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Grey-entropy analytical network process for green innovation practices

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Abstract

The green innovation practice is regarded as a drive in supply chain management. This evaluation is a multiple criteria decision making (MCDM) problem and has a significant impact on the operations of the firms. This study integrated MCDM techniques that are grey theory, entropy weight and the analytical network process together to evaluate the green innovation practices under uncertainty. Hence, the objective is to select an alternative in the presence of incomplete information using multiple green innovation criteria. The result is often greatly affected by the weights used in the evaluation process. The world's largest printed circuit board manufacturer firm demonstrated the applicability of the proposed model. Subsequently, the ranks of each alternative and sensitivity analysis were calculated from incomplete information and dependence relations by applying the proposed method.

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1. Introduction

In recent years, the firms have been developing a number of environmentally friendly programs and green products or services (Hoffmann, 2007; Zhu et al., 2008; Lee et al., 2009; Tseng, 2011a; Lin et al., 2011; Yung et al., 2011). The firms are expecting their suppliers to reduce their consumption of natural energy during the operation process in order to reduce the negative impacts on the environment. The European Union has established a variety of environmental policies, including RoHS (the restricted use of hazardous substances in electrical and electronic equipment) and WEEE (waste electronics and electrical equipment) Directives. These directives ban manufacturers, sellers, distributors and recyclers of electrical and electronic equipment from launching new equipment that contains hazardous materials on the market (Tseng, 2009a; Tseng 2010). Shrivastava (1995) suggested that firms can differentiate their products or services, improve quality and lower the cost of production through product and process innovations. They can also extend the environmental concept into their products or services design considerations. Nevertheless, few studies can be found in the literatures that seek the drivers of firm's green innovation practices (Lin et al., 2011; Tseng, 2011b). Unfortunately, green innovation practices involve high uncertainty and risk and many resources are

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consumed in the process. Hence, understanding green innovation is a feasible way for firms to acquire the necessary techniques and assistance.

Many firms thought environmental practices as an unnecessary investment or even were misled that this would obstruct their development and growth (Lee et al., 2009). Hence, all corporate activities now relate to green innovation practices. Improvements in a firm's environmental performance and compliance with environmental regulations contribute to a firm's competitiveness. Several studies presented the pioneer in green innovation will enjoy a higher price for green products or services, develop new market and gain competitive advantages (Hart, 1997; Chen et al., 2006; Tseng et al., 2011a;b). Rao and Holt (2005) conducted empirical study on green practices and their relationship between competitiveness and economic performance and showed the green practices can improve a firm's performance. Firms engaging in green innovation activity can not only minimize production waste and increase environmental performance, but also improve the overall performance and competitiveness and thereby green innovation practice. However, the limited understanding of firms' green innovation practices have hampered the development of a widely accepted framework that would characterize and categorize firm's green innovation activities. Nevertheless, few studies can be found in the literatures that seek the drivers of firm's green innovations (Lin et al., 2011; Tseng, 2011a;b). Hence, understanding green innovation practice is a feasible way through this study and acquires the necessary techniques and assistance.

In the literature, Sharma (2000) and Wu (2009) argued that different environmental strategies or practices are found to be associated with managerial interpretations, which can be seen either as threats or as opportunities for tackling various environmental issues. It is also argued that, today, management innovations may represent one of the most important and sustainable sources of competitive advantage for firms due to its context specific nature, among others (Eiadat et al., 2008). From this point of view, firms have been implementing proactive environmental strategies and practices by using management initiatives to mitigate the impact of their innovation activities on the environment (Melnyk et al., 2003). Other studies have noticed the application of environmental friendly equipment and technologies (Klassen and Whybark, 1999), and the investment in environmental protection measures in focal electronic manufacturing firms (Klassen and Vachon, 2003; Buysse and Verbeke, 2003). Moreover, well-designed environmental standards can increase a manufacturer's incentive to introduce green products and technologies, and differentiating their products and lowering the cost of production through product and process innovations are necessary. Chen et al. (2006) presented that green products and manufacturing process innovations are positively associated with a firm's competitive advantage. Chen (2008) introduced the concept of green core competencies as collective learning, and the capabilities of green innovations and environmental management have a positive influence on a firm's ability to develop green product and process innovations. Chiou et al. (2011) presented an empirical evidence to encourage firms to implement a green supply chain and green innovations in order to improve their environmental performance and to enhance their competitive advantage in the market. These studies presented green innovations specifically for environmental performance as drivers of the manufacturing firms and the supply chain.

Aforementioned, this evaluation requires identification of appropriate measures in order to complete a robust study and to advance the body of knowledge in the field, both academically and practically. Academically, greater attention needs to be focused on employing multi-criteria, assessing the criteria for content validity and purifying them through extensive literature reviews in order to effectively and empirically advance theory within this field (Malhotra and Grover, 1998; Lee et al., 2009). This study contributes to this perspective as it attempts to integrate a number of criteria from various literatures on innovation and environmental management (Lin et al., 2011; Tseng, 2011). Practically, firms can benefit from the development of reliable and valid aspects and criteria taken from the practices of case firms. The practitioner can apply these criteria for benchmarking and continuous improvement when seeking to harmonize environmental and innovation goals. The top managers may be aware of multiple criteria for forging green innovation practice but with different priorities in mind, thus positioning the weighting on aspects and criteria for evaluating the suitability. In contrast, the method of weighting aspects and criteria also reveals the priorities for the distribution of resources. This implies that the priority of the criteria and the relative weights set will interact with each other. In addition, this study can guide firms in green innovation practices and find practical applications for the multi-criteria decision making (MCDM) whilst considering expert opinion regarding environmental concerns.

In the real world, MCDM often deals with subjective human preferences. People express thoughts and perceptions using natural language, which can often be vague or difficult to state mathematically.

Since linguistic variables are not directly mathematically analyzable, to cope with this difficulty, each linguistic variable is associated with a grey number set that characterizes the meaning of each generic verbal term (Zhang et al., 2005). In existing literatures, linguistic variables are converted to grey numbers in the decision making process (Tseng et al., 2009a;b). The meaning of a word might be well defined and determining the boundaries with which objects do or do not belong becomes uncertain when using the word as a label for a set (Tseng, 2009a). Hence, the proposed method uses entropy weights to appropriately express human judgment in proposed criteria. However, the traditional statistical approach is no longer suitable for evaluating the proposed dependence relations of green innovation practice. A typical study to understand the hierarchical dependence relations and framework is through the use of the analytical network process (ANP) and it provides a more generalized model in decision-making without making assumptions about the independence of the higher-level aspects from lower-level criteria (Tseng et al., 2008; Vachon and Klassen, 2008). ANP has been successfully applied in solving a variety of MCDM problems and the entropy weight for this evaluation will avoid the subjectivity and overcome the error influences of extreme conditions in the real application. This study summarizes the principles of the theories and its modeling schemes in prediction and diagnosis, and reviews its practical application combined with linguistic preferences (Tseng, 2011; Lin et al., 2011). This study developed a hybrid approach to determine and integrate green innovation criteria.

Hence, this study evaluates the ability of different criteria that will enable focal electronic manufacturing firms to adopt green innovation practices. This leads to the following study question of how to determine the key criteria of green innovation practices. In order to identify the criteria, it is necessary to understand the effects of green innovation in previous years with regard to management, process, product and technology innovation perspectives on the adoption of green innovation practices. This also illustrate how a sensitivity analysis can be conducted within a pinching inputs to a decision making process. Accordingly, this study is designed to explore how the criteria are related to a firm's decisions when adopting various practices and showing which criteria affect firms' green innovation practice. The next section provides the methodology used to develop and validate the criteria which satisfied content validity, is presented in Section 3. Section 4 gives the results of this study, followed by a discussion these results in Section 5.

2. Method

Researchers describe green innovation practices as a strategic, decision-making, driver perspective used to improve the performance of a firm (Tseng, 2008). This study focused on criteria and their relevant associations, as described below. The definitions of grey theory, entropy weight, analytical network process and the procedures of the proposed approach are also briefly discussed.

2.1. Grey theory

Grey theory is a mathematical theory derived from the grey set and is an effective method used to resolve uncertainties in discrete data (Deng 1982). In this study, the basic definitions of grey systems, sets and numbers were applied (Zhang et al., 2005, Tseng, 2008).

Table 1. Grey number set

Criteria	$\otimes G$
Very Low	(0.00, 0.20)
Low	(0.20, 0.40)
Medium	(0.40, 0.60)
High	(0.60, 0.80)
Very High	(0.80, 1.00)

$\otimes V_{ij} = \otimes G_{ij}^{*} \times \otimes w_j$, $\otimes w_j$ is entropy weight

2.2. Entropy weight method

The pair comparison matrices, e-vector are multiplied by the entropy weights for each criterion to determine the corresponding weights of the criteria. is a distinguishing or identification coefficient, and its value lie between zero and one. It is set to 0.25, 0.5, 0.75 for sensitivity analysis.E-vectors can be calculated by multiplying entropy weights with the corresponding weight of criteria.

2.3. Analytical network process

Saaty (1996) developed a new analysis method that simultaneously takes into account both the relationships of feedback and dependence. A two-way arrow among different levels of criteria may graphically represent the interdependencies in an ANP model. If interdependencies are present within the same level of analysis, a "looped arc" may be used to represent such interdependencies. Figure 1 presented the hierarchical structure with the dependence relationship of the proposed framework. The following descriptions are the equations applied in this approach.

2.4 Proposed approach

In this study, grey possible degree and entropy weight were applied to the evaluation of green innovation practices. The objective of the study was to evaluate the application of grey entropy degree to the determination of green innovation criteria. To rank the suitability of the alternatives, grey theory was applied. In the proposed model, A = {A1, A2, …. A_m} is a discrete set of m possible alternatives, and C = {C1, C2,….C_n}is a set of n criteria and $\otimes w = \{\otimes w_1, \otimes w_2, ..., \otimes w_n\}$ is the vector of criteria weights. The weights and ratings of the alternatives were numbers located on the aforementioned interval scale. Results

Due to the prosperous and booming electronic consumption products and network market, Taiwan plant are built for integrated circuit (IC) substrates and entering the IC packing field met the customer demands in related products in 2008-2010. The firms are not only the largest professional OEM PCB manufacturers in Taiwan, but are also ranked as top manufacturers worldwide (focal firms in the electronic supply chain). The firms have insisted on the principle of "Highest quality and Customer first", and continue to spend a lot of effort on improving processes and new generation technology in order to develop green innovations and set up a fully quality system to meet customer environmental requirements. The electronic products being rapidly replaced and new green technologies and products explored, the management capability of developing and researching new green technology is a global competition resource, which can meet green product demands and launch new green products in the market. Green innovation is a driver concept for the firms in order to sustain their place in a competitive green market.

2.4. Problem description

The firm insists on the principle of "ISO 14000", and continues to spend a lot of effort on improving operation processes, developing green products and setting up a fully operational green quality system to meet customer environmental requirements. The expert group strived to recommend the green innovation criteria expected it to remain long-term competition in the intensive green market. The expert group reviewed the green innovation aspects and criteria as it is one of the most prioritized issues of the management team probed the further development. It intends to evaluate the most relevant criteria and made these criteria prior to persuasive as there is a growing need for an analytical and systematic way to find solutions in management decision procedures. For better handling of this problem, the management group, comprising of twenty experts, should proper evaluate the criteria of green innovation.

2.5. Proposed approach

1. A firm's ability to formulate green projects with suitable programming and resources of budget allocation, such as redefining operation and production processes to ensure internal efficiencies that

can help to implement green supply chain management, and re-design and improve products or services to obtain new environmental criteria or directives. Hence, the firm must be able to evaluate and install an environmental management system and ISO 14000 series, consume less water, electricity, gas and petrol, provide environmental awareness seminars and training for stakeholders and strictly control hazardous waste and emissions, etc (Zhu et al., 2010). Moreover, the planning of technical knowledge, skills, operations and commercial feasibility of green innovation is necessary to reduce the risk of innovation (Chen, 2008; Tseng, 2010a; Lin et al., 2011). A firm's ability to formulate green projects with suitable programming and resources of budget allocation, such as redefining operation and production processes to ensure internal efficiencies that can help to implement green supply chain management, and re-design and improve products or services to obtain new environmental criteria or directives. Hence, the firm must be able to evaluate and install an environmental management system and ISO 14000 series, consume less water, electricity, gas and petrol, provide environmental awareness seminars and training for stakeholders and strictly control hazardous waste and emissions, etc (Zhu et al., 2010). Moreover, the planning of technical knowledge, skills, operations and commercial feasibility of green innovation is necessary to reduce the risk of innovation (Chen, 2008; Tseng, 2010a; Lin et al., 2011).

Table 2. Grey number set Table 2. Green Innovation practices

	Criteria
Green innovation	■ Redefine operation and production processes to ensure internal efficiency that can help to implement green supply chain management
	■ Re-designing and improving product or service in environmental directives
	■ Reduction of hazardous waste, emission, etc
	■ Less consumption of e.g. water, electricity, gas and petrol
	■ Install environmental management system and ISO 14000 series
	■ Providing environmental awareness seminars and training for stakeholders
	■ Advanced green production technology
	■ Recycle, reuse and remanufacture material
	■ Use of cleaner technology such as energy, water and waste
	■ Sending in-house auditor to appraise environmental performance of supplier
	■ Process design and innovation and enhances R&D functions
	■ Low cost green provider: unit cost versus competitors' unit cost
	■ Degree of new green product competitiveness understand customer needs
	■ Evaluation of technical, economic and commercial feasibility of green products
	■ Recovery of company's end-of-life products and recycling
	■ Innovation of green products and design measures
	■ Investment in green equipment and technology
	■ Implementation of comprehensive material saving plan
	■ Management of documentation and information

2. Table 3 presents the linguistic preferences interpreted into grey numbers. Use linguistic preferences to convert grey numbers into crisp values and then perform fuzzy assessments according to Eqs. (6) to (8). The initial weights are Alternative= (A1, A2, A3, A4)= (0.685,0.795,0.685,0.785); The alternative ranking is A2> A4> A1> A3. WC= (C1, C2, C3, …….,C19) = (0.655, 0.755, 0.785, 0.683, 0.733, 0.633, 0.788, 0.700, 0.645, 0.555, 0.658, 0.765, 0.750, 0.855, 0.835, 0.675, 0.625, 0.695, 0.635). The criteria ranking is C14> C15> C7> C12> C3> C2> C13> C5>C8> C18> C4> C16> C11> C1> C9> C19> C6> C17> C10.
3. The entropy weight presented in Table 4, the weights from decomposed from matrix can be calculated by multiplying the grey relational coefficient with the corresponding weight of the criteria using Eqs. (11) to (15). is a identification coefficient. The maximum value of this function occurs at = (0.25, 0.5, 0.75)

Table 3. Criteria importance rating

	C1	C2	C3	… … … ... … …	C17	C18	C19	A1	A2	A3	A4	Weights	Ranking
C1	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.40, 0.60)	(0.60, 0.80)	(0.40, 0.60)	(0.80, 1.00)	(0.60, 0.80)	(0.40, 0.60)	(0.40, 0.60)	0.655	14
C2	(0.20, 0.40)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.60, 0.80)	(0.60, 0.80)	(0.00, 0.20)	(0.60, 0.80)	(0.60, 0.80)	(0.80, 1.00)	(0.80, 1.00)	0.755	6
C3	(0.80, 1.00)	(0.80, 1.00)	(0.40, 0.60)	…. …. …. …. …. ….	(0.60, 0.80)	(0.60, 0.80)	(0.80, 1.00)	(0.60, 0.80)	(0.60, 0.80)	(0.60, 0.80)	(0.60, 0.80)	0.758	5
C4	(0.80, 1.00)	(0.80, 1.00)	(0.40, 0.60)	…. …. …. …. …. ….	(0.20, 0.40)	(0.60, 0.80)	(0.60, 0.80)	(0.20, 0.40)	(0.60, 0.80)	(0.20, 0.40)	(0.60, 0.80)	0.683	11
C5	(0.80, 1.00)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.40, 0.60)	(0.40, 0.60)	(0.60, 0.80)	(0.40, 0.60)	(0.40, 0.60)	(0.80, 1.00)	(0.60, 0.80)	0.733	8
C6	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.40, 0.60)	(0.40, 0.60)	(0.60, 0.80)	(0.40, 0.60)	(0.40, 0.60)	(0.80, 1.00)	(0.60, 0.80)	0.633	17
C7	(0.20, 0.40)	(0.40, 0.60)	(0.20, 0.40)	…. …. …. …. …. ….	(0.60, 0.80)	(0.40, 0.60)	(0.40, 0.60)	(0.60, 0.80)	(0.40, 0.60)	(0.80, 1.00)	(0.40, 0.60)	0.788	3
C8	(0.60, 0.80)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	0.700	9
C9	(0.60, 0.80)	(0.60, 0.80)	(0.40, 0.60)	…. …. …. …. …. ….	(0.60, 0.80)	(0.40, 0.60)	(0.20, 0.40)	(0.80, 1.00)	(0.40, 0.60)	(0.60, 0.80)	(0.40, 0.60)	0.645	15
C10	(0.00, 0.20)	(0.60, 0.80)	(0.20, 0.40)	…. …. …. …. …. ….	(0.20, 0.40)	(0.20, 0.40)	(0.40, 0.60)	(0.80, 1.00)	(0.20, 0.40)	(0.20, 0.40)	(0.20, 0.40)	0.555	19
C11	(0.40, 0.60)	(0.60, 0.80)	(0.40, 0.60)	…. …. …. …. …. ….	(0.60, 0.80)	(0.20, 0.40)	(0.40, 0.60)	(0.80, 1.00)	(0.20, 0.40)	(0.60, 0.80)	(0.20, 0.40)	0.658	13
C12	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.20, 0.40)	(0.60, 0.80)	(0.40, 0.60)	(0.20, 0.40)	(0.60, 0.80)	(0.20, 0.40)	(0.60, 0.80)	0.765	4
C13	(0.40, 0.60)	(0.40, 0.60)	(0.20, 0.40)	…. …. …. …. …. ….	(0.40, 0.60)	(0.80, 1.00)	(0.80, 1.00)	(0.40, 0.60)	(0.80, 1.00)	(0.40, 0.60)	(0.80, 1.00)	0.750	7
C14	(0.40, 0.60)	(0.40, 0.60)	(0.60, 0.80)	…. …. …. …. …. ….	(0.80, 1.00)	(0.80, 1.00)	(0.20, 0.40)	(0.80, 1.00)	(0.80, 1.00)	(0.80, 1.00)	(0.80, 1.00)	0.855	1
C15	(0.40, 0.60)	(0.80, 1.00)	(0.00, 0.20)	…. …. …. …. …. ….	(0.80, 1.00)	(0.80, 1.00)	(0.40, 0.60)	(0.80, 1.00)	(0.80, 1.00)	(0.80, 1.00)	(0.80, 1.00)	0.835	2
C16	(0.40, 0.60)	(0.80, 1.00)	(0.80, 1.00)	…. …. …. …. …. ….	(0.80, 1.00)	(0.20, 0.40)	(0.40, 0.60)	(0.80, 1.00)	(0.20, 0.40)	(0.80, 1.00)	(0.20, 0.40)	0.675	12
C17	(0.20, 0.40)	(0.20, 0.40)	(0.20, 0.40)	…. …. …. …. …. ….	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	0.625	18
C18	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.20, 0.40)	(0.40, 0.60)	(0.20, 0.40)	(0.20, 0.40)	(0.40, 0.60)	(0.20, 0.40)	(0.40, 0.60)	0.695	10
C19	(0.40, 0.60)	(0.40, 0.60)	(0.80, 1.00)	…. …. …. …. …. ….	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	0.635	16
A1	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.80, 1.00)	(0.80, 1.00)	(0.20, 0.40)	(0.20, 0.40)	(0.40, 0.60)	(0.20, 0.40)	(0.40, 0.60)	0.685	3
A2	(0.60, 0.80)	(0.60, 0.80)	(0.80, 1.00)	…. …. …. …. …. ….	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	0.795	1
A3	(0.60, 0.80)	(0.40, 0.60)	(0.40, 0.60)	…. …. …. …. …. ….	(0.20, 0.40)	(0.80, 1.00)	(0.80, 1.00)	(0.20, 0.40)	(0.80, 1.00)	(0.80, 1.00)	(0.80, 1.00)	0.685	4
A4	(0.40, 0.60)	(0.40, 0.60)	(0.80, 1.00)	…. …. …. …. …. ….	(0.80, 1.00)	(0.40, 0.60)	(0.40, 0.60)	(0.80, 1.00)	(0.40, 0.60)	(0.40, 0.60)	(0.40, 0.60)	0.785	2

Table 4. Pair comparison after defuzzification, entropy weights and local weight

	A1	A2	A3	A4	E-vector	w_j	Entropy weights			Local weight		
							(0.25)	(0.50)	(0.75)	(0.25)	(0.50)	(0.75)
A1	1.000	0.810	0.814	0.787	0.451	0.230	0.214	0.317	0.415	0.170	0.251	0.329
A2	1.234	1.000	1.572	0.126	0.274	0.140	0.175	0.216	0.371	0.084	0.104	0.179
A3	1.229	0.636	1.000	1.995	0.657	0.335	0.278	0.341	0.451	0.321	0.393	0.520
A4	1.271	7.937	0.501	1.000	0.582	0.296	0.208	0.246	0.388	0.213	0.252	0.397

λmax= 0.752 ; CI: 0.094 ; CR: 0.084

4. Table 5 presented the unweighted supermatrix using Eqs. (16) and (17). Use Eq. (18) and weighted the green innovation practice criteria importance level with dependency relationships among criteria and alternatives. There are several pairs of comparison matrices to acquire the crisp value. The crisp values composed the unweighted supermatrix. For instance, the weights of column C1 of alternatives are 0.251, 0.104, 0.393, 0.252 (=0.5). The result obtains the normalized unweighted supermatrix from the multiplied result and is raised to limiting powers in order to calculate the overall priority weights for case firm.

Table 5. Unweighted supermatrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	A1	A2	A3	A4
C1	0.085	0.085	0.058	0.069	0.063	0.029	0.054	0.045	0.085	0.065	0.063	0.046	0.063	0.085	0.082	0.085	0.068	0.055	0.077	0.064	0.055	0.056	0.052
C2	0.038	0.063	0.086	0.056	0.068	0.034	0.064	0.075	0.063	0.043	0.035	0.044	0.048	0.051	0.065	0.065	0.068	0.067	0.065	0.067	0.065	0.029	0.056
C3	0.041	0.025	0.048	0.052	0.055	0.061	0.085	0.068	0.046	0.042	0.042	0.040	0.048	0.046	0.058	0.058	0.062	0.085	0.085	0.096	0.054	0.043	0.031
C4	0.075	0.066	0.048	0.034	0.048	0.075	0.051	0.055	0.054	0.053	0.043	0.052	0.048	0.047	0.050	0.038	0.055	0.044	0.051	0.108	0.032	0.019	0.034
C5	0.039	0.056	0.043	0.043	0.061	0.063	0.045	0.035	0.046	0.043	0.075	0.075	0.075	0.043	0.057	0.044	0.054	0.042	0.042	0.063	0.034	0.076	0.087
C6	0.069	0.038	0.045	0.044	0.045	0.066	0.042	0.043	0.048	0.075	0.044	0.046	0.048	0.045	0.046	0.048	0.045	0.046	0.045	0.051	0.041	0.010	0.075
C7	0.044	0.061	0.055	0.053	0.053	0.052	0.048	0.056	0.052	0.058	0.056	0.051	0.055	0.058	0.058	0.055	0.055	0.057	0.056	0.092	0.097	0.086	0.054
C8	0.026	0.055	0.073	0.043	0.097	0.085	0.045	0.036	0.045	0.093	0.046	0.085	0.038	0.075	0.075	0.075	0.040	0.037	0.043	0.038	0.065	0.075	0.085
C9	0.052	0.061	0.086	0.096	0.045	0.049	0.045	0.046	0.075	0.041	0.041	0.044	0.045	0.042	0.046	0.040	0.043	0.075	0.075	0.116	0.075	0.013	0.033
C10	0.066	0.037	0.046	0.050	0.047	0.044	0.048	0.050	0.053	0.041	0.047	0.075	0.048	0.050	0.051	0.046	0.045	0.046	0.046	0.053	0.086	0.013	0.087
C11	0.068	0.051	0.045	0.046	0.045	0.038	0.043	0.047	0.045	0.043	0.075	0.045	0.075	0.042	0.045	0.047	0.044	0.045	0.044	0.017	0.085	0.095	0.101
C12	0.050	0.046	0.052	0.052	0.051	0.068	0.047	0.051	0.081	0.048	0.049	0.044	0.052	0.052	0.052	0.048	0.053	0.051	0.056	0.021	0.032	0.088	0.032
C13	0.050	0.062	0.049	0.051	0.051	0.050	0.055	0.085	0.048	0.055	0.049	0.049	0.044	0.051	0.051	0.051	0.075	0.049	0.050	0.022	0.083	0.085	0.018
C14	0.042	0.062	0.042	0.085	0.043	0.042	0.095	0.084	0.041	0.075	0.041	0.078	0.085	0.091	0.045	0.075	0.042	0.077	0.039	0.031	0.038	0.038	0.015
C15	0.043	0.050	0.042	0.043	0.042	0.040	0.044	0.040	0.041	0.047	0.043	0.039	0.038	0.041	0.036	0.047	0.075	0.041	0.038	0.032	0.024	0.066	0.019
C16	0.074	0.043	0.044	0.045	0.044	0.046	0.052	0.043	0.042	0.042	0.085	0.048	0.044	0.044	0.041	0.037	0.042	0.048	0.045	0.028	0.021	0.032	0.032
C17	0.047	0.047	0.032	0.046	0.049	0.067	0.050	0.049	0.047	0.044	0.053	0.044	0.052	0.051	0.047	0.049	0.042	0.050	0.051	0.033	0.076	0.074	0.082
C18	0.043	0.045	0.055	0.045	0.046	0.044	0.042	0.045	0.043	0.042	0.068	0.043	0.046	0.042	0.046	0.045	0.035	0.039	0.045	0.037	0.032	0.068	0.090
C19	0.048	0.047	0.051	0.047	0.048	0.046	0.045	0.047	0.045	0.050	0.045	0.050	0.049	0.044	0.051	0.046	0.056	0.047	0.045	0.031	0.005	0.034	0.017
A1	0.251	0.286	0.334	0.218	0.417	0.296	0.274	0.194	0.198	0.221	0.296	0.261	0.247	0.198	0.315	0.239	0.216	0.285	0.265	0.315	0.254	0.247	0.275
A2	0.104	0.356	0.258	0.210	0.117	0.215	0.234	0.262	0.253	0.291	0.351	0.216	0.270	0.359	0.270	0.282	0.357	0.311	0.230	0.214	0.341	0.373	0.144
A3	0.393	0.257	0.227	0.342	0.212	0.234	0.214	0.274	0.284	0.216	0.099	0.269	0.256	0.191	0.188	0.247	0.112	0.221	0.267	0.228	0.237	0.203	0.337
A4	0.252	0.101	0.181	0.230	0.254	0.255	0.278	0.270	0.265	0.272	0.254	0.254	0.227	0.252	0.227	0.232	0.315	0.183	0.239	0.243	0.168	0.177	0.244

Table 6 presented the weighted supermatrix. The final weights are WC= (C1, C2, C3, ….C19) = (0.031, 0.028, 0.028, 0.026, 0.029, 0.023, 0.034, 0.031, 0.029, 0.027, 0.031, 0.024, 0.027, 0.023, 0.020, 0.019, 0.028, 0.025, 0.017). WA=(A1, A2, A3, A4)= (0.134,0.132,0.121,0.112). The top five criteria are as advanced green production technology; (2) Redefine operation and production processes to ensure internal efficiency that can help to implement green supply chain management (C1); Process design and innovation and enhances R&D functions (11); Recycle, reuse and remanufacture material (C8); Use of cleaner technology such as energy, water and waste (C9).

Table 6. Weighted supermatrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	A1	A2	A3	A4
C1	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
C2	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
C3	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
C4	0.026	0.025	0.025	0.025	0.026	0.025	0.025	0.026	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.026	0.025	0.025	0.026	0.026
C5	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
C6	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
C7	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
C8	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
C9	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
C10	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
C11	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
C12	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
C13	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
C14	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
C15	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
C16	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
C17	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
C18	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
C19	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
A1	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134
A2	0.132	0.133	0.132	0.132	0.132	0.132	0.133	0.133	0.132	0.132	0.132	0.132	0.132	0.133	0.133	0.133	0.132	0.133	0.132	0.132	0.133	0.133	0.132
A3	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
A4	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.112

5. Sensitivity analysis consequently has many manifestations in probabilistic risk analyses and there are many disparate approaches based on various measures of influence and response. Figure 3 and 4 presents the sensitivity analysis for criteria and alternatives. The sensitivity analysis depends on identification coefficient (ξ = 0.25, 0.5, 0.75). It performed for two fundamental reasons: to understand how the conclusions and inferences drawn from an assessment depend on its inputs, and to focus future empirical studies so that effort might be expended to improve estimates of inputs that would lead to the most improvement in the estimates of the decisions. For instance, while ξ = 0.25, the alternative weight is W_A= (0.124, 0.119, 0.108, 0.101). And while ξ = 0.5, the alternative weight is W_A= (0.134, 0.132, 0.121, 0.112). The details of decision making weights of alternative are presented in Table 7.

Table 7. Sensitivity analysis of four alternatives

Identification Coefficient	A1	A2	A3	A4
0.25	0.124	0.119	0.108	0.101
0.5	0.134	0.132	0.121	0.112
0.75	0.159	0.147	0.134	0.121

Table 8 presented the sensitivity analysis of nineteen criteria. Obviously, the decision pattern is very consistence when the identification coefficient is changed (ξ = 0.25, 0.5, 0.75). While ξ = 0.5, the alternative weight is W_C= (0.0307, 0.0282, 0.0280, 0.0255, 0.0289, 0.0232, 0.0344, 0.0305, 0.0291, 0.0272, 0.0306, 0.0239, 0.0267, 0.0234, 0.0189, 0.0192, 0.0283, 0.0251, 0.0174). The decision pattern is unaffected by the identification coefficient changed.

Table 8. Sensitivity analysis of green innovation practice criteria

Identification Coefficient	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
0.25	0.0380	0.0429	0.0402	0.0410	0.0446	0.0421	0.0377	0.0439	0.0401	0.0392	0.0398	0.0379	0.0408	0.0405	0.0420	0.0397	0.0405	0.0383	0.0414
0.5	0.0307	0.0282	0.0280	0.0255	0.0289	0.0232	0.0344	0.0305	0.0291	0.0272	0.0306	0.0239	0.0267	0.0234	0.0198	0.0192	0.0283	0.0251	0.0174
0.75	0.0232	0.0228	0.0232	0.0241	0.0268	0.0220	0.0343	0.0267	0.0201	0.0264	0.0211	0.0240	0.0210	0.0180	0.0195	0.0178	0.0285	0.0250	0.0174

Model uncertainty can be probed by analyzing in sensitivity analysis using different assumption. Such studies are often very difficult to conduct because of the large number of calculations that are required. This approach involved in multiple uncertainties at issue of incomplete information and linguistic preferences. Usually only a relatively tiny number of such analyses can be performed in practice. The proposed method can be used to in MCDM under linguistic preferences and incomplete information.

3. Conclusions

This study focused on the development of a quantitative evaluation of uncertainty using grey theory, ANP and entropy weighting together. The results of the proposed method reflected these uncertainties and were highly reliable by expressing the uncertainty of the model with grey-entropy model. The proposed criteria must be considered and evaluated simultaneously. The proposed method was employed to evaluate the criteria in vagueness, which is often inaccurate or uncertain. Moreover, the hierarchical model allows an evaluator to utilize qualitative and imprecise quantitative criteria by transforming linguistic expressions into crisp values. To employ criteria based on subjective judgments, this study applied grey numbers to represent linguistic preferences, which reduced cognitive burden during the evaluation process. However, in real green innovation practice, the information is not always complete and the majority of criteria are based on incomplete information. The proposed model incorporated hierarchical structure to obtain an effective method for the determination of weights from subjective judgments. This method is also useful for evaluating the final performance of a firm.

From a theoretical perspective, this study is one of the first to evaluate green innovation practice criteria based on linguistic preferences and grey-entropy theory in the electronic manufacturing firm.

One of the major practical contributions of this study is that it is the first attempt to use the concept of grey-entropy ANP to identify green innovation practice criteria for a manufacturing firm. To successfully compete in different firms, it is necessary for manufacturing firms to assess their supplier in green innovation practice. Environmental management and innovation are predicted to be the most important performance indicators for the green innovation practice of firms in the future. Further, the findings shed light on the strategies pursued by manufacturing firm to compete against rivals and provide the management with insights into the characteristics in the green innovation practice which is useful to them for formulating plans to benchmark and set targets for their practices.

In addition, this study proposed a hybrid MCDM for selecting alternatives in the presence of uncertainty and incomplete information. The evaluator's judgment is often uncertain, and incomplete information cannot always be evaluated with exact numbers. An empirical example of green innovation practice was used to illustrate the application of the proposed criteria in a firm. The experimental results indicated that the proposed approach is reliable and reasonable, and a selected alternative was selected from the four possible choices. The proposed model can easily and effectively accommodate validated criteria. The proposed model establishes a foundation for future research and is appropriate for predicting uncertain criteria. To improve the firm's performance and provide information that will have the greatest effect on reducing uncertainty, a firm can apply this model to evaluate and determine a supplier subject to green innovation practice.

Hence, organizations should implement environmental management, and integrate green innovation into business strategies in order to build and maintain competitive advantage. However, green managerial innovation may not necessarily lead to good environmental performance. Therefore, top management should focus predominantly on redefine operation and production processes to ensure internal efficiency that can help to implement green supply chain management, as there is a stronger link between process design and innovation and enhances R&D functions and environmental performance. One potential benefit of green innovation is that it increases the entry barriers of other competitors. Moreover, recycle, reuse and remanufacture material and uses of cleaner technology are able to enhance competitive advantage with green innovation practice.

The case study indicated that the proposed approach is performed an evaluation of a manufacturing firm, it still has certain limitations. The qualifications of the expert respondents need to be validated as they play an important role in setting the weights which may greatly affect the final ranking. This study confirmed that the respondents are senior managers and vice presidents who are familiar with the operations and in this evaluation. In addition, the proposed criteria need to be carefully selected. The criteria used are first obtained from literature and reviewed by the management to determine the appropriate criteria for the firm. Lastly, the results need to be validated. This study used the case firm's real data to verify the results. Hence, care must be taken before applying the proposed approach to other firms or other industries. Nevertheless, this study believes that the proposed method is applicable to a wide variety of MCDM problems under uncertainty. Future research may try to extend this research and apply this proposed approach to other MCDM problems in a similar setting.

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