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A business strategy selection of green supply chain management via an analytic network process☆

Chiau-Ching Chen [a], Hsu-Shih Shih [a,*], Huan-Jyh Shyur [b,1], Kun-Shan Wu [c,2]

[a] Graduate Institute of Management Sciences, Tamkang University, Tamsui, New Taipei 25137, Taiwan, ROC
[b] Department of Information Management, Tamkang University, Tamsui, New Taipei 25137, Taiwan, ROC
[c] Department of Business Administration, Tamkang University, Tamsui, New Taipei 25137, Taiwan, ROC

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ABSTRACT

This study designates green supply chain management (GSCM) strategies to effectively direct business functions and activities in the electronics industry. Enterprises conduct environmental scanning to understand the external environment and internal functions; a successful strategy identifies unique firm-owned resources and transforms them into capabilities. This study proposes a network to clarify managerial levels and firm-related content. It derives four business functions from product lifecycle management: design, purchasing, manufacturing, and marketing and service—and associates their related activities with "greenness". These functions and activities are a network's clusters and elements in an analytic network process (ANP) model with dependent relations. A detailed procedure solves complex GSCM strategy-selection problems and evaluates the most important activity in each business function. A case study takes a leading Taiwanese electronics company to identify the proposed procedure's stability.

1. Introduction

Environmental deterioration and global warming have prompted public concern over sustainability and environmental issues. In response to increased worldwide attention on the overall conditions of natural resources and the environment, several countries have adopted regulations such as the Restriction of Hazardous Substance in Electrical and Electronic Equipment (RoHS), Waste Electrical Electronic Equipment (WEEE), Eco-design Requirement for Energy Using Product (EuP), etc. Such legislation forces manufacturers to decrease pollution during the whole production process [1,2]. It is especially applicable for the electronics industry, with its rapid technology development, consumers' desire for the newest products, shorter product life-cycles, and indirect e-waste. Since hazardous materials are the greatest concern in electronics products, this study develops a green strategic selection guideline to aid company decisions.

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* Corresponding author. Tel.: +886 2 8631 3221; fax: +886 2 8631 3214.
E-mail addresses: 895620077@webmail.tku.edu.tw (C.-C. Chen), hshih@mail.tku.edu.tw (H.-S. Shih), shyur@mail.im.tku.edu.tw (H.-J. Shyur), kunshan@mail.tku.edu.tw (K.-S. Wu).
1 Tel.: +886 2 2621 5656x2881; fax: +886 2 2620 9737.
2 Tel.: +886 2 26215656x3374; fax: +886 2 2620 9742.

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Many manufacturers have adjusted their manufacturing philosophies and introduced environmental programs into their organizations. Through social and environmental responsibility (SER), some firms proactively recognize the urgency of environmental protection and have integrated environmental goals into their corporate strategies. Xerox and IBM have set up environmental criteria to manage end-of-life (EOL) products or to appraise their value. Sony has required all related suppliers to follow Green Partner Activities since 2001, and has improved its own green management efforts [3].

With rapid international business development, firms with relatively limited resources must outsource some business functions or operations, or purchase raw materials or components/sub-components from other suppliers to establish an interrelated supply-chain network. To advance their environmental performance, they must monitor their own operations and coordinate with other partners in their supply networks, including material suppliers, manufacturers, distributors, users, and so on. Supply-chain managers consider both traditional performance criteria and environmental criteria, or GSCM [3]. Taiwan's electronics manufacturing companies, such as Original Equipment Manufacturing (OEM) and Own Branding & Manufacturing (OBM), are essential players in the global supply chain and now proactively realize GSCM. An investigation of green businesses will be beneficial to them and the environment as well.

A literature review of GSCM yields studies linking green, environmental, or sustainable concepts to traditional supply-chain management, demonstrating how GSCM practices, definitions, and decision frameworks affect business operations [4–6]. Most studies emphasize reduction, re-manufacturing, recycling product design, process design, manufacturing practices, procurement, and some mixture of items across managerial levels. Integrating environmental concepts into these business functions ameliorates environmental pollution. However, a more elaborate and organized analysis allows efficient implementation of GSCM strategy.

Poole and Simon [7] suggested life-cycle analysis as a method of examining the overall environmental impact of a product. Kurk and Eagna [8] also extracted environmental attributes from each phase of a product's lifecycle, including raw-material extraction, product manufacturing, packaging and transport, use and service, and final disposal.

Few studies until now have emphasized developing GSCM strategies from an overall organizational perspective. Handfield et al. [9] observed the increasing importance of supply-chain strategy as management increasingly adopts environmental practices. Effectively achieving corporate green goals means linking an environmental corporate strategy with every business functional strategy, thus eliminating obstacles to environmental integration. Decision-makers should appropriately modify the contents and aims of environmental practices to match changes in business development. Many companies have just begun exploring environmental concerns and implemented environmentally-friendly activities, so they have not yet identified many environmentally-related factors. Rethinking the relationships between each factor of environmental practices is therefore necessary.

Key ingredients for a successful corporate strategy depend on whether resources or capabilities are rare, durable, or difficult to imitate. This study extends this concept, utilizing the product lifecycle management (PLM) viewpoint to choose business functions related to this process (design, purchasing, manufacturing, and marketing and service), and constructing a fundamental decision-making framework for "green" practices.

Past studies use MCDM approaches to analyze environmental problems [10,11]. This study chooses a single network of analytic network process (ANP) [12] to address the problem for several reasons. First, AHP and ANP are appropriate analytical tools for addressing locations, programs or strategy-selection problems, such as choosing an ideal location, program, or strategies [13–16]. Second, ANP permits a suitable analytical model to evaluate suppliers and minimize potential risks [17–19]. Third, ANP's more structured network not only helps decision makers understand the problem more clearly [20,21] but also saves more time than normal discussion without an organized process. It focuses the dependent and feedback relations among factors in the network, so that the dominance of influence among stakeholders, alternatives, criteria, and other specific elements is organized to mimic the actual decision-making environment. Finally, a single network maintains group focus on internal relationships and influences between core influential factors (main business functions).

Section 2 discusses key business functions, the factors of each function, and alternatives. Section 3 proposes a systematic ANP procedure and Section 4 demonstrates a case study with sensitivity analysis. Finally, the study draws conclusions and indicates directions for future research.

2. Literature review

To establish an adequate analytical network, this paper reviews green management perspectives, clarifies their definitions, and surveys the influential factors of each function based on the stages of PLM: green design, green purchasing, green manufacturing, and green marketing and service. Then, it examines GSCM strategy.

2.1. Green management perspective

Van Hoek [22] believed a business should face up to environmental issues and create competitive advantages through green initiatives. He used three approaches in green management [23]: reactive, proactive, and value-seeking. Noci [24] initially involved the green perspective in the supplier-selection process and divided corporate green strategies into reactive and proactive types. The former requests that suppliers only defer to regulators, while the latter expects suppliers to assist

Table 1
Types of green management perspectives and their characteristics.

Green management perspective	Characteristics
Proactive innovation	1. Raise the green management capabilities and then become part of the corporate strategy 2. Strengthen green management performance through innovation
Active integration	1. Outer: develop cooperative relations with partners in the supply chain 2. Inner: incorporate environmental programs with other business functions
Receptive learning	1. Introduce environmental initiatives non-spontaneously 2. Take a benchmark (organization) as a model
Reactive response	1. Behave in conformity with environmental regulations 2. Obey customers' environmental instructions

in green-product development and to align with any environmental requirements from the firm. Newman and Hanna [25] showed four continuous stages of a firm's environmental awareness: (i) reactive, (ii) receptive, (iii) constructive, and (iv) proactive.

In accordance with these classifications, this study suggests that a firm estimate situations to determine how many resources to invest in green management, allowing a strategic green attitude to develop GSCM strategies. Table 1 proposes four distinct green management perspectives and explains their characteristics.

2.2. Green design

During the design stage, the new product development (NPD) team usually determines the most essential material selection, production procurements, package design, and energy usage. These all influence the primary costs and profits of the new product and affect its environmental impact in each life-cycle phase [26]. Considerations include design-for-environment (DfE), eco-design, life-cycle design (LCD), or green design [8,27]. Some environmentally-friendly firms also design for disassembly, reuse, and recycling (DfDRR), because this "design for" concept not only enables the product and its components to be easily reused, remanufactured, or recycled at the end of its lifetime (EOF), but also helps to easily separate and replace electronic parts with longer life expectancies [28,29].

Although many companies have introduced DfE and DfDRR programs and modified new product designs toward environmental protection, conflicts exist between green requirements and traditional product performance (speed and convenience). Therefore, companies need innovations that balance between green considerations and practical functions, developing green products with multiple objectives [30]. Green design organizations should possess DfE concepts and control the following key factors: (i) abstaining from utilizing toxic substances, (ii) saving energy, (iii) complying with DfDRR principles, and (iv) increasing innovation capabilities.

2.3. Green purchasing

Companies traditionally see the purchasing function as playing a supportive role in achieving business objectives. However, many organizations introducing green programs have observed that green purchasing significantly eliminates waste, and therefore firms can re-evaluate the purchasing function to improve green management performance. In other words, companies do perceive the importance and strategic influences of green purchasing [31].

Green purchasing means focusing more on environmentally-conscious practices, including reducing resources, eliminating waste, recycling and reuse, purification, and substituting materials without affecting material property [32–34]. A firm implementing green purchasing can establish environmental standards in its purchasing policies for suppliers that involve supplier selection, evaluation, and relation development [32–34]. Some studies explore vendor selection from environmental managerial perspectives to qualitative and quantitative considerations [35]. This study claims that any organization conducting green purchasing should rate alternative suppliers according to the following three crucial factors: (i) green competencies, (ii) green image, and (iii) green management abilities.

2.4. Green manufacturing

As mentioned previously, green design outcomes affect sequential stages across the entire supply chain, but they rely on green manufacturing techniques and processes. Manufacturing processes consume a lot of energy acquired from burning various natural resources, such as coal, coke and natural gas, and combustion causes air pollution [36]. Electronics technology generates a large amount of waste. Previous green-manufacturing studies mainly discuss enhancing current production processes or techniques to decrease the generation of toxic matter [21,37,38].

Almost all current green-manufacturing studies explore two directions: (1) supplying a greener source of energy and saving energy via new technologies; and (2) extending the life-cycle of pollutants and wastes, and increasing the production

efficiency via new processes [36]. To sum up, successful green manufacturing should master four key factors in the production process: (i) the amount of energy and resource utilization; (ii) the green degree of energy; (iii) the amount of hazardous waste; and (iv) the number of reuses of hazardous waste.

2.5. Green marketing and service

Consumers experience the effect of global warming and climate change, and respond by reevaluating what they buy. These "green consumers" adjust their living habits and assess the green attributes of a product or service through their purchases. For example, green consumers save electric energy, recycle paper, return bottles or cans, and buy more environmentally-friendly products [39].

Green marketing emphasizes green characteristics during sale or promotion of products and services, and highlight reduced environmental destruction [40]. Green marketing should evolve into a strategic activity, including manipulating STP (segmenting, targeting, and positioning) and 4P (product, price, place, and promotion) activities, greening logistics, and developing green alliances [41]. Ginsberg and Bloom [39] reminded managers implementing green marketing strategies to continuously interact with internal and external customers, and then accumulate credibility for the products and services their companies create. A successful approach to green marketing and services requires organizations to: (i) make good use of information and communication technology tools, (ii) disclose environmental information of products and services, and (iii) apply extended producers' responsibility.

2.6. Green supply chain management strategy

Past studies have largely discussed and classified green manufacturing strategies or environmental strategies according to attitudes that companies hold toward green management. The simplest strategies are proactive and reactive [24]. After observing the ways that different industries "green" their supply-chain activities and how developing supply-chain relationships influences resources accumulation and varied performance outcomes, Simpon and Samon [42] proposed a broad range of strategies for GSCM. Depending on the degree of resource commitment and the complexity, their approach used risk-based strategy, efficiency-based strategy, innovation-based strategy, and closed-loop strategy.

(1) Risk-based strategy

Companies choosing this GSCM strategy invest minimal organizational resources in green management and ask their suppliers to comply with environmental requirements. Although some international environmental rules are difficult to refer to, it is the simplest GSCM strategy compared to other types. This strategy's ultimate goal is risk-minimization by passively accomplishing environmental programs.

(2) Efficiency-based strategy

Compared to the risk-based strategy above, this strategy is more complicated due to efficiency improvement through specific approaches. It not only allows for increased economic benefits, but also waste reduction and efficient resource use. Hence, environmental programs in this strategy type are primarily directed at firms to simultaneously reduce cost, meet operational optimization, and decrease environmental degradation.

(3) Innovation-based strategy

This strategy type guides companies to develop products from product life-cycles, enact stricter environmental requirements upon their suppliers, and even trains them to adjust operational processes to follow the newest environmental regulations. As a result, the innovation-based strategy forces companies to invest more resources and cultivate innovative capabilities for green management.

(4) Closed-loop strategy

This is the most complicated GSCM strategy. It links environmental performance to the entire supply chain. The simplest form is the closed-loop strategy: taking back materials produced from any production processes and end-of-life products and disposing of them. However, it requires much effort to be highly-integrated, cooperate with many parties, and develop specialized knowledge and technology. Therefore, this approach is the final goal for firms wishing to execute green management completely.

After reviewing green management perspectives, green business functions, and green supply-chain management strategies, the elements and their influences are organized as the core of the analysis structure for further development.

3. Proposed procedure for GSCM strategy selection

Because green strategies, regulations, and related activities are implicitly expressed in previous research, this study clarifies managerial levels and firms' related contents and directs a strategy-selection problem. It further proposes a systematic decision-support procedure. Two types of questionnaire clarify the influential dimensions and their factors, and gauge intensity among the manipulated factors. After obtaining the limiting priorities regarding the factors, the study executes a sensitivity analysis to guarantee a robust decision. The proposed procedure is easier to follow than Saaty's brainstorming [12] for tracing criteria and their interactions in a systematic way. The detailed procedure is presented as the following seven steps and in the flowchart (Fig. 1).

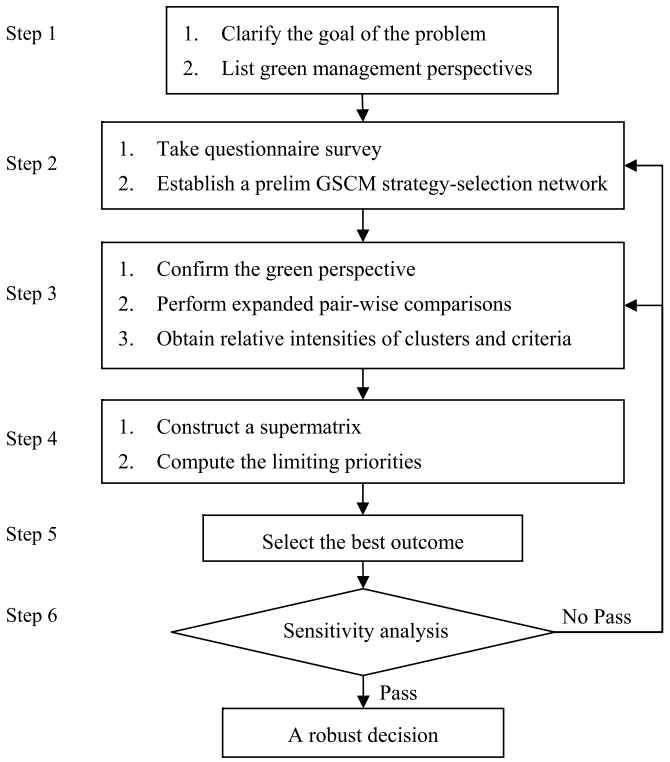

Fig. 1. Flowchart of the proposed approach.

Step 1: Clarify the goal of the problem and list different green management perspectives.

The first step of problem-solving is to identify the problem and detect the circumstance under which it occurs. Here, the problem is choosing suitable green strategies for an organization. The decision-makers consider inner and outer factors, including political, economical, and social development, and the risks the companies could face. These factors influence the company's green management direction. A similar concept also exists in the ANP, which is the control hierarchy. It assists decision makers in thinking about the spread of influence to all relevant factors. If the influencing relations are complicated, then it considers sub-criteria associated with the hierarchy.

Step 2: Take a questionnaire survey from experts to establish a preliminary GSCM strategy-selection network.

After identifying the objective, establish a network to represent the problem. The problem's structure is smaller, but relevant, and has precise pieces for ease of management [43]. Such a network probably considers the uncertainty and situations that will occur. Therefore, a questionnaire survey from experts helps subdivide the problem into several dimensions and establishes an appropriate set of network clusters and their elements, which are relevant to the control hierarchy.

As mentioned previously, it is possible to build group clusters in the analytical network according to green business functions derived from the PLM perspective, and elements included in each cluster with the literature review. Hence, the original framework was developed on the basis of the literature review; the researchers designed the first questionnaire and emailed it to the experts to collect their modifications to revise the definition of each cluster and criterion and confirm the relationships between each cluster to enhance the workability and practicability of the GSCM strategy-selection network.

Step 3: Confirm the green management perspective, perform expanded pair-wise comparisons, and obtain priorities of the clusters and their element in the network.

Researchers employed another questionnaire, Saaty's fundamental scale, to aggregate experts' opinions concerning how important or dominant one element is over another with respect to the criterion that compares them [44]. These opinions are realized by pair-wise comparisons to obtain a ranking of priorities. The survey illustrates the work in three stages: (i) check environmental activities performed in the company and then verify the green management perspective according to the characteristics of each green management perspective (Table 1); (ii) make pair-wise comparisons among related clusters which are judged by experts; and (iii) deal with the interactions, including outer dependence among clusters and inner dependence among elements, conduct further

pair-wise comparisons between the elements of any two clusters by experts to get priorities represented by the ratio scale. In the third step, this will be zero when there is no influence or interaction, which is an extra questionnaire beyond the analytic hierarchy process. All reciprocal matrices should pass the consistency check, whose value is less than 0.1.

Step 4: Construct a supermatrix and compute the limiting priorities.

Arrange all priority vectors, representing the impact of a given set of elements in a cluster on another element in the network, from the previous step as sub-columns of the corresponding column of an unweighted supermatrix, $\boldsymbol{W}$. Here, $\boldsymbol{W}$ is composed of k clusters (i.e., $\{C_1, C_2, \ldots, C_k\}$) and linkages of these clusters $\boldsymbol{W}_{ij}$, where $C_k = \{e_{k1}, e_{k2}, \ldots, e_{kn}\}$ are the elements of the cluster k,

$$\begin{array}{c} \\ \boldsymbol{W} = \end{array} \begin{array}{c} \begin{array}{cccccccccccc} & C_1 & & & & C_2 & & & \cdots & & C_k & \\ & e_{11} & e_{12} & \cdots e_{1n} & e_{21} & e_{22} & \cdots e_{2n} & \cdots & e_{k1} & e_{k2} & \cdots e_{kn} \end{array} \\ \begin{array}{cc} & e_{11} \\ & e_{12} \\ C_1 & \vdots \\ & e_{1n} \\ & e_{21} \\ C_2 & e_{22} \\ & \vdots \\ & e_{2n} \\ & \vdots \\ \vdots & e_{k1} \\ & e_{k2} \\ C_k & \vdots \\ & e_{kn} \end{array} \begin{bmatrix} W_{11} & & W_{12} & \cdots & W_{1k} \\ & & & & \\ & & & & \\ & & & & \\ W_{21} & & W_{22} & \cdots & W_{2k} \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ \vdots & & \vdots & & \vdots \\ W_{k1} & & W_{k2} & \cdots & W_{kk} \end{bmatrix} \end{array}, \tag{1}$$

where

$$\boldsymbol{W}_{ij} = \begin{bmatrix} W_{i_1 j_1} & W_{i_1 j_2} & \cdots & W_{i_1 j_{nk}} \\ W_{i_2 j 1} & 1W_{i_2 j_2} & \cdots & W_{i_2 j_{nk}} \\ \vdots & \vdots & \cdots & \vdots \\ W_{i_{ni} j_1} & W_{i_{nk} j_2} & \cdots & W_{i_{ni} j_{nj}} \end{bmatrix}.$$

If there is no linkage between clusters C_a and C_b, then $\boldsymbol{W}_{ab}$ equals zero. Each column of the unweighted supermatrix is then normalized and synthesized to account for the overall clusters' influence by column, and this operation makes the supermatrix's column stochastic, known as a weighted supermatrix $\boldsymbol{W}^a$. Afterwards, the limiting supermatrix $\boldsymbol{W}^n$ can be obtained with almost identical elements column-wise following this equation.

$$\boldsymbol{W}^n = \lim_{a \to \infty} \boldsymbol{W}^a. \tag{2}$$

The derived weights weight the elements of the corresponding column blocks of the weighted supermatrix. Two types of outcome are possible. One can obtain limiting priorities by multiplying the weighted supermatrix by itself n times until the columns stabilize [45]. The limiting priorities are the corresponding column values to each cluster and their elements.

Step 5: Select the best outcome.

The limiting supermatrix provides the priorities' information for the elements of each individual cluster. The strategy outcome with the highest value should be selected from the cluster of alternatives. Other priorities ranking in the different clusters are also provided.

Step 6: Execute sensitivity analysis on the final outcome (to ensure the stability of the model).

Sensitivity analysis shows how the optimal solution responds to changes in the input parameters or elements in the network. It systematically changes the elements' input parameters to see if the final selection is stable. One particular consideration is whether these changes alter the order of the final outcome by ANP [12].

Model validation verifies whether the model is sufficiently valid or credible [46]. Because the GSCM is a new issue with a broad spectrum, this study exerts sensitivity analysis by checking the strategy selection, with respect to possible inputs, to see if it fits top management's company strategy. The proposed validation step may generate some important study in the future.

The quantitative results derived from ANP can indicate the ranking of elements included in each cluster. The decision makers thus should realize the most important activity and view it as the starting point to carry out green programs, or combine other compatible and important activities of other business functions to support the decision-making process. After defining the comprehensive steps, this study demonstrates the procedure by an example.

4. Case study

Company *X* is one of Taiwan's leading electronics Original Equipment Manufacturing (OEM)/Own Branding & Manufacturing (OBM) companies. Its total revenue in 2007 was more than US$23 billion and it became a Fortune 500 company. As environmental concerns are increasing in the EU, Company *X* had to obey related rules and legislation to make sure their products could be sold in European countries. It discovered, however, that the cost of some green activities owing to legal controls would affect its high-profit achievement. To simultaneously adapt to social environmental concerns and remain sustainable, top management decided to adjust its profit goal and become a corporation devoted to the community, committing itself to social responsibilities. As this kind of transformation is very difficult, Company *X* needed to investigate how many environmental-related programs to implement in the organization and to understand the "green" degree of each core business function. Therefore, decision-makers organized a steering committee, built Green IT systems, and put DfE concepts into the design process for manufacturing environmental-friendly electronics products. It also disposes of EOF products and increases energy efficiency to reduce environmental degradation. The company still endeavors to enhance its green management capabilities, to become one of the most green electronics technology firms in the world, and to develop a better GSCM strategy to contribute to earth's environmental sustainability.

This study targets both key managers related to the green programs of Company *X* and some outside experts, hoping to assist Company *X* in confirming the best GSCM strategy. Since the relations are quite vague and complex, ANP can evaluate tangible and intangible factors and represent relations by a dependence and feedback network. ANP can thus help Company *X* choose the appropriate GSCM strategy.

Step 1: Clarify the goal of the problem and consider which green management perspective is similar to Company *X*'s real situation.

The problem is to choose a suitable GSCM strategy for Company *X*. The control hierarchy involves green management perspectives. The PLM identifies four business functions – design, purchasing, manufacturing, and marketing and service – and their related "green" activities. These functions and activities under strategies are organized into clusters and elements of the network, respectively.

The proposed model includes the upper control level (the goal and the control hierarchy of the firm), and the lower network level consisting of five clusters: green design, green purchasing, green manufacturing, green marketing and service, and GSCM strategies. Company *X* should confirm its green strategic attitude and then arrange other parts in the network level in sequence.

Step 2: Conduct a questionnaire survey from experts to establish a preliminary GSCM strategy-selection network.

To determine a network with the proper breadth and depth, this study asked five experts from inside and outside the company for their opinions via a questionnaire. Part A of the survey corrects the definition of each cluster, and Part B asks experts' opinions about the relationships between each cluster (Appendix A). Fig. 2 illustrates the proposed network after organizing their opinions and confirming the validity of the GSCM strategy-selection network.

Step 3: Confirm the green management perspective, perform expanded pair-wise comparisons, and obtain relative priorities of the clusters and their elements in the network.

The second questionnaire identifies the intensity and dependence relations among the clusters and criteria (Appendix B). Part A confirms Company *X*'s green management perspective; Part B and Part C are pair-wise comparisons between clusters and elements.

After querying five key managers responsible for planning and implementing green programs in the company, confirming that their green management perspective is proactive innovation, this study used Saaty's 1–9 fundamental scales to make pair-wise comparisons. The number of questions, other than AHP's, increased dramatically to check many dependent relations. Each matrix is measured by the inconsistency ratio (C.R) and then passed the check.

Step 4: Construct a supermatrix and compute the limiting priorities.

After checking the consistency of each pair-wise comparison from the above five managers, this study calculates the geometric mean of individual judgments to specify the group judgments for each pair-wise comparison [47]. Next, it inserts the priorities derived from the paired comparisons into the corresponding positions of the unweighted supermatrix (Eq. (1)). Then, it derives the weighted supermatrix by multiplying each block in the unweighted supermatrix by the corresponding cluster weight (Table 2). Finally, this study multiplies the weighted supermatrix by itself until all the columns of the matrix are identical and then obtains a limiting supermatrix (Eq. (2)),

$[D1, D2, D3, D4, P1, P2, P3, M1, M2, M3, M4, K1, K2, K3, A1, A2, A3, A4]^T = [0.0243, 0.0498, 0.1119, 0.0301, 0.0275, 0.1891, 0.0720, 0.0231, 0.0373, 0.0424, 0.0341, 0.0129, 0.0215, 0.0478, 0.0428, 0.0186, 0.1402, 0.0746]^T$.

Table 3 shows an abbreviated explanation of the five clusters and their 18 elements.

Step 5: Select the best outcome.

The normalized priorities of the four GSCM strategies captured from Table 4 are 0.1550, 0.0674, 0.5076, and 0.2699, respectively. The ideal mode sets the highest priority at one and rearranges the rest in proportion. The result

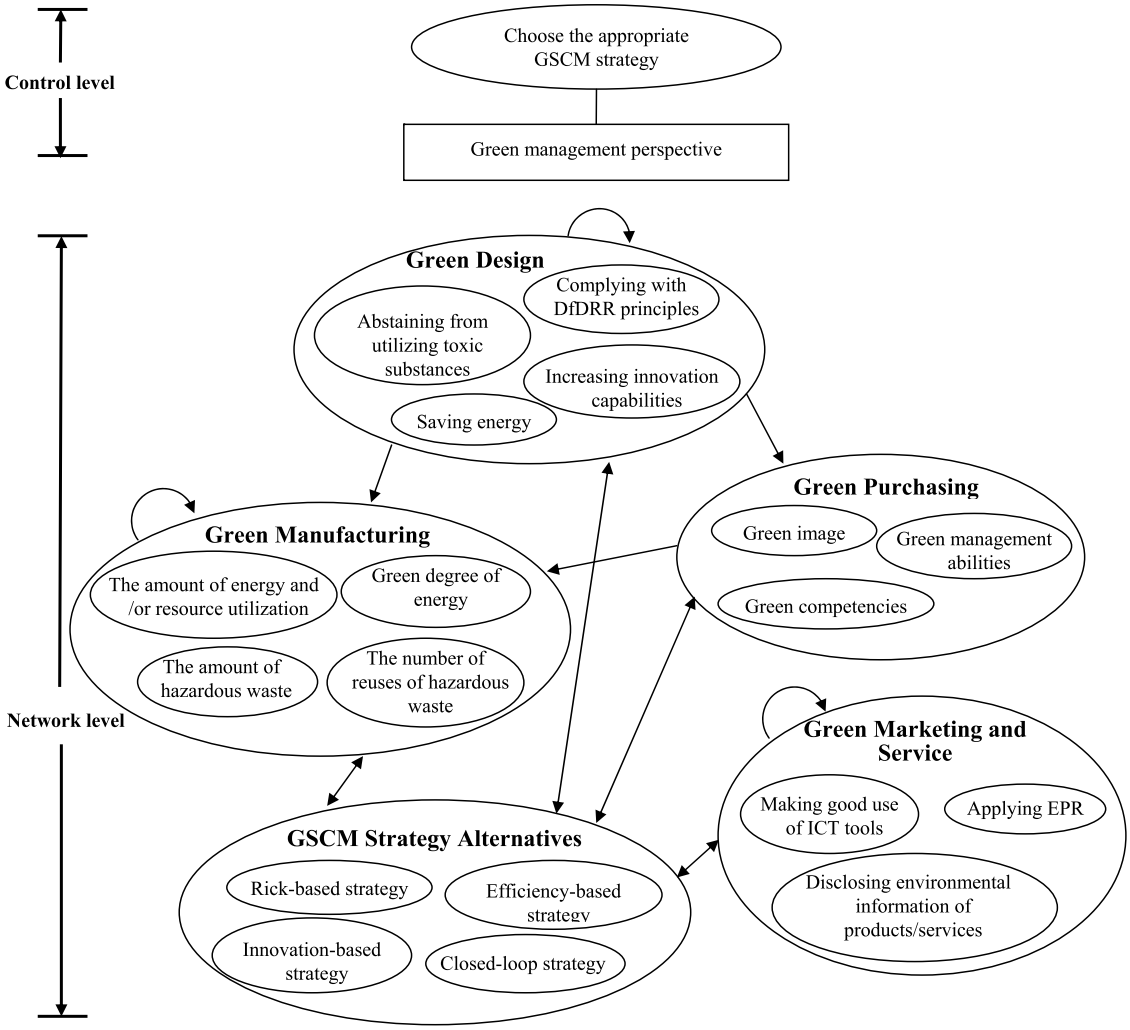

Fig. 2. The GSCM strategy-selection network.

Table 2
The cluster weights of the analysis.

	Green design	Green purchasing	Green manufacturing	Green marketing and service	GSCM strategy
Green design	0.27582	0.00000	0.00000	0.00000	0.48955
Green purchasing	0.10967	0.75000	0.00000	0.00000	0.18599
Green manufacturing	0.05722	0.25000	0.20000	0.00000	0.15640
Green marketing and service	0.00000	0.00000	0.00000	0.25000	0.16806
GSCM strategy	0.55729	0.00000	0.80000	0.75000	0.00000

shows that the innovation-based GSCM strategy is most suitable for Company *X*. In addition, the priorities of other elements in each cluster (i.e., green design, green purchasing, green marketing and service, and green manufacturing) are also advisable for the company.

Step 6: Execute sensitivity analysis on the final outcome to ensure the model's stability.

The sensitivity analysis is to understand if any parameter is more important in altering the final result. This study individually chooses one element and one cluster with higher priority for analysis.

6-1 *Criteria of the green design cluster*:

The priority of "green competencies", which is the highest priority in the limiting supermatrix, is increased and decreased by 10%–50%, respectively, but does not affect the overall rank of the green strategy much (Fig. 3).

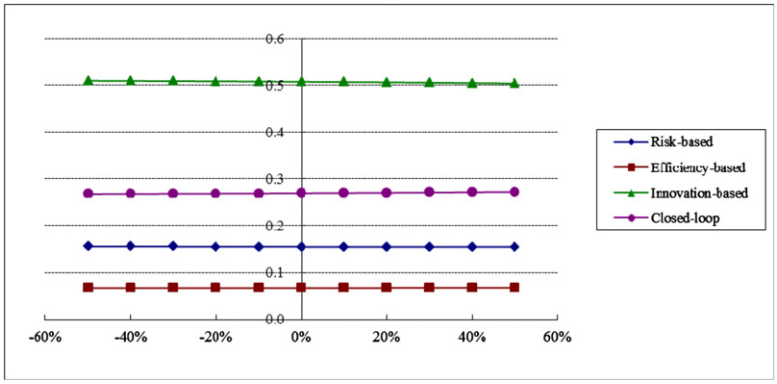

Fig. 3. Sensitivity analysis w.r.t. the change of the weight of "green competencies" of green purchasing. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Explanation of abbreviations.

$D1$	Abstaining from utilizing toxic substances
$D2$	Complying with DfDRR principles
$D3$	Increasing innovation capabilities
$D4$	Saving energy
$P1$	Green image
$P2$	Green competencies
$P3$	Green management abilities
$M1$	The amount of energy and/or resource utilization
$M2$	Green degree of energy
$M3$	The amount of hazardous waste
$M4$	The number of reuses of hazardous waste
$K1$	Make good use of ICT tools
$K2$	Disclose environmental information of products and services
$K3$	Apply EPR
$A1$	Risk-based strategy
$A2$	Efficiency-based strategy
$A3$	Innovation-based strategy
$A4$	Closed-loop strategy

Table 4
The overall results of the analysis.

GSCM strategy (alternatives)	Ideal	Normal
Risk-based	0.3054	0.1550
Efficiency-based	0.1328	0.0674
Innovation-based*	1.0000	0.5076
Closed-loop	0.5317	0.2699

6-2 *The cluster of green design*:

This study also increases and decreases the priority of the "green design" cluster by 10%–50%, respectively. The "innovation-based strategy" is still best for the company (Fig. 4).

Finally, this study uses the quantitative result of ANP analysis to draw a strategic coordinate graph (Fig. 5). First, it spreads four business functions on the four quadrants and places activities of the individual function in proper sequence according to their priorities obtained from the limiting supermatrix (the further "out" the position, the more important the activity).

The appropriate GSCM strategy for Company X is still the innovation-based strategy. The most important factor in the green design is thus innovation capabilities, and a company implementing green purchasing should understand the green competencies of each qualified supplier. In green manufacturing, the company should endeavor to decrease the amount of hazardous waste, and in green marketing and service, the company should apply extended producer responsibilities such as buying or taking back their products.

5. Discussion

One of the key components of a successful strategy is a thorough understanding of the competitive environments, especially during dynamic and unstable times. Using PEST (political, economic, social, and technological) analysis of the

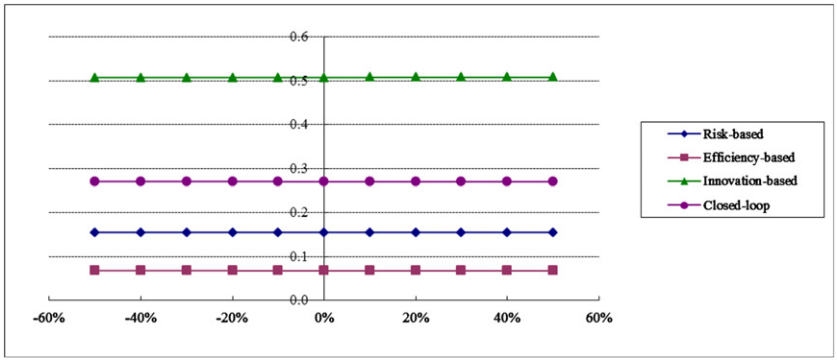

Fig. 4. Sensitivity analysis w.r.t. the change the weight of "green design". (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

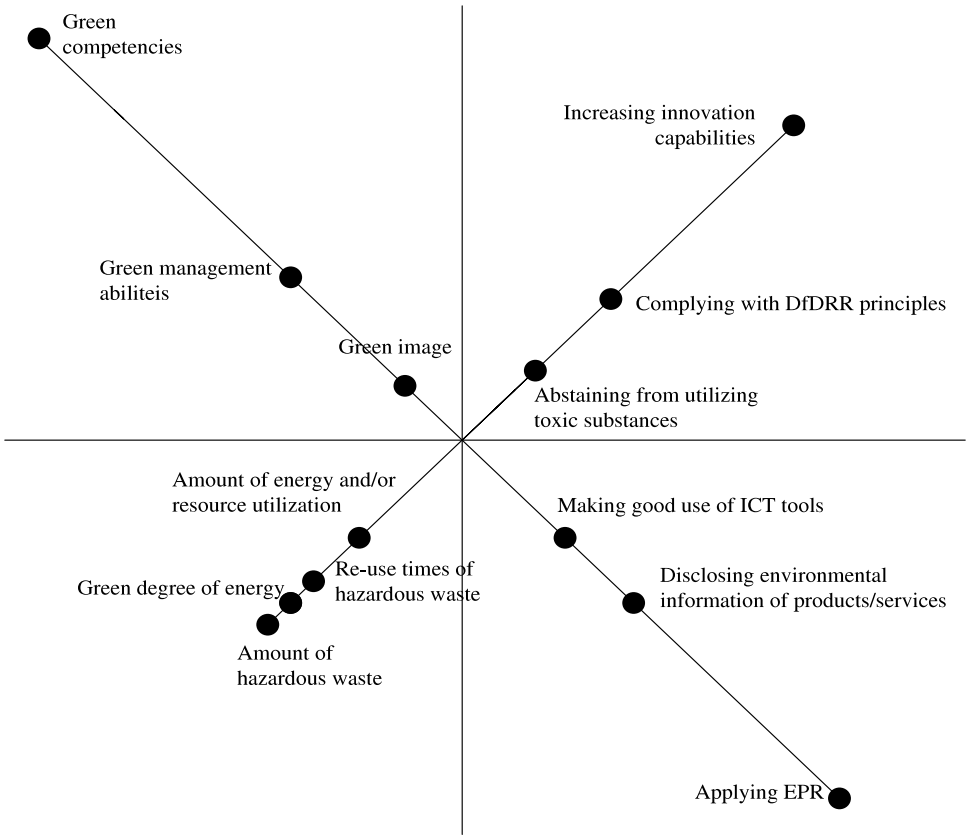

Fig. 5. Coordinate graph of each activity of the four business functions.

firm's external environment, this systematic framework could help firms monitor changes in the macro-environment. After assessing industry attractiveness, the firm can consider which industry is better or more suitable to invest in, helping form a corporate strategy for the firm. Top management should then identify the industry's competitiveness. Porter's "five-forces" analysis allows decision makers to understand the dynamics and relationships existing in the industry, and therefore to choose the best competitive strategy. Though strategic competitive analysis is the most widely utilized, it lacks an internal-factors analysis. Therefore, many companies use SWOT (strength, weakness, opportunity, and threat) analysis to self-assess competitive advantage.

This study uses a single ANP network with strategic thinking to provide a guideline for the electronics industry on how to choose an appropriate GSCM strategy and achieve an effective green management. Saaty's ANP methodology [12] is a popular MCDM technique that could help decision-makers to clarify the problem. It can classify criteria and alternatives

into each cluster, presented the relationships between each cluster by one-way or two-way arrows. Through this network, decision-makers may clearly understand a complex problem in a systematic way [21]. The ANP network is composed of two parts: (i) the upper lever is a control hierarchy or network, including the goal and control criteria, which affect the pair-wise calculations in the second part; and (ii) clusters and their interactions, which form a network of influence. After a series of pair-wise comparisons and calculations based on the network, the final limiting supermatrix yields the priorities [48,49].

For the components of the analytical network to be more practical and easier to understand for companies, this study uses PLM to investigate critical stages in the present procedures of most organizations. First, a firm must formulate a plan for the product or service it provides. "Design" is the core: designers or design departments of companies encompass DfE concepts as much as they possibly can to avoid using hazardous chemicals and to reduce costs that result from wastewater and solid waste disposal. Bhat [29] pointed out that an intelligent company should view green design as an approach to improve the competitiveness of its products. Second, because a large number of materials or parts are necessary to make up a product or to become a part of a service, companies should select sound suppliers to ensure the materials and components they buy satisfy environmental regulations, helping prevent hazardous substances from being created throughout the production process. Therefore, "purchasing" is another essential segment of the whole procedure. "Marketing and service" describe how a firm delivers finished goods to the market or a service to the consumer to attract consumers. As the electronics firm this study explores is involved in the manufacturing industry, "manufacturing" is the last and prerequisite function to take into consideration. To sum up, our analytical network defines "green design", "green purchasing", "green manufacturing", and "green marketing and service" as the main clusters of the network, and the remaining cluster is the "GSCM strategy", which presents four choices for decision-makers to choose.

As mentioned previously, if organizations want to choose an appropriate GSCM strategy, top management could refer to the results from several comprehensive analyses with a balance between short-term and long-term profits in business operations. The case company confirmed that the green management thinking is proactive, and the appropriate GSCM strategy presented in the final result is "innovation-based strategy". Companies utilizing the "innovation-based strategy" should possess professional environmental expertise and integrate specific relevant green activities, such as green design, green procurement to improve current processes, and product developments. In general, this strategy is more suitable for companies very concerned about environmental issues, which must invest some money or manpower into internal environmental improvement and promotion programs. One advantage of utilizing the ANP technique is to effectively evaluate which cluster and which factor are most important for achieving the chosen GSCM strategy in accordance with the green management perspective.

Empirical study demonstrates the effectiveness of the proposed model. Sensitivity analysis shows the optimal strategy to be robust. The rank of each GSCM strategy is very stable regardless of an increase or decrease in the priorities of one major element of the green manufacturing cluster, within a change of $\pm 50\%$ of the original priority value. The final step validates the workability of the model. After such analysis, the company under study has a clear understanding of how business functions affect the GSCM strategy selection, and which one is more critical than others. If Company X chooses the innovation-based strategy, then the key elements of each business function are: "increasing innovation capabilities" in green design, strengthening "green competencies" in green manufacturing, decreasing "the amount of hazardous wastes", and "applying extended producer responsibility" in green marketing and service from the graph-based analysis. Therefore, top management can allocate resources according to the weight of each element in the four business functions. For example, "green design" and "green manufacturing" could be key development departments. "Innovation" and "hazardous waste reduced" are the most influential factors of the two business functions from the analytical model. Therefore, when top management decides to implement the GSCM strategy, they should increase the innovation capabilities of the staff in the design or R&D department, demand that they know the manufacturing procedures, and discuss innovative and feasible ways to cut the amount of e-waste with colleagues in the manufacturing department. If the business and competitive environments change, then the decision makers can also adjust their GSCM strategy to respond to such changes. In addition, the procedure has potential application for any other electronics manufacturer in choosing an appropriate environmentally-friendly strategy to direct future management.

6. Conclusions

ANP is an appropriate technique to process an unstructured problem by considering mutually influential factors. It deals with tangible and intangible factors and represents the relations of dependence and feedback. Its result is stable through input changes and the convergence of the limiting supermatrix provides an advantage over other tools.

This study focuses on a green strategy selection for industry from the internal environment viewpoint. One could further consider external factors, such as social, legal, political, and regulatory factors, and establish the BOCR network for an elaborate analysis. It can also be extended to other activities, such as supplier selection, by adding more clusters in the network. The precise formulations of a real-world problem and well-established networks are difficult work. Although the results from the questionnaire survey can clarify the relations, efforts to investigate dependent and feedback relations in the network are cumbersome, and thus consistency in their judgments may not be enough. A systematic procedure might identify dependence relations among the clusters and their elements in the future. Therefore, it is important to revise the analytical procedure through other quantitative methods (i.e., ISM [50]) to simplify the dependence relations among the clusters and their elements more precisely.

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Appendix A

Questionnaire I

Part A

Definitions of influential clusters and their criteria for GSCM strategy selection

1. Definitions of clusters

	Extremely Disagree ⟷ Extremely Agree				
	1	**2**	**3**	**4**	**5**
(1) Green Design: Considering DfE and PLC concepts in product design stage	□	□	□	□	□
【Revised suggestions】					
	Extremely Disagree ⟷ Extremely Agree				
	1	**2**	**3**	**4**	**5**
(2) Green Purchasing: Establishing a series of environmental standards in purchasing policies for greening suppliers	□	□	□	□	□
【Revised suggestions】					

2. Definition of criteria

〈Green Design〉	Extremely Disagree ⟷ Extremely Agree				
	1	**2**	**3**	**4**	**5**
(1) Abstaining from utilizing toxic substances: Didn't choose harmful raw materials for production	□	□	□	□	□
【Revised suggestions】					

Part B

Confirmation relationships between each cluster considering GSCM strategy selection	**Y**	**N**
1-1 Green design affects Green purchasing	□	□
1-2 Green design affects Green manufacturing	□	□
1-3 Green design affects Green marketing and services	□	□
1-4 Green design affects GSCM strategy	□	□
2-1 Green purchasing affects Green design	□	□
2-2 Green purchasing affects Green manufacturing	□	□

Appendix B

Questionnaire II

Part A

Confirmation of green management perspectives

Comparing each characteristic of every green management viewpoints with environmental activities performed, and verifying green management perspectives proposed by your company.

	Green management perspectives	**Characteristics**
□	Proactive innovation	Raise the green management capabilities and then become part of the corporate strategy
		Strengthen green management performance through innovation

Part B

According to the green management perspective of your company, please make pair-comparisons on dimension for choosing the appropriate GSCM strategy

Q1：In green design dimension, please make pair-comparisons on each cluster

Cluster	Intensity																	Cluster
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Green design	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Green purchasing
Green design	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Green manufacturing
Green design	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	GSCM strategy
Green purchasing	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Green manufacturing

Part C

According to the green management perspective of your company, please make pair-comparisons on factors for choosing the appropriate GSCM strategy

Q1-1：In abstaining from utilizing toxic substances factor, please make pair-comparisons on each criteria

Criteria	Intensity																	Criteria
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Abstaining from utilizing toxic substances	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Complying with Df DRR principles

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