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Abstract

Purpose – In this study, an optimal green product is selected from three newly developed ecological products and a non-environmentally friendly product. An analytic network process (ANP), used widely for multi-criteria decision making (MCDM), is applied to account for the tradeoff issues among the criteria (quality, cost and green issue) in the new green product selection processes. The paper aims to discuss these issues.

Design/methodology/approach – This paper focuses on current social and consumer requirements. New product selection processes consider three major perspectives, i.e., quality, cost and environment, as criteria. The following two main methods are applied to respond to this multi-disciplinary issue: the eight quality dimensions proposed by Garvin are used to manage the quality issue, and a life cycle costing (LCC) method is applied for consideration of the cost and green issue. Therefore, the dependency issue among the criteria is considered, using a suitably selected method, the ANP method, and all the methods are applied to a real business, which produces roof tiles, for the delivery of a new optimal green product.

Findings – An optimal environmentally friendly product does not overcome the existing toxic product of the focused company. The environmental performance is necessarily balanced by the quality and cost capabilities.

Research limitations/implications – This paper focuses on the new product selection of roof tile products. The criteria or measuring indicators may be dissimilar, and cannot be applied to other products.

Practical implications – The proposed approach can be applied to other manufacturing companies or services to allow decision makers to make better determinations for a comprehensive dependency problem. The managers can apply the proposed model to benchmark the considered products as well as to find the weaknesses of products.

Originality/value – This method considers the relationship among quality, cost and environment for newly developed green products. The method produces better results than former MCDM studies which did not account for the dependency issue among the criteria.

Keywords Green product, Multi-criteria decision making, Product quality, Life cycle costing, Analytic network process

Paper type Research paper

1. Introduction

During the past several decades, intensive competitiveness in the manufacturing industry has been highly influenced by the customers' awareness of quality issue. This competitiveness implies that manufacturers who are not continually improving the quality and specifications of their products run a high risk of becoming outdated. Nevertheless, this concentration on quality can only be assumed because successful business philosophies accept no tradeoffs between quality and cost. Traditionally,

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better quality automatically produces higher costs. An enhancement in quality generally arises for several reasons, such as using higher quality material, increasing operating costs, etc. However, in real terms, the business management budget is typically limited. Therefore, manufacturers who focus on improving product quality and ignore the incremental costs that exceed the purchasing ability of consumers cannot compete with other manufacturers or sustain their businesses. Thus, concentration on both quality and cost has become critical considerations for businesses. Nevertheless, since the end of 1980s, the low-cost strategies and quality differentiation strategies have not been sufficient for sustainable competition in the intense marketplace anymore (Reed, 2003). The emerging issue of green consciousness has become increasingly critical, which has imposed additional constraints, especially on new product launching.

Therefore, environmental awareness is now a crucial management issue; moreover, environmental awareness is recognized as a managerial issue for improving corporate brands (Chan, 2001). Hence, currently, several organizations concentrate on green product development. Nevertheless, a single environmental focus does not lead to business success, similar to a single quality or a cost concentration. Traditionally, green products or environmentally friendly products incur higher costs and/or lower product quality. Therefore, when a manufacturer needs to decrease costs, it will negatively affect the quality of the product and its environmentally friendly capability. The higher price issue may be unavoidable because of several additional costs; however, this environmentally friendly product may not lead to a gain in the market share (Graviria, 1995). For reasons similar to those outlined, several studies agree that a positive outcome for financial performance is unlikely to be associated with ecological proactivity (e.g. Link and Naveh, 2006; Molina-Azorín *et al.*, 2009). Furthermore, the ecological benefits of the green concept may be counteracted by a reduction in quality. Therefore, green products that are only concerned with environmental issues and disregard the incremental costs that exceed the purchasing ability of consumers or the competitive quality of the products would negatively affect the success of the business. Moreover, Berger (1993) indicated that although consumers intend to respond to green awareness, they do not compromise on quality and price. Therefore, this tradeoff issue must be considered during this complex decision-making process. To survive, an organization must consider the cost, quality and green issue as a group, and optimize these considerations with the aim of providing advantages for all interested parties, including customers, manufacturers and the environment, before launching a new green product into the marketplace. Therefore, the decision method used for selecting a new green product must completely complement this complicated tradeoffs problem.

This study investigated a real business, a roof tile manufacturer, and the company wanted to launch a new product into the market. As previously argued, in this current competitive market, concentrating on quality in new product selection is no longer adequate. Financial and environmental issues must also be considered with the quality perspective to focus on the current comprehensive requirements of customers. Therefore, to achieve and sustain the business, in this study, the decision processes will focus on the following question: what appropriate decision method should be applied in the firm to optimize all concerned aspects? Hence, to answer the question, this study will apply the correct decision method considering the dependency issue and will assess the environmental, financial and qualitative aspects simultaneously. The remainder of this study is divided into six main sections. In the first section, related studies are reviewed. The second step briefly describes all the related methods. Next, a framework of this study is described, and a case study application of the proposed approach is analysed. In the remaining sections, the outcome of the study is discussed, and the conclusions are outlined.

2. Literature review

This section explores relevant studies classified into three domains: a measurement of quality, cost and environment of product, simultaneous consideration on quality cost and environment and analytic network process (ANP)-based benchmarking and decision-making.

2.1 A measurement of quality, cost and environment of product

Currently, business organizations are confronted with highly competitive and complex circumstances. Firms seriously attempt to protect and expand their volume and market share. Therefore, to stimulate revenue in this intensive competitiveness, the new products that match to the current requirements of customer must be delivered into the market, and several empirical studies identified that a green product contributes to a firm's competitive advantage by bringing new customers as well as fresh revenue (Nassimbeni, 2003; Chiou *et al.*, 2011). Nevertheless, the green product that brings environmental advantage is still required to concentrate on typically marketable issues; those of quality and cost. Peattie (2001) concluded that several customers are unwilling to tradeoff product quality for environmental ability. Zhou and his colleagues presented that consumers' preference is still mostly influenced by cost of product (Zhou *et al.*, 2009).

In the past, business organizations aiming to be business leaders could concentrate simply on the quality of the products because, in those days, product quality was recognized as the primary strategy for business achievement. Therefore, the improvement of quality was a major consideration in business organization (Foster and Sjoblom, 1996). Over the last century, several quality tools and methods have been developed such as control chart, Pareto chart, cause-and-effect diagrams, quality function deployment (QFD), zero defects approach, total quality management, Six Sigma, ISO9000, etc. Although several quality tools and methods have been proposed over the past century, quality experts have rarely defined an appropriately-comprehensive definition of quality. One of explicit and comprehensive definitions of quality was proposed by Garvin (1987). He defined quality into eight critical dimensions, composing of performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality. Since Garvin's method provides the approach to measure the quality of product, therefore, this quality measurement method can comprehensively assess the quality of considered product. In this study, this approach is selected to deal with the quality measurement.

Although quality is respected as the critical concentration in business competition, however, it is not adequate for the current intensive market anymore (Reed, 2003). Moreover, the previously mentioned quality tools and methods are monotonic, since they concentrate only on quality considerations. The quality methods and tools assume that there are no tradeoffs between quality and other aspects. Nevertheless, typically, there are relationships as well as tradeoffs between quality and cost. Normally, higher quality produces higher costs. Quality enhancement can be achieved from the input of high-quality materials, the use of better equipment or machines and from hiring more labour (Feigenbaum, 1986). However, in a typical organization, the cost budget for achieving the quality target is limited (Tang *et al.*, 2002). Therefore, the primary concentration on product quality is still suspected with regard to its value creation potential (Hendricks and Singhal, 1997) because a number of firms became bankrupt despite applying the quality management system (Vörös, 2006). Hence, whenever a manufacturer focuses only on improving the product quality but neglects the added cost and exceeds the affordability of the customers or suffers other unexpected consequences to its competitive ability, the sellable capability may be reduced, and it will negatively affect the sustainability of the business.

Since the weakness of monotonic was realized, many researchers adopted the quality tools and methods, combined with cost considerations, to strengthen organizational competitiveness. Feigenbaum (1986) integrated quality and costs by accounting for the overall cost of quality and deficiencies. Several researchers applied the quality costs approach and identified the tradeoffs issue between quality and cost (Fine, 1986; Carillo and Gaimon, 2000). However, most studies that applied the cost theory with the quality method generally considered only the present value of the cost. This present cost is only a portion of the overall costs or life cycle costs and is too narrow and specific. Therefore, in the last three decades, many researchers suggested life cycle cost or the life cycle costing (LCC) analysis because of its potential advantages to organizations competing in globally intensive markets. LCC can deliver crucial benefits to organizations including: enhancing the evaluation of product profitability; improving the capability of pricing considerations; and increasing the effectiveness of planning (Gulch and Baumann, 2004). Therefore, in the last several years, LCC has been applied for various objectives, such as to analyse the general life cycle cost, to select an alternative and to select new construction materials (e.g. Ehlen, 1997; Wong *et al.*, 2003). However, the original LCC still concentrates solely on the financial perspective and ignores environmental issues (Gulch and Baumann, 2004); hence, only this approach cannot bring a marketable product for manufacturers.

Since the late 1980s, it has been recognized that a cost-focused strategy and quality differentiation strategy are insufficient considerations for competing in a globally intensive market (Reed, 2003) because the green product has become another critical managerial consideration (Chan, 2001). There are several meanings of green product, but one of clear definition is defined by Reinhardt (1998): "the product that provides greater environmental benefits, or that imposes smaller environmental costs, than other similar products". He defined that green products are the products with lower ecological impact as well as greater environmental benefits compared to other commercial products. Several researches indicate that green product can bring several advantages to organizations. Green products contribute to increasing customer loyalty (Forte and Lamont, 1998) and enable companies and societies to achieve environmental sustainability (Huang and Wu, 2010). For these reasons, several methodologies have been improved to focus on green or environmental issues. However, there is one highly applied environmental method that considers the entire life cycle of the product, similar to LCC, that is the life cycle assessment (LCA). The LCA was identified as a useful tool for evaluating the performance of the products and their environmental impact and to achieve the goals of the company for green product development (Chan *et al.*, 2010). Nevertheless, similar to the LCC, the LCA specifically revolves around a single perspective unless its ecological dimension is considered. Therefore, as previously mentioned, companies cannot focus only on green considerations and neglect the issue that increasing costs may exceed the affordability of customers or the competitive capability of firms because this may have a negative impact and lead to an unsustainable business. Because LCA and LCC exhibit specific functions, several studies have adopted the cost consideration of the LCC together with environmental consideration of the LCA to strengthen their business performance, and to make their products more marketable. Many studies have separately applied the LCC associated with the LCA (Kosareo and Ries, 2007; Luo *et al.*, 2009), whereas several studies considered the tradeoff dependency among them by integrating the LCC with LCA to facilitate their studies (Kloepffer, 2008; Yu-rong *et al.*, 2009). Although, the integration of the LCC and LCA better improved the business approach, nevertheless, these two methods were not completely integrated because of the dissimilarity in their points of view and measuring units. Therefore, because of several potential advantages of LCC over LCA, such as: the cost is normally considered a reliable indicator of resource consumption, the cost is an easy way to assess the environmental effects and the data acquisitions and calculations of LCC are easily obtained, hence, Emblemsvåg and Bras (2000) initiated an improved LCC by consolidating the original LCC with an environmental cost following the LCA approach. The final output of the improved LCC is easy to understand because the outcome is shown in monetary units, similar to the original LCC. Therefore, in this study, the Emblemsvåg and Bras LCC approach is used to consider the life cycle of the product in terms of cost and environment.

2.2 Simultaneous consideration on quality, cost and environment

The literature review revealed that a small number of studies and methodologies simultaneously concentrated on the cost, quality and green issue of products along with the dependency issue. The green quality function deployment (GQFD) partially considers the quality and environmental issue. This method is an improvement on the original QFD because it integrates the QFD with the LCA to generate a more comprehensive tool (Cristofari *et al.*, 1996). Next, the GQFD has been continuously improved by adding the LCC, and this improved version is termed the GQFD-II (Zhang *et al.*, 1999). However, these comprehensive methods still do not consider the variety of ranges, or the units of the elements. Therefore, to account for the complicated issues, the multi-criteria decision making (MCDM) method was applied to handle the issues in GQFD and became the GQFD-III and the GQFD-IV. In the GQFD-III (Chetan and Ben, 2001), an analytic hierarchy process (AHP), a popular MCDM method, was used with the QFD to overcome the issue of the dissimilar LCA and LCC units and scales. The latest method, GQFD-IV, was developed using another MCDM, the fuzzy multi-attribute utility theory (FMAUT) method, to handle the costing issue because the FMAUT does not require the details of the manufacturing process and the processing data of the product. Nevertheless, even though the GQFD-III and GQFD-IV methods applied the MCDM to manage the dissimilarity in ranges and units, these improved methods still ignore the critical issue, which is the dependency among the considered issues. Therefore, to overcome the dependency problems, an appropriate method considering the relationship should be applied.

2.3 ANP-based benchmarking and decision making

Over the past few decades, a number of MCDM methodologies have been proposed (e.g. AHP, ANP, technique for order of preference by similarity to ideal solution; TOPSIS, elimination and choice expressing reality or elimination et choix traduisant la realité I; ELECTRE I, ELECTRE II, ELECTRE III, etc.). Some of the mentioned methods were applied for benchmarking (Ganguly and Guin, 2013; Singh and Kumar, 2013). Nevertheless, among the mentioned methods, the ANP is the only method that accounts for the dependency issue among considered factors (Sipahi and Timor, 2010). Because of this distinctive characteristic, the ANP was applied in several areas including a benchmarking domain. Bayazit (2006) used ANP in vendor selection decisions since his studied problem related to the multi-criteria supplier selection with interdependency issue. The ANP could suggest an optimal supplier and identify the priority and benchmark among the focused vendors. Perçin (2008) applied the ANP for selecting and benchmarking ERP systems. The study identified that the ANP is simple and flexible to evaluate ERP systems efficiently. Moreover, it can be a potential tool to organizations in ERP system selection decisions. At the same period, Kirytopoulos *et al.* (2008) used ANP for the selection of supplier in pharmaceutical industry. The ANP was applied to evaluate and select an optimal supplier. Moreover, the results of ANP were also applied for benchmarking the considered vendors.

In addition to benchmarking domain, the green consciousness was also studied along with the ANP application, even though the ANP that considered with the environmental issue was rarely studied. Zhu *et al.* (2010) developed the methodology to evaluate suppliers using the ANP and concentrated on the green factors. The outcomes indicated that the ANP was useful and versatile. Büyüközkan and Çifçi (2012) considered the green awareness among the automobile suppliers. The ANP was applied to account with the dependencies of green performance among considered vendors, and the best possible green supplier was identified by this proper decision method.

Because of the potential of dependency consideration, the ANP was used in other domains such as product development, performance measurement, project selection and others. Nevertheless, from the literature survey, no studies have adopted the ANP to prioritize or benchmark the products by considering on three dimensions that are cost, environment and quality aspects. The closest study (Lin *et al.*, 2010) applied the ANP for selecting suppliers by considering two dimensions; those of the product quality as well as the ecological awareness. Therefore, there is still no research applying the ANP to consider the quality, cost and environment. Hence, in this study, the ANP will be applied along with two stated methods, including LCC method of Emblemsvåg and Bras and eight quality dimensions of Garvin, and these proper methods will be examined in the coming section.

3. Methodology

The aim of this study is to construct a multi-criteria decision method considering the quality, cost and environmental dimensions concurrently for the selection of new green launching products. Therefore, the methods relating to this sustainably constructed framework consist of the classified product quality dimensions, the LCC which accounts for financial and environmental aspects and the ANP method. In this section, the related methods are described and the constructed framework will be discussed in next section.

3.1 Eight critical dimensions of quality

To measure the product quality of newly launching products, the appropriate criteria for assessment should be comprehensively identified to cover various dimensions of the product quality. Although the product quality is normally perceived as subjective recognition, it still requires representative items for quantification (Dunk, 2002). Hence, Garvin (1984) proposed a method to quantify product quality by bridging his concept with traditional consumer vantage points. Garvin describes eight critical dimensions of quality, described in Table I.

Dimension	Definition
Performance	The first dimension represents the primary characteristic of the product
Features	This dimension of quality refers to a secondary aspect of performances. However, the difference between the primary performance characteristics and the secondary performances is generally difficult to identify. The obvious points of differences are the features that rely on measurable characteristics and personal needs without prejudices
Reliability	This third element indicates the product's possibility for failure and malfunction over a specified period
Conformance	The conformance is the degree of operating characteristics that meets the design specifications or standards. This dimension is similar to the traditional quality approaches of quality experts
Durability	This dimension measures useful product life. Technically, durability is defined as the ability to endure or the usage ability of the product before it deteriorates and repair is impossible
Serviceability	This dimension refers to the ease, speed, courtesy and competence of the repair, service or installation
Aesthetics	A seventh dimension is subjective and involves individual judgement and personal preference
Perceived quality	This quality is generally represented by reputation, brand name, image or advertising rather than the product attributes. In addition, because the primary matter is based on reputation, this dimension is subjective

Table I.
Product quality dimensions and definition of Garvin's concept

The Garvin's method provides clear definitions of product quality, and the characteristics of Garvin's approach achieve to capture aspects of quality that are crucial for competitive success. Since this study aims to consider on three major perspectives that include product quality, therefore, the eight quality dimensions of Garvin properly match to the objective of this study. However, the eight quality dimensions of Garvin focus only on one dimension that is the measurement of product quality. Therefore, to perfectly select optimal product as the objective of this study, other methods considering on cost and environment must be accounted with the Garvin's concept.

3.2 LCC

Generally, life cycle is differentially divided into several perspectives, which are dependent on the decision maker. Normally, the typical dimensions of the life cycle consist of marketing, production, customer and product life cycle perspectives. However, the first three perspectives are generally perceived as the market life cycle, and these concepts only consider the private costs that directly impact a company's bottom line, ignoring the social responsible costs, whereas the product life cycle accounts for these costs Therefore, in this study, we selected an appropriate product LCC model following the Emblemsvåg and Bras (2000) approach, which can be adapted to additionally consider market life cycle issues. This life cycle model is composed of nine processes that can be depicted as Figure 1.

The upper half of Figure 1 depicts the processes typical of manufacturers who are familiar with these processes and focus on them routinely. In the past, the processes in the lower half of the figure were left to social responsibility; however, because of recent concerns for environmental awareness, manufacturers now also focus on the lower half of the figure. Moreover, these environmental-related processes require the proper strategies and the actions of the manufacturers depend on the company strategy.

For example, a number of firms must take back their products because of environmental and safety laws and regulations whereas others voluntarily take back their products because of their positive reputation. An alternative is to use a third party to take back the products. However, if these options are not used, the product will be discarded. Because the LCC model focuses on both the typical cost and the environmental cost, and as mentioned in the literature review, this method provides the outcome as a monetary unit, it is easily perceived and understood. Therefore, the LCC method will be applied to assess the cost and the environmental potential.

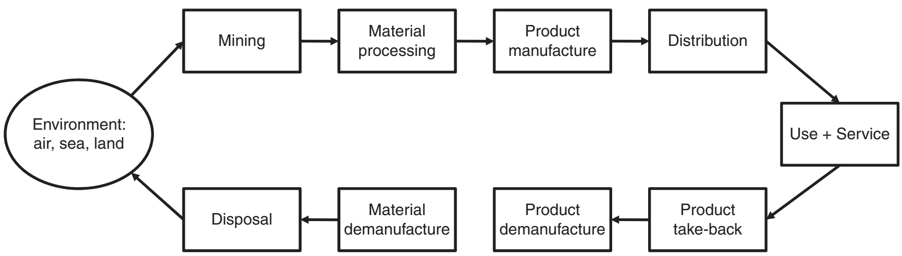
Nevertheless, the LCC method of Emblemsvåg and Bras still ignores another considered topic of this research, that is, product quality. However, the method accounting on product quality was already identified in the former section. Therefore, to apply both two selected methods, another concernment that must be considered in order to obtain an optimal new product is a tradeoff issue. Hence, the proper decision method that can account on tradeoffs and multi-criteria are being explored next.

3.3 ANP

The ANP is an improved version of the traditional AHP method. Typically, the AHP method assumes that there are no relationships within the clusters or between the cluster levels. Nevertheless, not all the decision problems can be completely formed into a hierarchal structure; moreover, the problems at management decision levels in particular usually involve interrelationships among the upper level elements and the lower level elements in a hierarchy because the AHP, which does not account for the dependency issue, is not suitable for interrelation problems. The ANP has been improved to overcome the weaknesses of the AHP method (Saaty, 2001). The ANP process can be separated into the following four main stages:

(1) Model the problem as a dependency network: the problem is transformed into a network model consisting of elements and clusters. Each element in a cluster can influence some or all of the elements of any other cluster, and this relationship is termed the outer dependence, represented by the arc connecting to the other elements in any other group. In contrast, a relationship among the nodes or elements within a cluster is termed the inner dependence and is represented by a looped arc.

(2) Calculating the priorities among the elements and establishing the original or unweighted supermatrix: the second step is concerned with prioritizing the elements among the inner elements and the outer elements. These priorities are obtained by making pairwise comparisons. To make a comparison,



Source: Emblemsvåg and Bras (2000)

Figure 1. Generic representation of a product life cycle.

the following generic question must be considered: how much more does one element influence another particular element over the other elements? The pairwise comparison process of the ANP is similar to the AHP. The relative importance scores of the compared elements are specified using a 1-9 scale.

(3) Calculating the priorities among clusters and establishing the weighted supermatrix: the supermatrix is constructed according to the dependency network model, and this matrix is processed to the new matrix, termed the weighted supermatrix. This matrix is obtained by identifying a cluster comparison to obtain a priority vector. The cluster comparisons represent the relative importance of influences between clusters. Next, the priority vector is obtained and it is multiplied to associate segments of the unweighted supermatrix.

(4) Calculating the limit supermatrix and obtaining final priorities: after the weighted supermatrix is acquired, it is changed to the limit supermatrix by raising it to powers until all entries converge. The final priorities of the elements can be acquired from corresponding columns in the limit supermatrix. Next, the highest priority alternative or the desired mix of alternatives is read.

In this section, the focused methods consisting of the eight quality dimensions of Garvin, the LCC of Emblemsvåg and Bras and the ANP are described. This multi-disciplinary approach is applied to the selection of a new green marketable product, which is preparing to be launched into the market by a real roof tile manufacturer. In the next section, a framework to construct and implement this study is described.

4. Research framework

To respond to the current trend of customer requirements, the quality, cost and environmental issues are incorporated simultaneously into the research framework. The proposed framework requires the appropriate methods to consider the various perspectives. According to literature reviews and methodology identification, three methods consisting of the eight quality dimensions of Garvin, the LCC of Emblemsvåg and Bras and the ANP are elaborately selected to overcome this comprehensive decision problem. These methods are the major components of the proposed framework, and the overall framework of this study can be separated into five main steps, as shown in Figure 2. The first stage addresses the product quality identification. The related key performance indicators (KPIs) are assigned to each quality dimension following the eight quality dimensions of Garvin. In this process, the firm needs to determine the relative indicators along with the measurement methods for each quality dimension. Each dimension can have more than one KPI, and the KPIs are specified by following the company's product standard and/or the nation's product standard. After the KPIs are identified completely, the firm needs to clearly specify the data acquisition in terms of

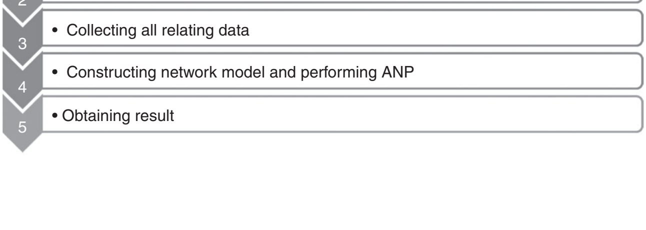


Figure 2.
A research framework for selecting a marketable green product

responsible persons as well as retrieval processes. Subsequently, in the second stage, the cost and environmental perspectives are quantified using the Emblemsvåg and Bras LCC approach. This consideration focuses on the costs and the environmental costs for the entire life cycle of each product, from the cradle to the grave. In this step, the firm must assess its own ability to collect and retrieve all the associated data because the scope of the Emblemsvåg and Bras LCC is quite extensive; moreover, this method relates the data simulation and the data estimation. Therefore, using these processes, the company absolutely requires massive resources to address the comprehensive and complicated data. After all the necessary processes for collecting the quality, cost and environmental cost data are completely identified, the third step begins: the collection of all identified data following the plan, which was determined by the first and the second steps. In the fourth step, the ANP approach is applied and the dependency network of the problem is constructed. Normally, following this framework, the main clusters are grouped into three clusters, product quality, LCC and alternative products. However, this network can be delicately constructed by separating the clusters into more than three groups, depending on the exhaustive requirements of the decision maker. After the network is completely constructed, the comparison and decision processes are performed following the ANP approach. In the last step, an optimal green product is obtained from the final priorities of the limit supermatrix from the previous step.

5. Application of research framework

This study was performed in a real company that manufactures roof tiles. The company plans to launch a new green product into the market as a substitute for outdated products and to stimulate the revenue of the company. However, the management requires that the new product selection approach must serve the current trend of customers' consideration of quality, cost and environmental issues. Therefore, the previously proposed framework is suitable for application to this issue. In this case, the company is developing three new green products that are in the research and development (R&D) stage. These products have not yet been chosen for launching into the market. Nevertheless, the product quality and the LCC data can be obtained from the quality-testing laboratory, from the accounting department and from the R&D department. However, for confidential reasons, some of the information has been concealed in accordance with a cooperative agreement. In this section, three new developing green roof products (P2, P3 and P4) are being examined along with one existing product (P1) to predict the different outcomes between environmentally unfriendly products and green products. The descriptions of these products are shown in Table II.

Product name	Product type	Description
Product A (P1)	Existing product (environmentally unfriendly product)	Raw materials consist of some toxicity such as asbestos
Product B (P2)	Newly developed green product	Each new product was developed by substituting a toxic material with a different environmentally friendly synthetic fibre
Product C (P3)	Newly developed green product	
Product D (P4)	Newly developed green product	

Note: For confidentiality reasons, the names and some details are concealed

Table II. Description and type of considered products

The first product, product A, is an existing product that has been produced for more than 50 years. This product contains a number of toxic and imperishable materials. The product is outdated and is not completely associated with any environmental issue. The second, third and fourth products are product B, product C and product D, respectively. These roofing products are environmentally friendly, containing both non-toxic material and biodegradable material. The company has developed these products as substitutes for its environmentally irresponsible product. In this study, the existing product and the three green products in development are investigated in terms of quality, cost and environment, following the framework proposed in the previous section. The application processes can be classified into the four major stages as described below.

5.1 Identifying indicators and data acquisition following eight quality dimensions

To quantify the product quality, KPIs and data acquisitions must first be identified. These indicators are specified following the eight quality dimensions of Garvin's approach, which can be classified into two major standards, Thailand's industrial standards and the manufacturer's standard. The indicators of each specified quality dimension are provided, and the data acquisitions of the considered quality are described in Table III.

In Table III, only five quality dimensions and data acquisitions are described. The performance, reliability and durability are referenced from Thailand's industrial standards, whereas the feature and serviceability are obtained from the company's standards. These identified indicators do not cover all eight of Garvin's quality dimensions because a number of the ignored dimensions do not relate to the Thailand's industrial standards and the company's standards, and, moreover, the company still does not have the appropriate tools, and methods to measure these quality dimensions. Therefore, in this study, three quality perspectives, conformance, aesthetics and perceived quality, are neglected. Hence, the quality consideration is reduced from eight dimensions to five dimensions. Moreover, in Table III, the data acquisitions are specifically identified for each quality dimension because the company consists of several sub-divisions in the R&D department. The data for performance, features and reliability were obtained from R&D laboratory 1, and the durability and serviceability outcomes were tested by R&D laboratory 2 and R&D laboratory 3, respectively. These clear identifications allow the data and information for the next stage to be easily and clearly obtained.

5.2 Indicating scope and acquisition of LCC data

In this step, the LCC according to Emblemsvåg and Bras, considering both financial and environmental considerations, is explored. This approach divides the relating costs into nine main stages, mining, material processing, product manufacture, distribution,

Quality dimension	Indicator	Data source
Performance (Q1)	Load-bearing capacity or LBC	R&D laboratory 1
Feature (Q2)	Bending moment or BM	R&D laboratory 1
Reliability (Q3)	Impact strength or IS	R&D laboratory 1
Durability (Q4)	Heat rain testing or HRT	R&D laboratory 2
Serviceability (Q5)	Ease of installation (hours/50 sq m)	R&D laboratory 3

Table III. Descriptions and data acquisitions of the product quality use and service, product take-back, product demanufacture, material demanufacture and the disposal process. Although this model is a comprehensive method considering the entire life cycle of the product, some data and information regarding the developing products are limited and difficult to estimate in the R&D stage. Therefore, before collecting the relevant data, the scope of the LCC should be indicated. The scope of the LCC is obtained from the consensus of experienced managements, the R&D managers of each project, the account managers and the sales managers. The managers consider two major concerns: first, which stage of the LCC can be calculated or estimated reliably? and second, how are these costs calculated? After the discussion of these questions, the focused scope and the data acquisitions are determined, as shown in Table IV.

From Table IV, it can be concluded that there is only one ignored stage, the mining process, in accordance with the lack of data on the import materials. The data acquisition of this process comes mainly from vendors supplying the raw materials. A number of these vendors are reluctant to provide the data and the remainder do not want to disclose their financial data for the materials. Therefore, most of the considering costs are calculated and estimated by the company itself. The calculated costs are derived from two main sources, the R&D department and the accounting department. The R&D department is the section most involved in new product development; therefore, the costs from six stages of the LCC, the material processing, product manufacture, use and service, product demanufacture, material demanufacture and disposal process are obtained from this department. The two types of costs that are derived from the accounting department are from the distribution and the product take-back process. These stages are typical processes that the accounting section usually addresses for existing products; therefore, these costs are calculated and estimated by this department. These identifications will facilitate the data and information collection for the upcoming step.

5.3 Collecting all relating data

After the scopes and sources of all of the relating data were completely identified, the data concerning the newly developed green products which rely on the product quality and the LCC are collected in this section following the approaches determined in the two previous steps. However, the data acquisition for the existing product was obtained using a different approach because the old product already has its own data collection processes from which the quality data can be retrieved from the quality-testing laboratory, and the financial data can be obtained from the accounting department.

LCC stage	Scope consideration	Data source
Mining (C1)	X	n/a
Material processing (C2)	✓	R&D department
Product manufacture (C3)	✓	R&D department
Distribution (C4)	✓	Accounting department
Use and service (C5)	✓	R&D department
Product take-back (C6)	✓	Accounting department
Product demanufacture (C7)	✓	R&D department
Material demanufacture (C8)	✓	R&D department
Disposal (C9)	✓	R&D department

Table IV. Scope and data acquisitions of LCC

Therefore, all the required data from the quality and the LCC can be obtained from the previously identified departments. Fortunately, these sections cover already-established calculation and collection data systems. In this section, the environmental cost calculation which is crucial to the environmental concern considerations of the operations, is related to the environment, compliance with the principles of definability, measurability, relevance and reliability and the belonging period of cost-effectiveness. For the LCC calculation, the discount rate is referenced from Thailand's Central Bank discount rate. In addition, when there is a lack of data or undefined data, the data will be ignored for all the products. For example, if product A lacks the minor transportation costs, the transportation costs for all products will also be ignored. The product quality and the LCC data (US$/tonne) of the existing product as well as the three newly developed products are shown in Table V.

5.4 *Constructing network model and performing ANP*

After all the related data for every product are collected, in this section, the ANP is constructed to obtain the final priorities, implying which is the optimal green product. The ANP procedure can be classified into four main steps.

5.4.1 Model the problem as a dependency network. In the first step of the ANP application, all related elements of the network must be completely determined. In this study, the quality, the LCC and the alternative consist of five, eight and four elements, respectively. Therefore, the full set of the constructed network comprises 17 elements that can be classified into three main clusters, i.e., quality, cost and environment (LCC) and product (alternative). Because each element can influence other inner and outer elements, all influences between the elements are identified by a consensus among the R&D managers, the project managers and the account managers. After discussion, the influences between the cluster level and element level can be concluded as shown in Table VI. For element dependency, each part in the influences matrix represents the dependency between two elements. For example, the first row identifies the comparison between the Q1 element and all other elements, and the values in this row are 0, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1 and 1, respectively. These values imply that the Q1 element

Collected data elements	Product A (P1)	Product B (P2)	Product C (P3)	Product D (P4)
Quality				
Performance (Q1)	420.89	367.44	309.32	280.51
Feature (Q2)	9.32	8.92	6.97	7.02
Reliability (Q3)	2,289.76	4,800.69	6,793.96	7,212.84
Durability (Q4)	51	54	51	62
Serviceability (Q5)	13	16	13.5	14
LCC (US$/tonne)				
Material processing (C2)	114.54	160.36	188.06	201.83
Product manufacture (C3)	52.36	59.28	61.73	66.65
Distribution (C4)	8.98	12.43	14.98	16.15
Use and service (C5)	19.79	24.32	28.94	31.54
Product take-back (C6)	10.32	14.32	12.53	9.89
Product demanufacture (C7)	29.84	20.82	16.92	15.77
Material demanufacture (C8)	34.76	25.31	20.43	17.54
Disposal (C9)	41.99	28.43	23.38	21.61

Table V.
Quality and LCC data

	Q1	Q2	Q3	Q4	Q5	C2	C3	C4	C5	C6	C7	C8	C9	P1	P2	P3	P4
Q1	0	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1
Q2	1	0	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1
Q3	1	1	0	1	1	1	1	0	0	0	0	0	0	1	1	1	1
Q4	1	1	1	0	1	1	1	0	0	0	0	0	0	1	1	1	1
Q5	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1	1	1
C2	1	1	1	1	0	0	0	0	0	0	0	1	0	1	1	1	1
C3	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	1	1
C4	1	1	1	1	0	1	1	0	0	0	0	0	0	1	1	1	1
C5	1	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1
C6	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1
C7	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1
C8	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	1	1
C9	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	1	1
P1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
P2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
P3	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
P4	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0

Table VI. Influences matrix of element level

influences all elements except itself, and the C4, C5, C6, C7, C8 and C9 elements. For cluster relationship, if any element has relationship with another element in other cluster or in the same cluster, it identifies the dependency between clusters. For instance, there is no value among any element of product cluster, so it means that there is no relationship within this cluster.

5.4.2 Calculating priorities among elements and establishing unweighted supermatrix. After the influences among the elements are obtained in this step, the priorities from the inner elements and from the outer elements are performed via a pairwise comparison process. Each comparison is performed by asking a generic question to compare two elements. For example, for the comparison between two elements influencing another element, the question is as follows: how much more does the feature element influence the reliability element compared to the performance element? This procedure is similar to the AHP comparison process. The pairwise comparison is performed only among elements that depend on each other, and the dependency between elements can be recognized by a value in each part of the matrix, which means the segment matrix that has value will make the pairwise comparison. For example, the pairwise comparison among Q1 (horizontal axis) with all elements in the vertical axis, all elements except Q1 and C6 have an influence on Q1. These interrelations can be classified into two main types of pairwise comparisons, which are the inner comparison and the outer comparison. First, the comparison in the cluster should be performed, and the comparisons in other clusters should then be performed one by one. However, every group that is compared must be considered a consistency via the consistency ratio (CR). Whenever the CR is greater than 10 per cent, the comparisons are not consistent and the following three improvement processes are required to improve this issue: first, determining the most consistent comparison in the matrix, second, indicating the new range for those inconsistent values and this decision should improve the CR and finally, changing the most inconsistent judgment. For example, the inner comparison of Q1 and its CR is presented in Table VII. Similarly, the outer comparison of Q1 with the LCC cluster and its CR is shown in Table VIII.

In the same way, the remaining relating elements are performed following the example approach. The pairwise comparisons are performed concurrently with the consistency check in every accounted element. When all the comparisons are complete, then all the priorities can be obtained. These priorities or eigenvectors are subsequently identified into the associate column of a matrix termed the unweighted supermatrix, shown in Table IX. Each segment in the unweighted supermatrix represents the impact of the dependency between two elements. The size of the unweighted supermatrix is derived by multiplying all considered elements by itself. Therefore, in this case, the size of the matrix is calculated from 17 elements multiplied by 17 elements, which equals 289 matrix segments.

5.4.3 Calculating priorities among clusters and establishing weighted supermatrix. The weighted supermatrix can be constructed by performing pairwise comparisons between the relating clusters following their interrelations, as implied in Table VI. In this case, every cluster depends on itself and on other clusters, except a product cluster does not depend on itself but still depends on other clusters. These clusters are compared pairwise following all relations to perceive the cluster priorities. Hence, all clusters are compared with themselves and each other, except the product cluster, which ignores the comparison with itself. Furthermore, along with each comparison, the consistency check must be performed. In this way, other clusters also perform these comparisons concurrently with a CR consideration, and after these processes are complete, the overall cluster priorities can be presented, as shown in Table X. The values in each segment of this cluster matrix are applied for multiplying with the corresponding segments of the unweighted supermatrix. For example, the weight of the LCC in the cluster matrix that equals 0.4000 is multiplied with all the relating segments in which the comparisons between the LCC elements and LCC elements in the unweighted supermatrix. This calculation process is performed for the entire matrix to deliver the weighted supermatrix, as shown in Table XI.

Table VII. Pairwise comparison of performance among inner elements of quality cluster

Q1	Q2	Q3	Q4	Q5	eigenvector
Q2	1	2	1	4	0.3593
Q3	1/2	1	1/2	3	0.1999
Q4	1	2	1	4	0.3593
Q5	1/4	1/3	1/4	1	0.0815

Note: Consistency ratio = 0.0077

Table VIII. Pairwise comparison of performance among outer elements of the LCC cluster

Q1	C2	C3	C4	C5	C7	C8	C9	Eigenvector
C2	1	4	8	6	5	5	6	0.4558
C3	1/4	1	4	3	4	4	3	0.1728
C4	1/8	1/4	1	1/2	1/3	1/3	1/2	0.0379
C5	1/6	1/3	2	1	1/2	1/2	1	0.0616
C7	1/5	1/4	3	2	1	1	2	0.1052
C8	1/5	1/4	3	2	1	1	2	0.1052
C9	1/6	1/3	2	1	1/2	1/2	1	0.0616

Note: Consistency ratio = 0.0137

Cluster	Element	Q1	Q2	Q3	Q4	Q5	C2	C3	C4	C5	C6	C7	C8	C9	P1	P2	P3	P4
		Quality					LCC								Product			
Quality	Q1	0.0000	0.5587	0.3899	0.5594	0.4011	0.3133	0.3683	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3330	0.3192	0.3102	0.2000
	Q2	0.3593	0.0000	0.1523	0.2353	0.1713	0.1763	0.1929	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1893	0.1840	0.1609	0.1000
	Q3	0.1999	0.1352	0.0000	0.1442	0.0689	0.0986	0.0704	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0590	0.1093	0.1609	0.2000
	Q4	0.3593	0.2280	0.3899	0.0000	0.3587	0.3133	0.3683	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3330	0.3192	0.3102	0.4000
	Q5	0.0815	0.0781	0.0679	0.0611	0.0000	0.0986	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0858	0.0683	0.0578	0.1000
LCC	C2	0.4558	0.4558	0.4510	0.4223	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.4224	0.4270	0.4308	0.4308
	C3	0.1728	0.1728	0.1742	0.1668	0.0000	0.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1972	0.1641	0.1494	0.1494
	C4	0.0379	0.0379	0.0379	0.0368	0.0000	0.2000	0.1667	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0327	0.0349	0.0322	0.0322
	C5	0.0616	0.0616	0.0627	0.0614	1.0000	0.2000	0.8333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0910	0.0578	0.0839	0.0839
	C6	0.0000	0.0000	0.0000	0.0355	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0526	0.0566	0.0486	0.0486
	C7	0.1052	0.1052	0.0877	0.1080	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0927	0.1009	0.0856	0.0856
	C8	0.1052	0.1052	0.0877	0.1080	0.0000	0.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0575	0.1009	0.0856	0.0856
	C9	0.0616	0.0616	0.0987	0.0614	0.0000	0.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0538	0.0578	0.0839	0.0839
Product	P1	0.5462	0.4554	0.0591	0.1054	0.1409	0.5462	0.4236	0.4236	0.4554	0.3509	0.0729	0.0729	0.0652	0.0000	0.0000	0.0000	0.0000
	P2	0.2323	0.2628	0.1760	0.1894	0.4554	0.2323	0.2270	0.2270	0.2628	0.1091	0.1699	0.1699	0.2064	0.0000	0.0000	0.0000	0.0000
	P3	0.1377	0.1409	0.2888	0.1894	0.1409	0.1377	0.2270	0.2270	0.1409	0.1891	0.2844	0.2844	0.3642	0.0000	0.0000	0.0000	0.0000
	P4	0.0838	0.1409	0.4762	0.5158	0.2628	0.0838	0.1223	0.1223	0.1409	0.3509	0.4729	0.4729	0.3642	0.0000	0.0000	0.0000	0.0000

Table IX. Unweighted supermatrix

5.4.4 Calculating limit supermatrix and obtaining final priorities. To obtain a limit supermatrix, the weighted supermatrix increases the powers until all the entries in the matrix converge. After all the columns are similar, the final priorities can be obtained from any column in the limit supermatrix, as shown in Table XII, and each value in a row represents the priority of the element indicated in that row. For example, the first row in Table XII indicates that the same value in every column is 0.0642, which means that the Q1 (performance) has a priority value as 0.0642. To understand the expected result, the overall synthesised priorities of the products (alternatives) can be concluded as in Figure 3.

6. Discussion

Figure 3 shows the synthesised priorities of each product. Product A exhibits the highest weight value of 0.3277. Product B, product C and product D exhibit a normalized limiting value of 0.2266, 0.2038 and 0.2419, respectively. Although product A has the highest priority, it is an existing product of the focused company, which was brought in for comparison with the newly developed products. Therefore, from the synthesised priorities, the new product that should be selected for launching into the market is product D, which is the second highest priority. From Table V, it can be concluded that product D, which is a green product, exhibits the two highest quality results (Q3 and Q4) and four (C6, C7, C8 and C9) outstanding LCC elements. These four LCC elements directly relate with the environmentally friendly issues. The elements revolve around the processes of product take-back, product and material demanufacture as well as product disposal. Although product D has several of the highest results among the other products, these elements still depend on and influence the other elements. Moreover, most of the elements are not the first priority, except Q4. From Table XII, if we prioritise the quality and the LCC elements, and then match them with the real data from Table V, all related products can be classified to the best product in each element, as shown in Table XIII.

Product D exhibits two highest quality elements and four top LCC elements. In quality cluster, product D is the best in the Q3 and the Q4 element. Q4 is identified as the highest priority in the quality cluster, whereas Q3 is the lowest priority. In the LCC group, product D has the top rank in C6, C7, C8 and C9, none of which are in the first three rankings in the LCC cluster. As mentioned, product D can achieve several elements, but most of the elements are not crucial, except Q4, which is the most important element in the quality cluster. However, these results are not sufficient to make product D outrank product A. Product A also exhibits two of the highest quality elements (Q1 and Q2), and four of the top LCC elements (C2, C3, C4 and C5), similar to product D. However, most of these elements are top priority elements, which differ from the elements that product D achieves. Q1 and Q2 are the second and fourth rank of the quality issue, and C2, C3 and C5 are the top three of the LCC cluster. These crucial elements allow product A to be the first priority, and product D is second in rank.

Table X.
Weighting of the cluster matrix

	Quality	LCC	Product
Quality	0.2000	0.2000	0.3333
LCC	0.4000	0.4000	0.0000
Product	0.4000	0.4000	0.6667

Table XI. Weighted supermatrix

Cluster		Quality					LCC								Product			
	Element	Q1	Q2	Q3	Q4	Q5	C2	C3	C4	C5	C6	C7	C8	C9	P1	P2	P3	P4
Quality	Q1	0.0000	0.1117	0.0780	0.1119	0.0802	0.0627	0.0737	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1110	0.1064	0.1034	0.0667
	Q2	0.0719	0.0000	0.0305	0.0471	0.0343	0.0353	0.0386	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0631	0.0613	0.0536	0.0333
	Q3	0.0400	0.0270	0.0000	0.0288	0.0138	0.0197	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0197	0.0364	0.0536	0.0667
	Q4	0.0719	0.0456	0.0780	0.0000	0.0717	0.0627	0.0737	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1110	0.1064	0.1034	0.1333
	Q5	0.0163	0.0156	0.0136	0.0122	0.0000	0.0197	0.0000	0.0000	0.3333	0.0000	0.0000	0.0000	0.0000	0.0286	0.0228	0.0193	0.0333
LCC	C2	0.1823	0.1823	0.1804	0.1689	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5000	0.0000	0.2816	0.2846	0.2872	0.2872
	C3	0.0691	0.0691	0.0697	0.0667	0.0000	0.0800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1315	0.1094	0.0996	0.0996
	C4	0.0152	0.0152	0.0152	0.0147	0.0000	0.0800	0.0667	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0218	0.0232	0.0215	0.0215
	C5	0.0246	0.0246	0.0251	0.0246	0.4000	0.0800	0.3333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0607	0.0385	0.0559	0.0559
	C6	0.0000	0.0000	0.0000	0.0142	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0351	0.0377	0.0324	0.0324
	C7	0.0421	0.0421	0.0351	0.0432	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0618	0.0673	0.0571	0.0571
	C8	0.0421	0.0421	0.0351	0.0432	0.0000	0.0800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0384	0.0673	0.0571	0.0571
	C9	0.0246	0.0246	0.0395	0.0246	0.0000	0.0800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0359	0.0385	0.0559	0.0559
Product	P1	0.2185	0.1822	0.0236	0.0422	0.0564	0.2185	0.1694	0.4236	0.3036	0.3509	0.0729	0.0364	0.0652	0.0000	0.0000	0.0000	0.0000
	P2	0.0929	0.1051	0.0704	0.0758	0.1822	0.0929	0.0908	0.2270	0.1752	0.1091	0.1699	0.0850	0.2064	0.0000	0.0000	0.0000	0.0000
	P3	0.0551	0.0564	0.1155	0.0758	0.0564	0.0551	0.0908	0.2270	0.0939	0.1891	0.2844	0.1422	0.3642	0.0000	0.0000	0.0000	0.0000
	P4	0.0335	0.0564	0.1905	0.2063	0.1051	0.0335	0.0489	0.1223	0.0939	0.3509	0.4729	0.2364	0.3642	0.0000	0.0000	0.0000	0.0000

Table XII.
Limit supermatrix

Cluster		Quality					LCC								Product			
	Element	Q1	Q2	Q3	Q4	Q5	C2	C3	C4	C5	C6	C7	C8	C9	P1	P2	P3	P4
Quality	Q1	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642	0.0642
	Q2	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360
	Q3	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242	0.0242
	Q4	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644	0.0644
	Q5	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389	0.0389
LCC	C2	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511	0.1511
	C3	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638
	C4	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268	0.0268
	C5	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721	0.0721
	C6	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128	0.0128
	C7	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289	0.0289
	C8	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383	0.0383
	C9	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328	0.0328
Product	P1	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133	0.1133
	P2	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783	0.0783
	P3	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705	0.0705
	P4	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836	0.0836

However, product A is the existing product, which will be retired and substituted in the near future. In this case, we included it in the analysis to compare it with the newly developed green products because environmentally friendly products must be compensated with higher costs and lower quality. For example, although product D exhibits a low LCC in several environmental dimensions, at the same time, it has very high material costs, manufacturing costs as well as installation and service cost; moreover, a number of critical important quality performance issues, such as performance and feature, are also significantly lower than the environmentally irresponsible product. This compensation issue relates to several previous studies (Berger, 1993; Graviria, 1995). However, the toxic product cannot be sustained in the current market. In several developed countries, the toxic material and the environmentally unfriendly product are banned by law. For example, asbestos, which is a raw material for product A, has been banned in the USA and in several developed countries in Europe for health and safety reasons. Moreover, the green product is also indicated as the crucial element to overcome the currently high-competitive market (Chan, 2001). The product provides the advantage of increasing customer loyalty (Forte and Lamont, 1998). Therefore, in this focused company, the proposed green product will substitute the existing product in the near future.

The ANP not only indicates the optimal product but also benchmarks the green product with the toxic product. These potential advantages conform to several former studies (Bayazit, 2006; Kirytopoulos *et al.*, 2008; Perçin, 2008). Moreover,

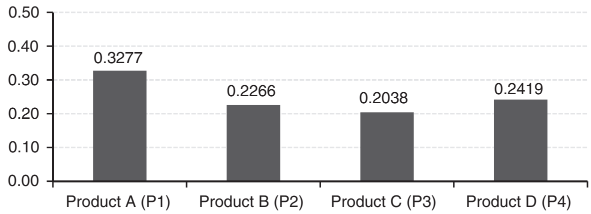


Figure 3. Overall synthesised priorities of product cluster

	Limiting weight	Rank	Best product
Quality			
Performance (Q1)	0.0642	2	Product A (P1)
Feature (Q2)	0.0360	4	Product A (P1)
Reliability (Q3)	0.0242	5	Product D (P4)
Durability (Q4)	0.0644	1	Product D (P4)
Serviceability (Q5)	0.0389	3	Product B (P2)
LCC (*US$/tonne*)			
Material processing (C2)	0.1511	1	Product A (P1)
Product manufacture (C3)	0.0638	3	Product A (P1)
Distribution (C4)	0.0268	7	Product A (P1)
Use and service (C5)	0.0721	2	Product A (P1)
Product take-back (C6)	0.0128	8	Product D (P4)
Product demanufacture (C7)	0.0289	6	Product D (P4)
Material demanufacture (C8)	0.0383	4	Product D (P4)
Disposal (C9)	0.0328	5	Product D (P4)

Table XIII. Element ranking in groups and matching with the best product this research also deeply compares all considered elements or KPIs that focus on quality, cost and environmental issues. This benchmarking suggests the gap between green products with the typical product. Therefore, from this outcome, the company realizes the problems, and then can plan to improve the weaknesses of environmentally friendly product in the future.

Furthermore, to monitor the robustness of this study, a sensitivity analysis of the two most likely situations was undertaken. In the first case, the relative importance of the green elements consisting of product take-back (C6), product demanufacture (C7), material demanufacture (C8) and disposal (C9) are increased 25 per cent (highest possibility). This process has generated different final weights, but the position of the alternative is still the same. Product A (0.2823) is still the best alternative, and in decreasing order of alternatives are product D (0.2759), product C (0.2245) and product B (0.2172). The final priorities in this case are depicted in Figure 4. In this case, the sensitivity analysis shows that there are no relevant changes in the ranking of the alternatives. The results of this sensitivity analysis imply that the highest increment of environmental weight lead to the decrement of quality and cost importance. Nevertheless, this enhanced significance of green dimensions still could not achieve some traditional considerations; those of performance (Q1), durability (Q4) and material processing cost (C2). Since these typical concernments are the most significant of overall importance, therefore, this characteristic makes the environmentally friendly product unable to overcome the toxic product or existing product. In the second case, it is assumed that all clusters have equal evaluation weights (0.3333). In this situation, this case delivers different limiting weights and provides minor dissimilar final priorities and consecutive orders as follows: product A (0.3135), product D (0.2563), product B (0.2283) and product C (0.2018). In this case, to compare the final synthesised priorities between the two sensitivity analysis cases and the original ANP, Figure 4 was generated.

In this study, the ANP technique allows the focused company to discover the optimal roof regarding the tradeoff characteristic among the green marketable products and toxicity product. For theoretical implications, the ANP method is flexible and appropriate to accommodate application to this research as same as other decision problems. The ANP provides a proper approach to consider with the tradeoff issue among entire elements. Moreover, the ANP associated with quality of Garvin and LCC of Emblemsvåg and Bras contributes a new approach for making decision in a new product selection process. This approach provides the proper decision process considering to current customer's requirement to the practitioners. Furthermore, it expresses the integration of ANP with other measurement methods to become a multi-disciplinary decision method that an academic researcher can further utilize

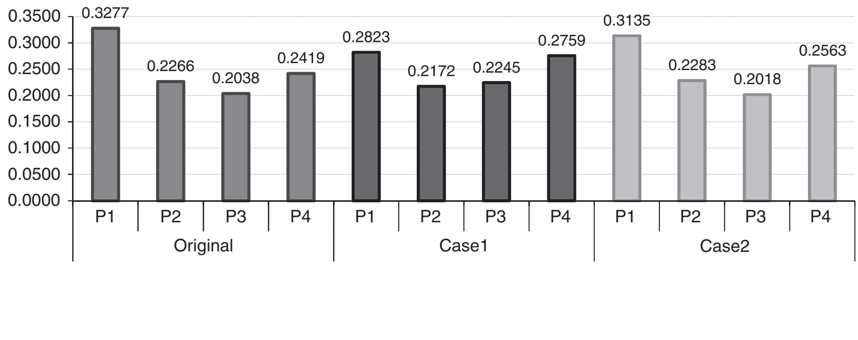


Figure 4.
Final synthesised priorities of alternative cluster from original ANP analysis and two cases of sensitivity analysis

this approach with other MCDMs. For practical implications, the outcomes of this study suggests that the ANP considering on quality, cost and environmental issues is feasible for selecting the new product. By understanding the dependency among considered elements, this consideration approach can be applied with all product domains. The top managements can use the result to select the optimal product, to benchmark the concentrated products or to find the gap in order to improve their weaknesses. The distinctive strength of this model over other typical considerations is that this approach focuses on the tradeoff issue or compensation characteristic among quality, cost and environmental capability. This methodology is built to respond to the current requirement of customers.

7. Conclusion

Currently, green products are globally accepted for several reasons, such as customer requirement, regulations and laws as well as business competition. This issue can produce many positive outcomes for the customer, society, the environment and manufacturing companies. Although green products are environmentally friendly, they are not sustainable in a highly competitive market if businesses do not simultaneously consider two critical issues, product quality and the cost of the product. Typically, green products that focus on the environmental issues will not succeed in the marketplace if the incremental cost and purchasing ability of the customer are ignored. Moreover, for the same reasons, green products cannot succeed in the market if the quality is lower than customer expectations. Therefore, the simultaneous consideration of these three issues becomes a critical consideration for businesses. In this study, we propose two methodologies consisting of the eight quality dimensions of Garvin and the LCC. Garvin's quality is applied to consider the product quality, and the LCC is used to manage the cost and environmental issues. Nevertheless, these methods consider these issues separately and do not involve the dependency issue among these topics. Typically, green products are delivered with higher costs and/or a possible lower quality; therefore, whenever a manufacturer needs to decrease its costs, it will reduce its quality and environmentally friendly capability. The higher price issue may be unavoidable because of additional costs. Furthermore, the environmental benefits from the green product may be compensated by a reduction in the quality; therefore, whenever a manufacturer needs to decrease costs, it will negatively affect its quality and environmentally friendly capability. Moreover, customers who require green products do not compromise on the cost and quality of the products. Therefore, this tradeoff issue must be considered in the complex decision-making process. Elaborate consideration of the tradeoff issue must be performed during the selection process because a wrong decision may lead to decreasing the competitive capability and losing market share and profits for the company. To address this comprehensive decision, this study applies the ANP method because it has the potential to account for the interdependence issue. The ANP considers the environment, cost and quality issues along with an alternative at the same time.

In this study, the ANP approach considering the three issues mentioned above is performed to select an optimal product in a real business, a roof tile manufacturer. The company intends to launch a newly developed product into the market by substituting an outdated product. The proposed ANP processes assist the focused company to benchmark three newly developed products and one existing product. The existing product is considered as the optimal product although the product is toxic. However, this product will be retired in the near future because of laws and regulations. If we consider only the three newly developed products, the optimal green product exhibits several of the highest quality and environment performances. Nevertheless, regarding the material and manufacturing costs, it is still expensive compared with the existing product. The detailed benchmarking in element level can be properly carried out by the distinctive characteristic of ANP. Moreover, the result of this study also corresponds with several previous studies that identify the balance between the cost, quality and green issues. After the results are obtained, the sensitivity analysis is conducted to account for the robustness of the study. The outcomes imply that there are no relevant changes in the ranking of the alternatives when increasing the environmental priorities, and the ranking among the alternatives is slightly sensitive to the varied weights of the clusters.

In future studies, the focused company will first implement the proposed method which includes several processes and produces a large amount of information. To sustain this decision-making approach, knowledge management methods will be applied using these processes in future studies. However, for other studies, the proposed framework of this study can be applied to other domains including goods and services.

References

Bayazit, O. (2006), "Use of analytic network process in vendor selection decisions", *Benchmarking: An International Journal*, Vol. 13 No. 5, pp. 566-579.

Berger, I. (1993), "The relationship between environmental attitudes and behaviour", *Canadian Journal of Marketing Research*, Vol. 12 No. 1, pp. 36-43.

Büyüközkan, G. and Çifçi, G. (2012), "A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers", *Expert Systems with Applications*, Vol. 39 No. 3, pp. 3000-3011.

Carillo, J.E. and Gaimon, C. (2000), "Improving manufacturing performance through process change and knowledge creation", *Management Science*, Vol. 46 No. 2, pp. 265-288.

Chan, C.C., Yu, K. and Yung, K. (2010), "Green product development by using life cycle assessment (LCA), theory of inventive of problems solving (TRIZ)", *Manufacturing Automation (ICMA) Proceeding of the International Conference in Hong Kong*, *Hong Kong Polytech University*, *Hong Kong*, pp. 24-29.

Chan, R.Y. (2001), "Determinants of Chinese consumers – green purchase behaviour", *Psychology & Marketing*, Vol. 18 No. 4, pp. 389-413.

Chetan, M. and Ben, W. (2001), "Green quality function deployment III: a methodology for developing environmentally conscious products", *Journal of Design and Manufacturing Automation*, Vol. 1 Nos 1/2, pp. 1-16.

Chiou, T.Y., Chan, H.K., Lettice, F. and Chung, S.H. (2011), "The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan", *Transportation Research*, Vol. 47 No. 6, pp. 822-836.

Cristofari, M., Deshmukh, A. and Wang, B. (1996), "Green quality function deployment", *International Journal of Environmentally Conscious Design & Manufacturing*, Vol. 5 No. 2, pp. 13-18.

Dunk, A.S. (2002), "Product quality, environmental accounting and quality performance", *Accounting, Auditing Accountability Journal*, Vol. 15 No. 5, pp. 719-732.

Ehlen, M.A. (1997), "Life-cycle cost of new construction materiae", *Journal of Infrastructure Systems*, Vol. 3 No. 4, pp. 129-133.

Emblemsvåg, J. and Bras, B. (2000), *Activity-Based Cost and Environmental Management – A Different Approach to the ISO 14000 Compliance*, Kluwer Academic Publishers, Norwell, MA.

Feigenbaum, A.V. (1986), "Quality: the strategic business imperative", *Quality Progress*, Vol. 19 No. 2, pp. 26-30.

Fine, H.C. (1986), "Quality improvement and learning in productive systems", *Management Science*, Vol. 32 No. 10, pp. 1301-1315.

Forte, M. and Lamont, B. (1998), "The bottom-line effect of greening (implications of ecological awareness)", *The Academy of Management Executive*, Vol. 12 No. 1, pp. 89-91.

Foster, G. and Sjoblom, L. (1996), "Quality improvement drivers in the electronic industry", *Journal of Management Accounting Research*, Vol. 8 No. 1, pp. 55-86.

Ganguly, K.K. and Guin, K.K. (2013), "A fuzzy AHP approach for inbound supply risk assessment", *Benchmarking: An International Journal*, Vol. 20 No. 1, pp. 129-146.

Garvin, A.D. (1984), "What does 'product quality' really mean?", *MIT Sloan Management Review*, Vol. 26 No. 1, pp. 25-43.

Garvin, A.D. (1987), "Competing on the eight dimensions of quality", *Harvard Business Review*, Vol. 65 No. 6, pp. 101-109.

Graviria, D. (1995), "Introducing the ecolabelling concept: experience of Colombia", *International Trade Forum*, Vol. 395 No. 3, pp. 8-11.

Gulch, P. and Baumann, H. (2004), "The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making", *Building and Environment*, Vol. 39 No. 5, pp. 571-580.

Hendricks, B.K. and Singhal, V.R. (1997), "Does implementing an effective TQM program actually improve operating performance? Empirical evidence from firms that have won quality awards", *Management Science*, Vol. 43 No. 9, pp. 1258-1274.

Huang, Y.C. and Wu, Y.C.J. (2010), "The effects of organizational factors on green new product success", *Management Decision*, Vol. 48 No. 10, pp. 1539-1567.

Kirytopoulos, K., Leopoulos, V. and Voulgaridou, D. (2008), "Supplier selection in pharmaceutical industry: an analytic network process approach", *Benchmarking: An International Journal*, Vol. 15 No. 4, pp. 494-516.

Kloepffer, W. (2008), "Life cycle sustainability assessment of products", *International Journal of Life Cycle Assessment*, Vol. 13 No. 2, pp. 89-95.

Kosareo, L. and Ries, R. (2007), "Comparative environmental life cycle assessment of green roofs", *Building and Environment*, Vol. 42 No. 7, pp. 2606-2613.

Lin, C.T., Chen, C.B. and Ting, Y.C. (2010), "An ERP model for supplier selection in electronics industry", *Expert Systems with Applications*, Vol. 38 No. 3, pp. 1760-1765.

Link, S. and Naveh, E. (2006), "Standardization and discretion: does the environmental standard ISO 14001 lead to performance benefits?", *IEEE Transactions on Engineering Management*, Vol. 53 No. 4, pp. 508-519.

Luo, L., Voet, E.V.D. and Huppes, G. (2009), "Life cycle assessment and life cycle costing of bioethanol from sugarcane in Brazil", *Renewable and Susaable Energy Reviews*, Vol. 13 Nos 6/7, pp. 1613-1619.

Molina-Azorín, J.F., Claver-Cortés, E., López-Gamero, M.D. and Tarí, J.J. (2009), "Green management and financial performance: a literature review", *Management Decision*, Vol. 47 No. 7, pp. 1080-1100.

Nassimbeni, G. (2003), "Local manufacturing systems and global economy: are they compatible?: the case of the Italian eyewear district", *Journal of Operations Management*, Vol. 21 No. 2, pp. 151-171.

Peattie, K. (2001), "Golden goose or wild goose? The hunt for the green consumer", *Business Strategy and the Environment*, Vol. 10 No. 4, pp. 187-199.

Perçin, S. (2008), "Using the ANP approach in selecting and benchmarking ERP systems", *Benchmarking: An International Journal*, Vol. 15 No. 5, pp. 630-649.

Reed, P. (2003), *Strategic Marketing Planning*, Thomson Learning, Melbourne.

Reinhardt, F.L. (1998), "Environmental product differentiation: implications for corporate strategy", *California Management Review*, Vol. 40 No. 4, pp. 43-73.

Saaty, T.L. (2001), *The Analytic Network Process: Decision Making with Dependence and Feedback*, RWS Publications, Pittsburgh, PA.

Singh, H. and Kumar, R. (2013), "Hybrid methodology for measuring the utilization of advanced manufacturing technologies using AHP and TOPSIS", *Benchmarking: An International Journal*, Vol. 20 No. 2, pp. 169-185.

Sipahi, S. and Timor, M. (2010), "The analytic hierarchy process and analytic network process: an overview of applications", *Management Decision*, Vol. 48 No. 5, pp. 775-808.

Tang, J., Fung, R.Y.K., Xu, B. and Wang, D. (2002), "A new approach to quality function deployment planning with financial consideration", *Computers andaperations Research*, Vol. 29 No. 11, pp. 144-1463.

Vörös, J. (2006), "The dynamics of price, quality and productivity improvement decisions", *European Journal of Operational Research*, Vol. 170 No. 3, pp. 809-823.

Wong, N.H., Tay, S.F., Wong, R., Ong, C.L. and Sia, A. (2003), "Life cycle cost analysis of rooftop gardens in Singapore", *Building and Environment*, Vol. 38 No. 3, pp. 499-509.

Yu-rong, G., Yuan, C. and Yi-qun, L. (2009), "Integrated life-cycle costs analysis and life-cycle assessment model for decision making of construction project", *2009 IEEE the 16th International Conference on Industrial Engineering and Engineering Management Proceeding of International Conference in Hong Kong, IEEE*, *Macau*, pp. 448-453.

Zhang, Y., Wang, H.-P. and Zhang, C. (1999), "Green QFD – II, a life cycle approach for environmentally conscious manufacturing by integrating LCA and LCC into QFD matrices", *International Journal of Production Research*, Vol. 37 No. 5, pp. 1075-1091.

Zhou, K.Z., Brown, J.R. and Dev, C.S. (2009), "Market orientation, competitive advantage, and performance: a demand-based perspective", *Journal of Business Research*, Vol. 62 No. 11, pp. 1063-1070.

Zhu, Q., Dou, Y. and Sarkis, J. (2010), "A portfolio-based analysis for green supplier management using the analytical network process", *Supply Chain Management: An International Journal*, Vol. 15 No. 4, pp. 306-319.

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