, health and safety, ethics, environment, and management systems [58]. Recently, a number of international electronics companies have focused on the EICC Code of Conduct in conducting risk assessment of supply chain responsibility. Fox example, HP adopted the EICC Code of Conduct by engaging with their suppliers in a social and environmental management scheme. In 2012, HP conducted audits of production suppliers in terms of the EICC Code of Conduct and worked closely with manufacturing partners and component suppliers, providing support and training to improve environmental performance and transparency [59].

The suppliers of brand name companies such as Dell, HP, IBM, Intel, and SONY are mainly from Taiwan, one of the most industrialized countries in the Asia-Pacific region and home to a large number of electrical and electronics manufacturers involved in original equipment manufacturing (OEM) and original design manufacturing (ODM) [10]. As a result, these electronics companies are subject to customer requests for environmental and social responsibility in accordance with EICC Code of Conduct. In order to be effective in the selection and evaluation of green suppliers in the electronics industry, environmental criteria from the EICC Code of Conduct have therefore been widely been adopted by OEM or ODM firms to manage and engage with their suppliers (See Table 3).

Table 3. Environmental criteria for supplier selection from EICC Code of Conduct Version 4.

Dimension	Criteria	Description
Environmental	Environmental Permits and Reporting	All required environmental permits (e.g., discharge monitoring), approvals and registrations are to be obtained, maintained and kept current and their operational and reporting requirements are to be followed
	Pollution Prevention and Resource Reduction	Waste of all types, including water and energy, are to be reduced or eliminated at the source or by practices such as modifying production, maintenance and facility processes, materials substitution, conservation, recycling and re-using materials.
	Hazardous Substances	Chemicals and other materials posing a hazard if released to the environment are to be identified and managed to ensure their safe handling, movement, storage, use, recycling or reuse and disposal.
	Wastewater and Solid Waste	Wastewater and solid waste generated from operations, industrial processes and sanitation facilities are to be characterized, monitored, controlled and treated as required prior to discharge or disposal.
	Air Emissions	Air emissions of volatile organic chemicals, aerosols, corrosives, particulates, ozone depleting chemicals and combustion by-products generated from operations are to be characterized, monitored, controlled and treated as required prior to discharge.
	Product Content Restrictions	Participants are to adhere to all applicable laws, regulations and customer requirements regarding prohibition or restriction of specific substances, including labeling for recycling and disposal.
Management systems	Company Commitment	A corporate social and environmental responsibility policy statements affirming Participant's commitment to compliance and continual improvement, endorsed by executive management.
	Management Accountability and Responsibility	The Participant clearly identifies company representative[s] responsible for ensuring implementation of the management systems and associated programs. Senior management reviews the status of the management system on a regular basis.
	Legal and Customer Requirements	A process to identify, monitor and understand applicable laws, regulations and customer requirements, including the requirements of this Code.
	Risk Assessment and Risk Management	A process to identify the environmental, health and safety3 and labor practice and ethics risks associated with Participant's operations. Determination of the relative significance for each risk and implementation of appropriate procedural and physical controls to control the identified risks and ensure regulatory compliance
	Improvement Objectives	Written performance objectives, targets and implementation plans to improve the Participant's social and environmental performance, including a periodic assessment of Participant's performance in achieving those objectives.
	Training	Programs for training managers and workers to implement Participant's policies, procedures and improvement objectives and to meet applicable legal and regulatory requirements.
	Communication	A process for communicating clear and accurate information about Participant's policies, practices, expectations and performance to workers, suppliers and customers.
	Worker Feedback and Participation	Ongoing processes to assess employees' understanding of and obtain feedback on practices and conditions covered by this Code and to foster continuous improvement.
	Audits and Assessments	Periodic self-evaluations to ensure conformity to legal and regulatory requirements, the content of the Code and customer contractual requirements related to social and environmental responsibility.
	Documentation and Records	Creation and maintenance of documents and records to ensure regulatory compliance and conformity to company requirements along with appropriate confidentiality to protect privacy.

3. Methodology

The methodology for constructing a novel hybrid MCDM model to evaluate the environmental performance of suppliers in this study has three phases. The first phase involves identification of criteria used to evaluate the environmental management competence of suppliers. In this study, green supplier criteria were determined from both literature reviews and interviews with the managers of electronics firms. After identifying consistent criteria, the DANP method was used to examine interrelationships between and influential weights among the criteria. In the final phase, VIKOR was used to rank the suppliers of an example electronics company in terms of their competence in environmental management.

3.1. Building a Network Relation Map Using the DEMATEL

The DEMATEL was developed with the belief that pioneering scientific research methods and their appropriate use could improve the understanding of a specific cluster of intertwined problems, thus contributing to the identification of workable solutions using a hierarchical structure. The methodology, according to the concrete characteristics of objective affairs, can confirm interdependence among variables/attributes and restrict the relationship reflecting their characteristics using an essential system and a development trend [60]. The DEMATEL method is increasingly being used to determine the interrelationships of factors through a cause–effect relationship diagram, particularly to determine the critical factors of reverse supply chains [61], SaaS adoption [62], airline safety management systems [63], and performance evaluation in the hotel industry [64]. Therefore, DEMATEL modeling best fits the problem examined in the present study and offers the advantage of a systematic approach toward identifying the relationships in green supplier management in the electronics industry.

The following steps make up the DEMATEL process:

***Step 1**: Calculating the average matrix*

Suppose we have *H* experts in this study and *n* factors to consider. Each respondent is asked to indicate the degree to which he/she believes a factor, *i*, affects factor *j*. Pairwise comparisons between any two factors are denoted by x^k_{ij} and are given an integer score of 0 to 4, representing "No influence (0)", "Low influence (1)", "Medium influence (2)", "High influence (3)", and "Very high influence (4)" [65]. Figure 1 shows an example of an influence map. Each letter represents a factor in the system. An arrow from *c* to *d* shows the effect that *c* has on *d*; the strength of its effect is 4 (very high influence). DEMATEL can convert the structural relations between the factors of a system into an intelligible map of that system. The scores provided by each respondent provide an $n \times n$ non-negative answer matrix $\boldsymbol{X}^k = [x^k_{ij}]$, with $k = 1, 2, \ldots, H$. Therefore, $\boldsymbol{X}^1, \boldsymbol{X}^2, \ldots, \boldsymbol{X}^H, \boldsymbol{X}^k$, are the answer matrices for each of the *H* experts, with each element of $\boldsymbol{X}^k = [x^k_{ij}]_{n\times n}$ being an integer denoted by x^k_{ij}. The diagonal elements of each answer matrix $\boldsymbol{X}^k = [x^k_{ij}]_{n\times n}$ are all set to 0. The $n \times n$ average matrix $\boldsymbol{A}$ for all expert opinions can then be computed by averaging the scores of the $\boldsymbol{H}$ experts as follows:

$$a_{ij} = \frac{1}{H}\sum_{K=1}^{H} x^k_{ij} \quad (1)$$

The average matrix $\mathrm{A} = [a_{ij}]_{n\times n}$ is also called the original average matrix. $\boldsymbol{A}$ shows the initial direct effects a factor has on and receives from other factors. The causal effect between each pair of factors in a system can be outlined by drawing an influence map.

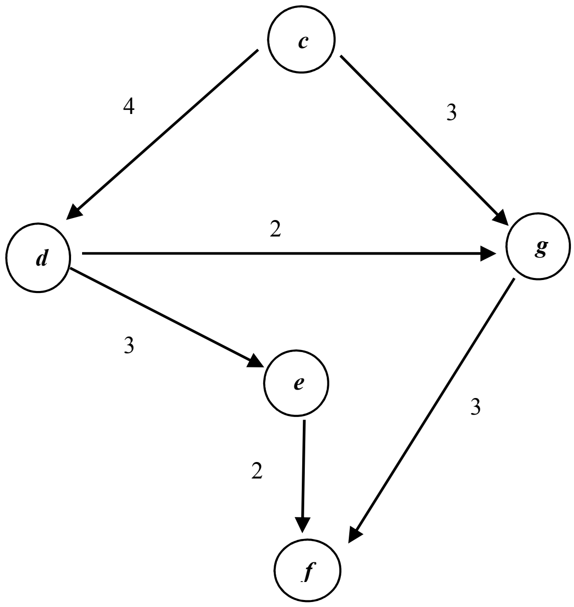

Figure 1. Example of an influence map revised from Lin *et al.* [66].

Step 2: *Calculating the direct influence matrix*

The normalized initial direct-relation matrix $\boldsymbol{D}$ is obtained by normalizing the average matrix $\boldsymbol{A}$ with the following method:
Let,

$$s = \min\left[\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n}\left|a_{ij}\right|}, \frac{1}{\max_{1\le i\le n}\sum_{i=1}^{n}\left|a_{ij}\right|}\right] \quad (2)$$

Thus,

$$\mathrm{D}=\frac{A}{s} \quad (3)$$

As the sum of each row j of matrix $\boldsymbol{A}$ represents the direct effects of each element on others, $\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}$ represents the one with the highest direct influence. Likewise, as the sum of each column i of matrix $\boldsymbol{A}$ represents the direct effects on factor i, $\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}$ represents the one most influenced by other factors. The positive scalar s is equal to the larger of the two extreme sums. Matrix $\boldsymbol{D}$ is obtained by dividing each element of A by the scalar. Note that each element d_{ij} of matrix $\boldsymbol{D}$ is between 0 and 1.

Step 3: *Computing the total relation matrix*

Indirect effects between factors are measured by powers of $\boldsymbol{D}$. A continuous decrease in the indirect effects of factors, including the powers of matrix $\boldsymbol{D}$—*i.e.*, $\boldsymbol{D}^2$, $\boldsymbol{D}^3$, $\boldsymbol{D}^\infty$—guarantees convergent solutions to the matrix inversion similar to an absorbing Markov chain matrix. Note that $\lim_{m\to\infty}\boldsymbol{D}^m = [0]_{n\times n}$ and

$\lim_{m\to\infty}(\boldsymbol{I}+\boldsymbol{D}+\boldsymbol{D}^2+\boldsymbol{D}^3+\ldots+\boldsymbol{D}^m)=(\boldsymbol{I}-\boldsymbol{D})^{-1}$, where 0 is the $n \times n$ null matrix and I is the $n \times n$ identity matrix. The total relation matrix $\boldsymbol{T}$ is an $n \times n$ matrix and is defined as follows:

$$\boldsymbol{T}=[t_{ij}]:=\sum_{i=1}^{\infty}D^i=D(I-D)^{-1}\ i,j=1,2,\ldots,n \tag{4}$$

as $\lim_{k\to\infty}\boldsymbol{D}^k=[0]_{n\times n}$

where $\boldsymbol{D}=[d_{ij}]_{n\times n}$, $0\le d_{ij}<1$, and $0\le\left(\sum_i d_{ij},\sum_j d_{ij}\right)<1$. At least one column sum $\sum_j d_{ij}$ or one row sum $\sum_i d_{ij}$ equals 1.

We also define $\boldsymbol{r}$ and $\boldsymbol{c}$ as $n \times 1$ vectors representing the sum of the rows and the sum of the columns of the total relation matrix $\boldsymbol{T}$ as follows:

$$\boldsymbol{r}=[r_i]_{n\times 1}=\left(\sum_{j=1}^{n}t_{ij}\right)_{n\times 1} \tag{5}$$

$$\boldsymbol{c}=[c_j]'_{1\times n}=\left(\sum_{i=1}^{n}t_{ij}\right)'_{1\times n} \tag{6}$$

where superscript' denotes transposition.

Let r_i be the sum of the i-th row in matrix $\boldsymbol{T}$. Therefore, r_i shows the total effects, both direct and indirect, of the i-th factor on other factors. Let c_j denote the sum of the j-th column in matrix $\boldsymbol{T}$. The value c_j shows the total effects, both direct and indirect, on factor j from other factors. Therefore, the sum $(r_i + c_i)$ gives an index (*i.e.* the position) representing the total effects both exerted and received by the i-th factor. In other words, $(r_i + c_i)$ shows the degree of importance that the i-th factor plays in the system (*i.e.* total sum of effects exerted and received). Moreover, the difference ($r_i - c_i$, also called the relation) shows the net effect; the i-th factor contributes to the system. When $(r_i - c_i)$ is positive, the i-th factor is a net causer; when $(r_i - c_i)$ is negative, the i-th factor is a net receiver [67,68].

***Step 4**: Setting the threshold value and obtaining the cognition map*

To obtain the cognition map from the factors, a threshold value p should be established to extricate negligible effects from the total influence of matrix $\boldsymbol{T}$ [69]. Only some criteria, whose effect in matrix $\boldsymbol{T}$ is greater than the threshold value, should be chosen and shown in a network relationship map (NRM) of influence [68].

3.2. Combining the DEMATEL and ANP to Calculate the Evaluation Weights by NRM

The ANP is the general form of the AHP, which is used in MCDM to address restrictions on hierarchical structures [70]. However, the survey questionnaire used in the ANP is too difficult for interviewees to complete [64,71]. Moreover, most studies assumed that each cluster in the ANP has equal weight in obtaining a weighted supermatrix [25,28,30]. To improve on this shortcoming, we used a novel combination of the DEMATEL and ANP techniques called the DANP to determine the influential weights of the criteria based on the NRM of the DEMATEL. Recently, the DANP has been widely applied in different areas of tourism policy [31], best vendor selection [28], performance evaluation for hot spring hotels [64], and the web sites of national parks [72]. The DANP process involves the following steps:

Step 1: *Establishing an unweighted supermatrix*

The total-influenced matrix is obtained from the DEMATEL. Each column is summed up for normalization. The total-influenced matrix $T_c = [t_{ij}]_{n \times n}$ is obtained by the criteria, and $T_D = [t_{ij}^D]_{m \times m}$ is obtained by the dimensions (clusters) from T_c. Next, the supermatrix T_c is normalized for the ANP weights of the dimensions (clusters) using the influence matrix T_D.

$$\boldsymbol{T}_c = \begin{array}{c} \\ \\ D_1 \\ \vdots \\ D_i \\ \vdots \\ D_3 \end{array} \begin{array}{c} \\ \\ c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \\ c_{21} \\ c_{22} \\ \vdots \\ c_{2m_2} \\ \vdots \\ c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \overset{\begin{array}{ccccc} D_1 & & D_j & & D_n \\ c_{11}\ldots c_{1m_1} & \cdots & c_{j1}\ldots c_{jm_j} & \cdots & c_{n1}\ldots c_{nm_n} \end{array}}{\begin{bmatrix} \boldsymbol{T}_c^{11} & \cdots & \boldsymbol{T}_c^{1j} & \cdots & \boldsymbol{T}_c^{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{i1} & \cdots & \boldsymbol{T}_c^{ij} & \cdots & \boldsymbol{T}_c^{in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{n1} & \cdots & \boldsymbol{T}_c^{nj} & \cdots & \boldsymbol{T}_c^{nn} \end{bmatrix}} \quad (7)$$

After normalizing the total-influence matrix $\boldsymbol{T}_c$ through the dimensions (clusters), a new matrix T_c^{α} is obtained, as shown in Equation (8).

$$\boldsymbol{T}_c^{\alpha} = \begin{array}{c} \\ \\ D_1 \\ \vdots \\ D_i \\ \vdots \\ D_n \end{array} \begin{array}{c} \\ \\ c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \\ c_{21} \\ c_{22} \\ \vdots \\ c_{2m_2} \\ \vdots \\ c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \overset{\begin{array}{ccccc} D_1 & & D_j & & D_n \\ c_{11}\ldots c_{1m_1} & & c_{j1}\ldots c_{jm_j} & \cdots & c_{n1}\ldots c_{nm_n} \end{array}}{\begin{bmatrix} \boldsymbol{T}_c^{\alpha 11} & \cdots & \boldsymbol{T}_c^{\alpha 1j} & \cdots & \boldsymbol{T}_c^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{\alpha i1} & \cdots & \boldsymbol{T}_c^{\alpha ij} & \cdots & \boldsymbol{T}_c^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{\alpha n1} & \cdots & \boldsymbol{T}_c^{\alpha nj} & \cdots & \boldsymbol{T}_c^{\alpha nn} \end{bmatrix}} \quad (8)$$

The normalization $\boldsymbol{T}_c^{\alpha 11}$ is explained and that of the other $\boldsymbol{T}_c^{ann}$ is the same as above.

$$d_{ci}^{11} = \sum_{j=1}^{m_1} t_{ij}^{11}, i = 1,2,...,m_1 \quad (9)$$

$$\boldsymbol{T}_c^{\alpha 11} = \begin{bmatrix} t_{c11}^{11}/d_{c1}^{11} & \cdots & t_{c1j}^{11}/d_{c1}^{11} & \cdots & t_{c1m_1}^{11}/d_{c1}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{11}/d_{ci}^{11} & \cdots & t_{cij}^{11}/d_{ci}^{11} & \cdots & t_{cim_1}^{11}/d_{ci}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{cm_11}^{11}/d_{cm_1}^{11} & \cdots & t_{cm_1j}^{11}/d_{cm_1}^{11} & \cdots & t_{cm_1m_1}^{11}/d_{cm_1}^{11} \end{bmatrix} = \begin{bmatrix} t_{c11}^{\alpha 11} & \cdots & t_{c1j}^{\alpha 11} & \cdots & t_{c1m_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{\alpha 11} & \cdots & t_{cij}^{\alpha 11} & \cdots & t_{cim_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{cm_11}^{\alpha 11} & \cdots & t_{cm_1j}^{\alpha 11} & \cdots & t_{cm_1m_1}^{\alpha 11} \end{bmatrix} \quad (10)$$

Let the total-influence matrix match and fall into the interdependence clusters. The result is the unweighted supermatrix, which is based on the transposition of the normalized influence matrix $\boldsymbol{T}_c^{\alpha}$ by the dimensions (clusters), that is, $\boldsymbol{W} = (\boldsymbol{T}_c^{\alpha})'$.

$$\boldsymbol{W} = (\boldsymbol{T}_c^{\alpha})' = \begin{array}{c c} & \begin{array}{ccccc} \boldsymbol{D}_1 & & \boldsymbol{D}_j & & \boldsymbol{D}_n \\ c_{11}\ldots c_{1m_1} & & c_{j1}\ldots c_{jm_j} & \cdots & c_{n1}\ldots c_{nm_n} \end{array} \\ \begin{array}{cc} \boldsymbol{D}_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ \vdots & \begin{array}{c} c_{21} \\ c_{22} \end{array} \\ \boldsymbol{D}_i & \begin{array}{c} \vdots \\ c_{2m_2} \end{array} \\ \vdots & \vdots \\ \boldsymbol{D}_n & \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} & \begin{bmatrix} \boldsymbol{W}^{11} & \cdots & \boldsymbol{W}^{i1} & \cdots & \boldsymbol{W}^{n1} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{W}^{1j} & \cdots & \boldsymbol{W}^{ij} & \cdots & \boldsymbol{W}^{nj} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{W}^{1n} & \cdots & \boldsymbol{W}^{in} & \cdots & \boldsymbol{W}^{nn} \end{bmatrix} \end{array} \quad (11)$$

If the matrix $\boldsymbol{W}^{11}$ is blank or 0 as shown as Equation (12), then the matrix between the clusters or the criteria is independent and has no interdependent. The other $\boldsymbol{W}^{nn}$ values are as above.

$$\boldsymbol{W}^{11} = (\boldsymbol{T}^{11})' = \begin{array}{c c} & \begin{array}{ccccc} \boldsymbol{c}_{11} & \cdots & \boldsymbol{c}_{1i} & \cdots & \boldsymbol{c}_{1m_1} \end{array} \\ \begin{array}{c} \boldsymbol{c}_{11} \\ \vdots \\ \boldsymbol{c}_{1j} \\ \vdots \\ \boldsymbol{c}_{1m_1} \end{array} & \begin{bmatrix} t_{c11}^{\alpha 11} & \cdots & t_{ci1}^{\alpha 11} & \cdots & t_{cm_1 1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c1j}^{\alpha 11} & \cdots & t_{cij}^{\alpha 11} & \cdots & t_{cm_1 j}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c1m_1}^{\alpha 11} & \cdots & t_{cim_1}^{\alpha 11} & \cdots & t_{cm_1 m_1}^{\alpha 11} \end{bmatrix} \end{array} \quad (12)$$

Step 2: *Obtaining the weighted supermatrix*

Each column is added for normalization.

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

The total-influence matrix $\boldsymbol{T}_D$ is normalized, and a new matrix $\boldsymbol{T}_D^{\alpha}$ is obtained, 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 $\boldsymbol{T}_D^{\alpha}$ complete the unweighted supermatrix to obtain the weighted supermatrix.

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

Step 3: *Limiting the weighted supermatrix*

The weighted supermatrix is limited by raising it to a sufficiently large power *k* until the supermatrix converges and becomes a long-term stable supermatrix to obtain the global priority vectors (called the DANP weights), such as $\lim_{\boldsymbol{h}\to\infty}(\boldsymbol{W}^{\alpha})^{\boldsymbol{h}}$.

3.3. Ranking the Alternatives Using the VIKOR Method

The compromise ranking method (known as VIKOR) was introduced as an applicable technique to implement in MCDM [73]. It is based on the concept of the positive- and negative-ideal solution used to evaluate the standards of different projects competing with the MCDM model (Opricovic and Tzeng 2004) [74]. The positive-ideal solution represents the alternative with the highest value, whereas the negative-ideal solution represents that with the lowest value. VIKOR ranks and selects from a set of alternatives, determines compromise solutions for a problem with conflicting criteria, and assists decision makers in generating the final decision [29]. Various studies have found VIKOR a suitable technique to evaluate each alternative for each criterion function [27,29]. The compromise-ranking algorithm VIKOR involves the following steps [27,29,75]:

Step 1: *Determining the best and the worst values*

The best value is f_j^* and the worst is f_j^-. These two values can be computed using Equations (16) and (17), respectively.

$$f_j^* = \max_i f_{ij}, i = 1, 2, \ldots\ldots\ldots.m \tag{16}$$

$$f_j^- = \min_i f_{ij}, i = 1, 2, \ldots\ldots\ldots.m \tag{17}$$

where, f_j^* is the positive-ideal solution and f_j^- is the negative-ideal solution for the *j*th criterion.

Step 2: *Calculating the distance*

In this step, the distance from each alternative to the positive ideal solution is computed.

$$S_i = \sum_{j=1}^{n} w_j \left(\left| f_j^* - f_{ij} \right| \right) / \left(\left| f_j^* - f_j^- \right| \right) \tag{18}$$

$$Q_i = \max_i \left\{ w_j \left(\left| f_j^* - f_{ij} \right| \right) / \left(\left| f_j^* - f_j^- \right| \right) \;\middle|\; j = 1, 2, \ldots\ldots n \right\} \tag{19}$$

where w_j represents the weights of the criteria from the DANP; S_i indicates the mean of group utility and represents the distance of the *i*th alternative achievement to the positive ideal solution; and Q_i represents the maximal regret of each alternative.

Step 3: *Calculating the index value*

The index value is defined as follows:

$$R_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1 - v)\left[\frac{Q_i - Q^*}{Q^- - Q^*}\right] \tag{20}$$

Where $S^* = \min_i S_i$ (or setting the best $S^* = 0$), $S^- = \max_i S_i$ (or setting the worst $S^- = 1$), $Q^* = \min_i Q_i$ (or setting the best $Q^* = 0$), and $Q^- = \max_i Q_i$ (or setting the worst $Q^- = 1$). Equation (20) can be rewritten as $\mathrm{R}_i = \mathrm{v}\mathrm{S}_i + (1 - v)\, Q_i$, when $S^* = 0$ and $Q^* = 0$ (*i.e.*, all criteria achieve the ideal level) and $S^- = 1$ and $Q^- = 1$ (*i.e.* the worst situation). In the equation, *v* is introduced as the weight for the strategy of maximum group utility, and *1-v* is the weight of the individual regret. In Equation (20), when *v* = 1, it indicates the decision-making process that can use the strategy of maximum group utility. Conversely, when *v* = 0, it indicates the decision-making process that can use the strategy of minimum individual regret. In general, *v* = 0.5 will be used if the decision process involves both maximum group utility and individual regret [27,74]. The compromise solution is determined by the VIKOR method and can be accepted by the decision makers based on a maximum group utility of the majority and a minimum of the individual regret of the opponent.

4. Case Study of an Electronics Company

The case company chosen for use in this research is a worldwide leader in electronic and computing product development, including motherboards, desktop PCs, notebooks, broadband, wireless systems, game consoles, and networking equipment. This company is interested in incorporating environmental management into supplier evaluation and selection for GSCM because it is under great pressure from buyers and has become a member of EICC. Although the case company embraced the EICC Code of Conduct's questionnaire in implementing supplier evaluations to help establish a green supply chain, the assessment criteria of the EICC Code of Conduct do not consider the different significance and weights of each criterion. To be effective in its supplier evaluation and selection, the case company wished to implement a systematic method of evaluating suppliers based on their competency in environmental management under the EICC Code of Conduct. In view of this, a hybrid MCDM model was proposed for use by the case company in evaluating green suppliers and selecting those with sound environmental management competences.

4.1. Identifying Consistent Evaluation Criteria

To better define the criteria used in the selection of green suppliers in the electronics industry in general, as well as for the company used for our case study, 17 criteria in two dimensions were identified based on the environmental and management systems of the EICC Code of Conduct, as shown in Table 4.

Table 4. The proposed framework for green supplier selection.

Dimension	Criteria
Environment (D_1)	Environmental permits and reporting (C_1)
	Pollution prevention and resource reduction (C_2)
	Hazardous substances (C_3)
	Wastewater and solid waste (C_4)
	Air emissions (C_5)
	Product content restrictions (C_6)
Management system (D_2)	Company commitment (C_7)
	Management accountability and responsibility (C_8)
	Legal and customer requirements (C_9)
	Risk assessment and risk management (C_{10})
	Performance objectives with implementation plan and measures (C_{11})
	Training (C_{12})
	Communication (C_{13})
	Worker feedback and participation (C_{14})
	Audits and assessments (C_{15})
	Corrective action process (C_{16})
	Documentation and records (C_{17})

4.2. Determining the Relationships between Criteria by DEMATEL

The DEMATEL method was used to examine interdependence and influence relationships between the 17 criteria. Five managers from the case company were asked to complete the questionnaires using a five-point scale (*i.e.*, 0 for no influence, 1 for low, 2 for moderate, 3 for high and 4 for very high) to indicate the influence of each criterion on another criterion within their respective organization. The average initial influence 17 × 17 matrix A (Table 5) was obtained by pairwise comparison in terms of influences and directions. The normalized initial direct-relation matrix $\boldsymbol{D}$ was calculated using Equations (1)–(3) (Table 6). The total influence matrix $\boldsymbol{T}$ (Table 7) was derived from Equation (4). The NRM of the influential relationship was constructed based on vectors r and c (Table 8) using Equations (5) and (6), as shown in Figure 2.

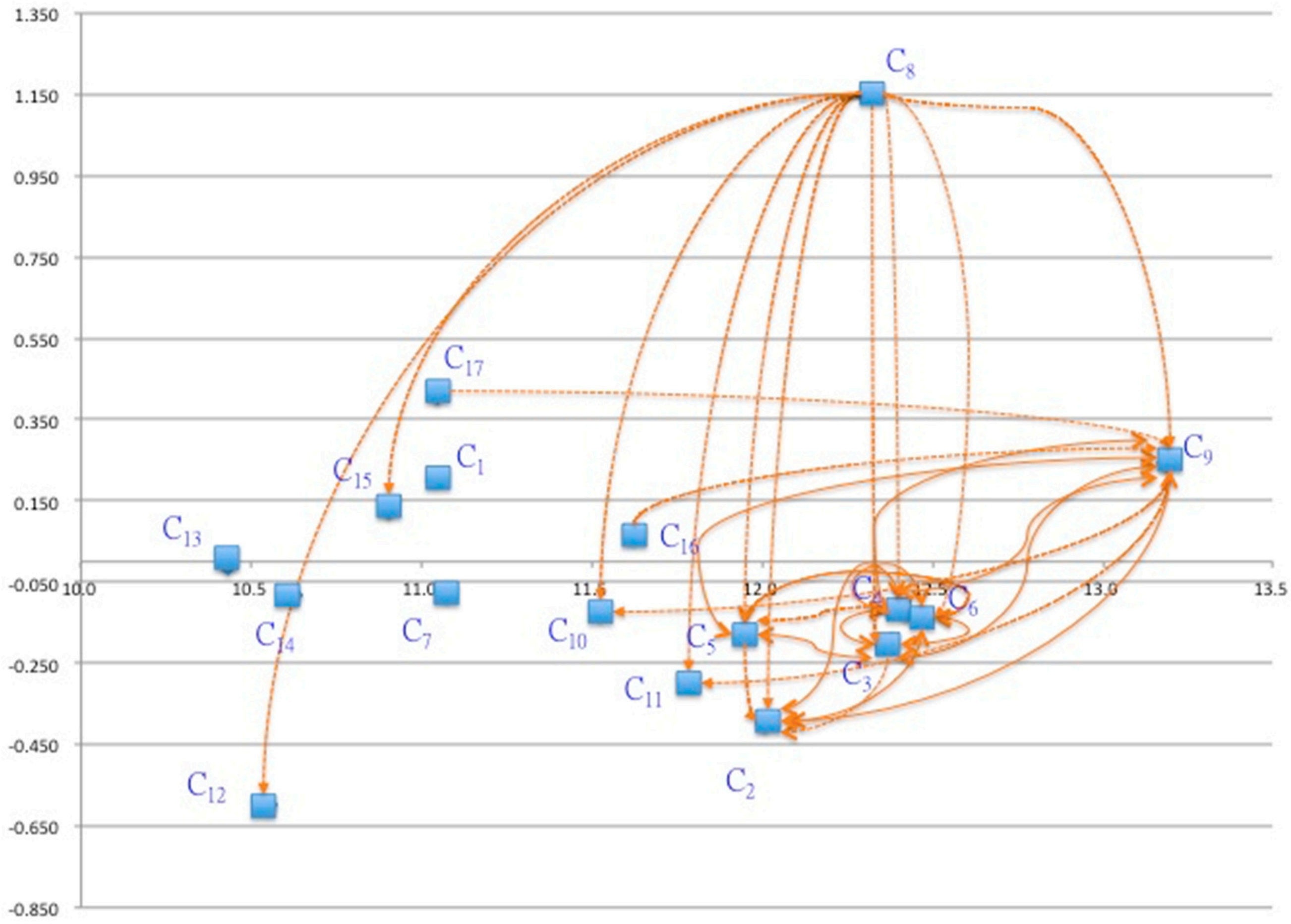

Figure 2. The causal diagram.

The NRM of the criteria was identified by the DEMATEL. The influential relationships within the 17 criteria were revealed. Considering the significance of environmental management in green supplier selection, as presented in Table 8, importance was ranked as $C_9 > C_6 > C_4 > C_3 > C_8 > C_2 > C_5 > C_{11} > C_{16} > C_{10} > C_7 > C_{17} > C_1 > C_{15} > C_{14} > C_{12} > C_{13}$ according to the degree of importance ($r_i + c_i$). Contrary to the importance of individual criteria, management accountability and responsibility (C_8), documentation and records (C_{17}), legal and customer requirements (C_9), environmental permits and reporting (C_1), audits and assessments (C_{15}), and corrective action process (C_{16}) are net causers in accordance with the value of difference ($r_i - c_i$).

Table 5. The initial influence matrix.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**	**C17**
C1	0.000	3.200	3.400	3.400	3.400	2.800	2.200	2.400	3.200	2.600	3.200	3.000	1.800	1.600	2.200	2.800	2.600
C2	3.200	0.000	3.400	3.400	3.400	3.400	2.800	2.400	3.000	2.800	2.600	2.800	2.400	2.400	2.200	2.800	2.400
C3	3.200	4.000	0.000	3.800	3.400	3.600	2.800	2.600	3.600	3.200	2.600	2.600	2.000	2.400	2.400	2.800	2.600
C4	3.200	3.800	4.000	0.000	3.200	3.400	2.800	2.600	3.600	2.400	3.000	3.000	2.400	2.600	2.400	3.200	2.600
C5	3.200	3.800	3.800	3.000	0.000	3.400	2.600	2.200	3.600	3.000	2.800	2.600	1.800	2.800	2.400	2.800	2.200
C6	2.800	3.400	3.400	3.400	3.200	0.000	3.000	2.800	3.600	3.000	3.000	2.800	2.200	3.000	3.200	3.000	2.600
C7	2.400	2.800	2.600	2.400	2.400	2.800	0.000	3.000	2.800	2.800	3.000	2.800	2.600	2.600	2.800	2.600	2.600
C8	2.800	3.000	3.200	3.400	3.200	3.400	3.400	0.000	3.400	3.000	3.800	3.600	3.600	3.600	3.600	3.200	3.200
C9	3.200	3.600	3.800	3.600	3.800	3.600	3.000	3.000	0.000	3.600	3.000	2.800	3.200	2.600	3.400	3.400	3.400
C10	2.600	3.000	3.200	2.800	2.800	3.200	2.400	2.200	3.000	0.000	3.200	2.400	2.600	2.600	2.800	3.000	2.800
C11	2.400	3.200	2.800	3.000	2.600	3.200	3.000	3.000	2.800	2.800	0.000	2.800	2.800	2.600	2.600	2.800	2.600
C12	2.400	2.400	2.600	2.800	2.600	2.600	2.400	2.800	2.600	2.400	2.600	0.000	2.600	1.800	2.000	2.000	2.000
C13	2.000	2.000	2.000	2.200	2.000	2.400	2.800	3.200	3.200	3.000	3.000	2.800	0.000	2.800	2.600	2.400	2.200
C14	2.000	2.600	2.200	2.600	2.600	2.400	3.000	3.400	2.800	2.600	3.000	2.000	3.200	0.000	2.200	2.400	2.000
C15	2.200	2.600	2.800	3.000	2.800	3.000	2.600	2.600	3.200	2.800	3.200	2.400	2.600	2.600	0.000	2.400	2.200
C16	2.000	2.800	2.600	3.200	3.000	3.000	2.200	2.800	3.200	2.800	3.000	2.800	2.800	3.200	3.000	0.000	3.400
C17	2.400	2.200	3.400	3.200	3.000	3.200	2.600	2.800	3.400	2.800	2.600	2.400	2.200	2.600	2.200	3.600	0.000

Table 6. The normalized direct-influence matrix.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**	**C16**	**C17**
C1	0.000	0.060	0.064	0.064	0.064	0.052	0.041	0.045	0.060	0.049	0.060	0.056	0.034	0.030	0.041	0.052	0.049
C2	0.060	0.000	0.064	0.064	0.064	0.064	0.052	0.045	0.056	0.052	0.049	0.052	0.045	0.045	0.041	0.052	0.045
C3	0.060	0.075	0.000	0.071	0.064	0.067	0.052	0.049	0.067	0.060	0.049	0.049	0.037	0.045	0.045	0.052	0.049
C4	0.060	0.071	0.075	0.000	0.060	0.064	0.052	0.049	0.067	0.045	0.056	0.056	0.045	0.049	0.045	0.060	0.049
C5	0.060	0.071	0.071	0.056	0.000	0.064	0.049	0.041	0.067	0.056	0.052	0.049	0.034	0.052	0.045	0.052	0.041
C6	0.052	0.064	0.064	0.064	0.060	0.000	0.056	0.052	0.067	0.056	0.056	0.052	0.041	0.056	0.060	0.056	0.049
C7	0.045	0.052	0.049	0.045	0.045	0.052	0.000	0.056	0.052	0.052	0.056	0.052	0.049	0.049	0.052	0.049	0.049
C8	0.052	0.056	0.060	0.064	0.060	0.064	0.064	0.000	0.064	0.056	0.071	0.067	0.067	0.067	0.067	0.060	0.060
C9	0.060	0.067	0.071	0.067	0.071	0.067	0.056	0.056	0.000	0.067	0.056	0.052	0.060	0.049	0.064	0.064	0.064

Table 6. *cont.*

	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$	$\mathbf{C_9}$	$\mathbf{C_{10}}$	$\mathbf{C_{11}}$	$\mathbf{C_{12}}$	$\mathbf{C_{13}}$	$\mathbf{C_{14}}$	$\mathbf{C_{15}}$	$\mathbf{C_{16}}$	$\mathbf{C_{17}}$
C_{10}	0.049	0.056	0.060	0.052	0.052	0.060	0.045	0.041	0.056	0.000	0.060	0.045	0.049	0.049	0.052	0.056	0.052
C_{11}	0.045	0.060	0.052	0.056	0.049	0.060	0.056	0.056	0.052	0.052	0.000	0.052	0.052	0.049	0.049	0.052	0.049
C_{12}	0.045	0.045	0.049	0.052	0.049	0.049	0.045	0.052	0.049	0.045	0.049	0.000	0.049	0.034	0.037	0.037	0.037
C_{13}	0.037	0.037	0.037	0.041	0.037	0.045	0.052	0.060	0.060	0.056	0.056	0.052	0.000	0.052	0.049	0.045	0.041
C_{14}	0.037	0.049	0.041	0.049	0.049	0.045	0.056	0.064	0.052	0.049	0.056	0.037	0.060	0.000	0.041	0.045	0.037
C_{15}	0.041	0.049	0.052	0.056	0.052	0.056	0.049	0.049	0.060	0.052	0.060	0.045	0.049	0.049	0.000	0.045	0.041
C_{16}	0.037	0.052	0.049	0.060	0.056	0.056	0.041	0.052	0.060	0.052	0.056	0.052	0.052	0.060	0.056	0.000	0.064
C_{17}	0.045	0.041	0.064	0.060	0.056	0.060	0.049	0.052	0.064	0.052	0.049	0.045	0.041	0.049	0.041	0.067	0.000

Table 7. The total influence matrix.

	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$	$\mathbf{C_9}$	$\mathbf{C_{10}}$	$\mathbf{C_{11}}$	$\mathbf{C_{12}}$	$\mathbf{C_{13}}$	$\mathbf{C_{14}}$	$\mathbf{C_{15}}$	$\mathbf{C_{16}}$	$\mathbf{C_{17}}$
C_1	0.267	0.362	0.369	0.368	0.358	0.360	0.313	0.316	0.374	0.332	0.353	0.327	0.288	0.292	0.304	0.334	0.308
C_2	0.331	0.315	0.379	**0.378**	0.367	0.379	0.332	0.325	**0.381**	0.345	0.352	0.332	0.307	0.314	0.312	0.343	0.312
C_3	0.345	**0.401**	0.335	**0.400**	**0.383**	**0.399**	0.346	0.342	**0.407**	0.366	0.367	0.343	0.313	0.327	0.329	0.357	0.329
C_4	0.348	**0.400**	**0.408**	0.337	**0.382**	**0.398**	0.349	0.346	**0.411**	0.356	0.377	0.352	0.323	0.333	0.332	0.367	0.332
C_5	0.335	**0.386**	**0.390**	0.376	0.312	**0.384**	0.333	0.326	**0.396**	0.352	0.360	0.333	0.300	0.324	0.320	0.347	0.313
C_6	0.342	**0.394**	**0.399**	**0.398**	**0.383**	0.339	0.353	0.350	**0.412**	0.367	0.378	0.350	0.320	0.341	0.346	0.364	0.333
C_7	0.303	0.347	0.348	0.344	0.334	0.352	0.268	0.321	0.360	0.329	0.343	0.317	0.297	0.303	0.308	0.324	0.302
C_8	0.368	**0.417**	**0.425**	**0.428**	**0.412**	**0.430**	0.388	0.328	**0.440**	**0.395**	**0.422**	**0.391**	0.370	0.378	**0.380**	0.396	0.369
C_9	0.374	**0.427**	**0.435**	**0.431**	**0.422**	**0.433**	0.380	0.380	0.379	**0.404**	**0.407**	0.376	0.362	0.360	0.375	0.399	0.371
C_{10}	0.316	0.362	0.369	0.362	0.351	0.370	0.320	0.317	0.375	0.290	0.357	0.320	0.306	0.312	0.318	0.341	0.314
C_{11}	0.315	0.368	0.365	0.368	0.350	0.372	0.333	0.333	0.374	0.342	0.303	0.329	0.312	0.315	0.317	0.340	0.313
C_{12}	0.278	0.313	0.320	0.322	0.310	0.320	0.285	0.292	0.327	0.296	0.309	0.242	0.273	0.265	0.270	0.287	0.267
C_{13}	0.282	0.318	0.321	0.324	0.311	0.329	0.303	0.310	0.350	0.318	0.328	0.303	0.238	0.293	0.292	0.306	0.281
C_{14}	0.285	0.331	0.328	0.334	0.325	0.333	0.310	0.317	0.347	0.314	0.331	0.293	0.297	0.247	0.288	0.309	0.281
C_{15}	0.300	0.345	0.352	0.355	0.341	0.356	0.315	0.315	0.368	0.330	0.347	0.311	0.298	0.304	0.259	0.321	0.295
C_{16}	0.312	0.366	0.367	0.376	0.362	0.374	0.324	0.334	**0.386**	0.347	0.361	0.334	0.316	0.330	0.328	0.295	0.331
C_{17}	0.314	0.350	0.374	0.370	0.356	0.372	0.325	0.328	**0.384**	0.341	0.348	0.322	0.300	0.314	0.309	0.352	0.266

Threshold value: 0.379. The values were marked when higher than the threshold value.

Table 8. The sum of influences exerted and received.

Dimension	Criteria	r_i	c_i	$r_i + c_i$	Rank	$r_i - c_i$	Rank
Environment (D_1)	Environmental permits and reporting (C_1)	5.624	5.414	11.039	13	0.210	4
	Pollution prevention and resource reduction (C_2)	5.804	6.203	12.006	6	−0.399	16
	Hazardous substances (C_3)	6.089	6.285	12.374	4	−0.196	14
	Wastewater and solid waste (C_4)	6.149	6.272	12.422	3	−0.123	10
	Air emissions (C_5)	5.887	6.059	11.946	7	−0.173	13
	Product content restrictions (C_6)	6.170	6.300	12.470	2	−0.131	12
Management system (D_2)	Company commitment (C_7)	5.499	5.576	11.075	11	−0.077	8
	Management accountability and responsibility (C_8)	6.737	5.580	12.317	5	1.157	1
	Legal and customer requirements (C_9)	6.715	6.472	13.187	1	0.243	3
	Risk assessment and risk management (C_{10})	5.699	5.823	11.522	10	−0.125	11
	Performance objectives with implementation plan and measures (C_{11})	5.747	6.042	11.789	8	−0.296	15
	Training (C_{12})	4.977	5.574	10.551	16	−0.598	17
	Communication (C_{13})	5.209	5.219	10.428	17	−0.010	7
	Worker feedback and participation (C_{14})	5.268	5.353	10.621	15	−0.085	9
	Audits and assessments (C_{15})	5.513	5.387	10.900	14	0.127	5
	Corrective action process (C_{16})	5.843	5.779	11.622	9	0.064	6
	Documentation and records (C_{17})	5.727	5.317	11.044	12	0.410	2

4.3. Finding the Influential Weight of Criteria Using the DANP

This study used the DANP method to obtain the weights of the 17 criteria and two dimensions based on the influence network of the total influence matrix $\boldsymbol{T}$ produced by the DEMATEL. First, the DANP was used to compare the criteria and calculate an unweighted supermatrix (Table 9) and weighted supermatrix (Table 10). The limiting power of the weighted supermatrix to confirm the supermatrix was converged, and it became a long-term stable supermatrix, obtaining the weights of all criteria (Table 11). Each row represents the weights of each criterion.

The influential weights of criteria were determined by the DANP. In terms of the relative weights of criteria for evaluating green suppliers in Table 12, the 10 prioritized criteria were: hazardous substances (C_3), product content restrictions (C_6), wastewater and solid waste (C_4), pollution prevention and resource reduction (C_2), air emissions (C_5), environmental permits and reporting (C_1), legal and customer requirements (C_9), performance objectives with implementation plan and measures (C_{11}), risk assessment and risk management (C_{10}), and corrective action process (C_{16}). The results show that majority of the 10 prioritized issues fall within the environmental dimension. Moreover, hazardous substances (C_3) and product content restrictions (C_6) are rated as the top two criteria in the selection of green suppliers. This finding is fully supported by Hsu and Hu [10]; their study pointed out that competency in the management of hazardous substances is crucial in supplier selection since suppliers will be asked to demonstrate that their products conform to the RoHS directive, particularly in the electronics industry. Current management measures regarding the use of hazardous substances in the electronics industry require suppliers to implement and acquire the IECQ QC 080000 HSPM system certification for managing hazardous substances in products and processes. A study conducted by Morose, Shina, and Farrell in 2011 [76] revealed the global initiative of the electronics industry to utilize lead-free materials in the production of printed circuit boards, particularly in those intended for use in electrical and electronic equipment. Considering the significant weights of the criteria, managers should select the best and appropriate suppliers through the VIKOR method in the proposed MCDM model.

Table 9. Unweighted supermatrix based on the DANP.

	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	0.267	0.362	0.369	0.368	0.358	0.360	2.084	0.313	0.316	0.374	0.332	0.353	0.327	0.288	0.292	0.304	0.334
C_2	0.331	0.315	0.379	0.378	0.367	0.379	2.149	0.332	0.325	0.381	0.345	0.352	0.332	0.307	0.314	0.312	0.343
C_3	0.345	0.401	0.335	0.400	0.383	0.399	2.262	0.346	0.342	0.407	0.366	0.367	0.343	0.313	0.327	0.329	0.357
C_4	0.348	0.400	0.408	0.337	0.382	0.398	2.273	0.349	0.346	0.411	0.356	0.377	0.352	0.323	0.333	0.332	0.367
C_5	0.335	0.386	0.390	0.376	0.312	0.384	2.184	0.333	0.326	0.396	0.352	0.360	0.333	0.300	0.324	0.320	0.347
C_6	0.342	0.394	0.399	0.398	0.383	0.339	2.255	0.353	0.350	0.412	0.367	0.378	0.350	0.320	0.341	0.346	0.364
C_7	0.303	0.347	0.348	0.344	0.334	0.352	2.027	0.268	0.321	0.360	0.329	0.343	0.317	0.297	0.303	0.308	0.324
C_8	0.368	0.417	0.425	0.428	0.412	0.430	2.481	0.388	0.328	0.440	0.395	0.422	0.391	0.370	0.378	0.380	0.396
C_9	0.374	0.427	0.435	0.431	0.422	0.433	2.522	0.380	0.380	0.379	0.404	0.407	0.376	0.362	0.360	0.375	0.399
C_{10}	0.316	0.362	0.369	0.362	0.351	0.370	2.130	0.320	0.317	0.375	0.290	0.357	0.320	0.306	0.312	0.318	0.341
C_{11}	0.315	0.368	0.365	0.368	0.350	0.372	2.137	0.333	0.333	0.374	0.342	0.303	0.329	0.312	0.315	0.317	0.340
C_{12}	0.278	0.313	0.320	0.322	0.310	0.320	1.863	0.285	0.292	0.327	0.296	0.309	0.242	0.273	0.265	0.270	0.287
C_{13}	0.282	0.318	0.321	0.324	0.311	0.329	1.886	0.303	0.310	0.350	0.318	0.328	0.303	0.238	0.293	0.292	0.306
C_{14}	0.285	0.331	0.328	0.334	0.325	0.333	1.936	0.310	0.317	0.347	0.314	0.331	0.293	0.297	0.247	0.288	0.309
C_{15}	0.300	0.345	0.352	0.355	0.341	0.356	2.050	0.315	0.315	0.368	0.330	0.347	0.311	0.298	0.304	0.259	0.321
C_{16}	0.312	0.366	0.367	0.376	0.362	0.374	2.158	0.324	0.334	0.386	0.347	0.361	0.334	0.316	0.330	0.328	0.295
C_{17}	0.314	0.350	0.374	0.370	0.356	0.372	2.137	0.325	0.328	0.384	0.341	0.348	0.322	0.300	0.314	0.309	0.352

Table 10. Weighted supermatrix based on the DANP.

	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	0.047	0.057	0.057	0.057	0.057	0.055	0.055	0.055	0.056	0.055	0.055	0.056	0.054	0.054	0.054	0.053	0.055
C_2	0.064	0.054	0.066	0.065	0.066	0.064	0.063	0.062	0.064	0.064	0.064	0.063	0.061	0.063	0.063	0.063	0.061
C_3	0.066	0.065	0.055	0.066	0.066	0.065	0.063	0.063	0.065	0.065	0.063	0.064	0.062	0.062	0.064	0.063	0.065
C_4	0.065	0.065	0.066	0.055	0.064	0.064	0.063	0.064	0.064	0.064	0.064	0.065	0.062	0.063	0.064	0.064	0.065
C_5	0.064	0.063	0.063	0.062	0.053	0.062	0.061	0.061	0.063	0.062	0.061	0.062	0.060	0.062	0.062	0.062	0.062
C_6	0.064	0.065	0.065	0.065	0.065	0.055	0.064	0.064	0.064	0.065	0.065	0.064	0.063	0.063	0.065	0.064	0.065
C_7	0.056	0.057	0.057	0.057	0.057	0.057	0.049	0.058	0.057	0.056	0.058	0.057	0.058	0.059	0.057	0.055	0.057
C_8	0.056	0.056	0.056	0.056	0.055	0.057	0.058	0.049	0.057	0.056	0.058	0.059	0.060	0.060	0.057	0.057	0.057
C_9	0.067	0.066	0.067	0.067	0.067	0.067	0.065	0.065	0.057	0.066	0.065	0.066	0.067	0.066	0.067	0.066	0.067
C_{10}	0.059	0.059	0.060	0.058	0.060	0.059	0.060	0.059	0.060	0.051	0.059	0.059	0.061	0.060	0.060	0.059	0.060

Table 10. *Cont.*

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
C11	0.063	0.061	0.060	0.061	0.061	0.061	0.062	0.063	0.061	0.063	0.053	0.062	0.063	0.063	0.063	0.062	0.061
C12	0.058	0.057	0.056	0.057	0.056	0.057	0.058	0.058	0.056	0.056	0.057	0.049	0.058	0.056	0.056	0.057	0.056
C13	0.051	0.053	0.051	0.052	0.051	0.052	0.054	0.055	0.054	0.054	0.054	0.055	0.046	0.056	0.054	0.054	0.052
C14	0.052	0.054	0.054	0.054	0.055	0.055	0.055	0.056	0.054	0.055	0.055	0.053	0.056	0.047	0.055	0.056	0.055
C15	0.054	0.054	0.054	0.054	0.054	0.056	0.056	0.056	0.056	0.056	0.055	0.054	0.056	0.055	0.047	0.056	0.054
C16	0.059	0.059	0.059	0.060	0.059	0.059	0.059	0.059	0.059	0.060	0.059	0.058	0.059	0.059	0.058	0.050	0.062
C17	0.055	0.054	0.054	0.054	0.053	0.054	0.055	0.055	0.055	0.055	0.054	0.054	0.054	0.053	0.054	0.057	0.046

Table 11. Influential weights of stable matrix of DANP.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
C1	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
C2	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
C3	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
C4	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
C5	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
C6	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064
C7	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
C8	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
C9	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
C10	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
C11	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
C12	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
C13	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
C14	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
C15	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
C16	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
C17	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054

Table 12. Local and global weights of criteria.

Dimension and Criteria	Local Weights	Global Weights	Rank
D_1	0.395		**2**
C_1	0.055	0.148524	6
C_2	0.063	0.170006	4
C_3	0.064	0.172141	1
C_4	0.064	0.171497	3
C_5	0.061	0.165730	5
C_6	0.064	0.172103	2
D_2	0.605		**1**
C_7	0.057	0.089744	12
C_8	0.057	0.090071	11
C_9	0.066	0.104083	7
C_{10}	0.059	0.093706	9
C_{11}	0.061	0.097216	8
C_{12}	0.056	0.089565	13
C_{13}	0.053	0.084159	17
C_{14}	0.054	0.086153	15
C_{15}	0.055	0.086726	14
C_{16}	0.059	0.092954	10
C_{17}	0.054	0.085624	16

4.4. Evaluating the Green Performance of Suppliers Using VIKOR

After the weights of the criteria were determined using the DANP, the VIKOR method was used to evaluate the environmental performance of suppliers (Table 13). In this study, five suppliers for the electronics company profiled in the case study were assessed in terms of their environmental performance based upon the 17 identified criteria. Given the ease of applying the proposed model to the case company used in this research, the v value of VIKOR was set to 0.5, based on both maximum group utility and individual regret in expert opinions. As R_i represents the gap between the alternative and the ideal solution, S_3 contains the smallest gap in terms of the value of VIKOR, followed by S_1, S_4, S_5, and S_2. The sum of these values for each alternative is provided in Table 13, which shows that S_3 is the most suitable supplier.

Table 13. VIKOR results.

Dimension	Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
D_1	C_1	0.00000	0.05865	0.00000	0.00000	0.05865
	C_2	0.00000	0.06713	0.00000	0.03357	0.03357
	C_3	0.00000	0.06797	0.00000	0.03399	0.06797
	C_4	0.00000	0.06772	0.00000	0.00000	0.06772
	C_5	0.00000	0.06544	0.00000	0.00000	0.06544
	C_6	0.00000	0.06796	0.00000	0.00000	0.06796

Table 13. *Cont.*

Dimension	Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
	C_7	0.00000	0.05431	0.00000	0.02715	0.05431
	C_8	0.00000	0.05450	0.00000	0.02725	0.05450
	C_9	0.00000	0.06298	0.00000	0.03149	0.06298
	C_{10}	0.02932	0.05670	0.00000	0.02835	0.05670
	C_{11}	0.00000	0.05883	0.00000	0.02941	0.05883
D_2	C_{12}	0.00000	0.05420	0.00000	0.02710	0.05420
	C_{13}	0.00000	0.05093	0.00000	0.02546	0.05093
	C_{14}	0.00000	0.05213	0.00000	0.02607	0.05213
	C_{15}	0.00000	0.05248	0.00000	0.02624	0.05248
	C_{16}	0.00000	0.05625	0.00000	0.02812	0.05625
	C_{17}	0.00000	0.05181	0.00000	0.02591	0.05181
S_j		0.02932 (2)	1.00000(5)	0.00000(1)	0.37012 (3)	0.96643 (4)
R_j		0.02932 (2)	0.06797(5)	0.00000(1)	0.03399 (3)	0.06797 (4)
Q_j		0.230362 (2)	1.00000(5)	0.00000(1)	0.435058 (3)	0.983217 (4)

5. Discussion

Despite the growing interest evident in the previous literature concerning the selection of green suppliers, there are limitations on the integration of environmental performance standards from the EICC Code of Conduct in the evaluation and selection of suppliers in the electronic supply chain. The EICC Code has been widely adopted by companies in the assessment of social responsibility and the environmental performance of their operational sites and those of their suppliers [77]. The EICC Code covers five areas of ethics: environmental conditions, labor standards, worker health and safety, and management systems. This is consistent with the findings of Ekener-Petersen and Finnveden [78]; the ICT industry is working to address environmental and social responsibility concerns, for example through the EICC and the Global e-Sustainability Initiative (GeSI). Considering the situation for environmental conduct based on the EICC Code of Conduct as it applies to green suppliers, the proposed framework of 17 criteria from real cases is an obvious advantage for electronic firms in assessing environmental performance in accordance with their buyers' requirements.

According to the empirical study in Section 4, our proposed hybrid MCDM model could provide more relevant results. The DANP technique is beneficial to firms preferring to complete the questionnaire within one 17 × 17 matrix, instead of using the DEMATEL with ANP methods, which requires two types of questionnaires. This evidence was reinforced through discussion with the five managers from the case company, in which they indicated that the DANP was easy to implement in determining the weighting and causal relationships between green performance criteria. As shown in Figure 2, the criterion of management accountability and responsibility (C9) is rated as the number one priority in helping managers with their decision-making regarding suppliers and improving upon the importance given to the weightings of the DANP criteria. For example, in this study, hazardous substances (C_3) and product content restrictions (C_6) were regarded as the top two criteria for evaluating green suppliers. This evidence is consistent with the study of Hsu and Hu [10]; the problem of hazardous substances for supplier selection is crucial in green supply chain management since the Restriction of Hazardous

Substances (RoHS) directives were passed by the European Union (EU). Suppliers have to meet minimum requirements in order to be eligible to work with the focal firm in the supply chain [18]. Finally, the VIKOR method is applied to select appropriate green suppliers and to analyze gaps in the desired level of green performance for each supplier. This can help managers devise strategies for effectively minimizing gaps in the green performance of potential suppliers.

As noted previously, discussions of the empirical results from the DANP with managers from the case company have focused mainly on collaborative initiatives with suppliers for improving their environmental performance. The case company has launched capability-building programs by directly engaging management and employees of suppliers to help build green management competencies. The emerging results in this study are fully supported by the Supplier Development theory of Krause and Ellram [79]; any effort by the buying firm to increase the performance and/or capabilities of the supplier and to meet the buying firms' short and/or long terms supply needs is supported. Development in the field of operations management and supply chains has been recognized as a strategic management approach to help organizations maintain a competitive advantage [80–82]. Given the growing environmental concerns in supply chain management, green supplier development programs [12,83–85] have been initiated. As pointed out by Fu, Zhu and Sarkis [84], companies make their supply chains greener not only by selecting existing green suppliers, but also by assisting their suppliers with green initiatives designed to improve business and competitive performance.

6. Conclusions and Future Research

To facilitate a green supply chain in the electronics industry, a supply chain-based conceptual framework and operational model incorporating environmental management into the selection of suppliers has been presented. By identifying the related criteria of environmental management activities for the proposed framework, a hybrid MCDM model integrating the DANP and VIKOR methods for selecting green suppliers was applied to a sample electronics company.

Compared to the content of previous literature, the proposed framework makes several contributions to the evaluation and selection of green suppliers. First, a novel hybrid MCDM model for evaluating green suppliers, with emphasis on environmental performance and management systems, was developed. This was based mainly on the EICC CoC. Such a framework with 17 criteria based upon an actual case study is rarely described in earlier literature. Second, the DEMATEL method was applied in selecting suppliers and proved to be an appropriate method for delineating the structure of a completely interdependent supplier selection problem model and for obtaining the a solution to that problem. Third, the DANP was used to provide considerable weighting to the 17 criteria. The top two criteria, namely identification of hazardous substances and product content restrictions, were derived. The advantage of the DANP for companies is that the complex, huge and time-consuming comparison matrix of the ANP is avoided. DANP modeling serves as a new and simpler method offering insights to managers in selecting suppliers systematically. Finally, an empirical study was conducted to demonstrate the application of the hybrid MCDM model combining the DANP with the VIKOR method. This proposed model considers both maximum group utility and individual regret to measure the gaps between alterative and ideal solutions, thereby strengthening the ability to conduct environmental performance assessments of suppliers in spite of a lack of quantitative information. Based on the results from the case study, this model demonstrates a potential advantage in selecting appropriate suppliers based on environmental performance.

Although the results obtained from this research are satisfactory, there is still room for improvement. The proposed model of environmental management and management systems is derived mainly from the EICC Code of Conduct; the other aspects of ethics, health and safety, and labor should be further incorporated into the selection and evaluation of sustainable suppliers. The outcomes concerning the environmental performance of suppliers using the hybrid MCDM method in this study were determined exclusively by five managers of the case company. Increasing the number of participating experts from the electronics industry would provide a more generalized model of supplier carbon management. In response to the preference of decision-makers in assigning precise numerical values, fuzzy DANP and fuzzy VIKOR methods could be applied in future research.

Author Contributions

Tsai Chi Kuo and Jie-Ying Li designed the research; Tsai Chi Kuo and Jie-Ying Li performed the research; Jie-Ying Li and Chia-Wei Hsu collected and analyzed data; Tsai Chi Kuo, Chia-Wei Hsu, and Jie-Ying Li wrote the paper; finally, Chia-Wei Hsu revised the paper. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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