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A Decision-Making Model for Sustainable Supplier Evaluation and Selection

by

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Declaration of Authenticity and Author's Rights

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Dedication

I would like to dedicate this Thesis to everyone who played a role in my academic accomplishments: my family and my friends, who supported me with love and understanding. Without you, I could have never reached this current level of success.

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Abstract

With the growing concerns in sustainability, manufacturers have been obliged by various stakeholders to embed environmental and social concerns into their supply chain activities. In recent years, sustainability practises have become a major topic of conversation for automobile manufacturers. One of the necessary components of a car is tyres, and the most important raw material to produce car tyres is rubber. The tyre industry dominates rubber consumption, and Thailand is currently the largest natural rubber producer based on value, accounting for 37% of global production (IRSG, 2021). Although there is a lot of research on other car parts such as gear box, car seat, digital technology, and battery from an academic perspective, tyre rubber still lacks comprehensive knowledge on sustainability. Moreover, tyres are rapidly becoming a new issue in both environment and social, which will affect the automotive industry. This led this research to start not only evaluating and selecting the suppliers' economic abilities, but also their competencies in environmental and social aspects. Sustainable supplier evaluation and selection is based on well-established criteria that can differ between economic dimensions, environmental dimensions, and social dimensions as selection criteria drive the decision process.

The aim of this research is to propose a combined multicriteria decision making model by using Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) applied in the sustainable supplier evaluation and selection process in the tyre rubber industry in Thailand. In this research, there are three main objectives: (1) identify the set of main- and sub-criteria in sustainability for supplier evaluation and selection, (2) prioritise the order of main- and sub-criteria for evaluating and selecting sustainable suppliers, and (3) examine and validate a proposed decision-making model of sustainable supplier evaluation and selection. Additionally, this research also aimed to reveal differences in sustainable supplier selection between two tier size of suppliers, Tier 1 large-sized firms (LEs) and Tier 2 small and medium-sized local firms (SMEs).

This research provides a framework of the sustainable selection criteria for suppliers in the tyre rubber industry. This framework consists of three main criteria (economic, social, and environment), fourteen sub-criteria level 1, and forty-six sub-criteria level 2. The model is a part of the multiple criteria decision-making (MCDM) model. This combined multicriteria decision making model consists of two parts: sustainable criteria weights determination and LEs and SMEs suppliers ranking. The proposed method combines the strength of the fuzzy set in handling the uncertainty that are associated with human being's subjective judgement. Fuzzy AHP is applied to obtaining sustainable criteria weight and Fuzzy TOPSIS for suppliers ranking. To achieve the above goals, this research employed a mixed research method. It used qualitative (interviews) and quantitative (questionnaires) research methods. These supplier selection decision makers consisted of fifty managers including purchasing managers, supply chain managers, finance manager, production and quality managers, logistics managers, general managers and chief executive officer with higher level of experience.

After analysing the collected data, a result of main criteria weight from the pair-wise comparisons in FAHP showed that the economic criterion was significantly highest with a weight of 41%, environment with 37% and social aspects with a weight of 22%. The social attributes of suppliers in tier 2 local suppliers were the least important selection criteria compared with the economic criteria.
However, tier 1 suppliers identified that environmental and social dimensions are more concerned for being sustainability. For the sub-criteria level 1, there was agreement or decision similarity between the two tiers about their importance criteria in the cost and price, the environmental management, financial stability, employee's welfare and right, and green product. In an opposite way, this research noticed that there were two criteria that had contradictions between the two groups of decision makers. These are ethics and pollution control. Then, for sustainable supplier ranking, Fuzzy TOPSIS is used in this problem area to select the most appropriate sustainable supplier of tyre rubber in Thailand. From twenty suppliers in two tiers, there are three suppliers from tier 1 and two suppliers from tier 2 local. The ranking of them was determined in terms of closeness index values. The result implies that both tier 1 and tier 2 suppliers are likely to take actions to adopt sustainable practices in the tyre rubber industry in Thailand. For sensitivity analysis, the criteria weights and rank of tyre rubber suppliers rarely changed when changing the values of attitudes and fuzzification factors. The results indicated that the proposed multicriteria decision making model is robust. For future research, a comparative study between decision makers from tyre rubber industry and other industries in Thailand and/or other countries that have less of a relationship with the sustainability should consider. Also, it would be beneficial to have government interviewees involved in this study as their insights could help address policy issues or problems of high concern at the country level.

LIST OF ABBREVIATIONS

TBL	Triple Bottom Line
SSCM	Sustainable Supply Chain Management
SCM	Supply Chain Management
GSCM	Green Supply Chain Management
CSR	Corporate Social Responsibility
ISO	International Organisation for Standardisation
SME	Small and Medium-sized Enterprise
OEM	Original Equipment Manufacturer
MCDM	Multi-Criteria Decision Making
SAW	Simple Additive Weightage
DEMATEL	Decision Making Trial and Evaluation Laboratory
AHP	Analytic Hierarchy Process
FAHP	Fuzzy Analytic Hierarchy Process
ANP	Analytic network process
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
FTOPSIS	Fuzzy Technique for Order of Preference by Similarity to Ideal Solution
ELECTRE	Elimination and Choice Translating Reality
QFD	Quality function deployment
GDP	Gross Domestic Product
JV	Joint Venture
LE	Large-sized Enterprise
EC	Economic dimension
SC	Social dimension
ENV	Environmental dimension
CI	Consistency Index
RI	Random Index
CR	Consistency Ratio
TFN	Triangular Fuzzy Number
FPIS	Fuzzy Positive Ideal Solution
FNIS	Fuzzy Negative Ideal Solution
CC	Closeness Index

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1. Introduction

1.1 Background

Sustainability goals are becoming increasingly important for companies, and the purchasing function plays a crucial role in achieving sustainability goals in supplier selection for several reasons (Schneider and Wallenburg, 2012). Firstly, the purchasing function is responsible for selecting suppliers based on criteria such as quality, cost, and delivery. By incorporating sustainability criteria, such as the supplier's environmental and social performance, into supplier selection, the purchasing function can help to ensure that sustainability considerations are taken into account in the purchasing process (Tate et al., 2010). Secondly, the purchasing function can also play a key role in ensuring supply chain transparency by requiring suppliers to disclose information about their environmental and social performance. This can help to identify potential sustainability risks and opportunities for improvement (Carter & Rogers, 2008). Thirdly, the purchasing function can work collaboratively with suppliers to promote sustainable practices. For example, by setting sustainability targets and providing guidance on how to achieve them, the purchasing function can help to incentivize suppliers to improve their sustainability performance (Walker et al., 2008). Finally, sustainable practices, such as reducing energy consumption and waste, can result in cost savings for both the buyer and supplier. By working with suppliers to implement sustainable practices, the purchasing function can help to reduce costs while also promoting sustainability (Handfield et al., 2014). Since Consequently, buyer-supplier relationships are central to improving sustainability performance (Leppelt et al., 2013). The actions of supply chain partners can have a significant impact on buying companies, so organisations now need to take more responsibility for the actions of their suppliers due to stakeholder pressure and longevity (Touboulic et al., 2014). For example, Mmereki et al. (2019) argued in South Africa, that the production of waste tyres leads to health problems in communities. Another issue emerged in the automobile industry. Mansouri (2016) analysed the effects that lead to unethical actions in emissions testing. Visser (2008) said that global warming has increased awareness of pollution and environmental factors, leading to consideration of pollution in developing countries. Not only the actions of a buyer, but also those of its suppliers can directly affect the reputation and performance of a buyer's supply chain, both positively and negatively. The potential consequences of supplier actions highlight the importance for companies to clarify and implement their sustainability goals (Carter and Easton, 2011). These pressures have highlighted the need for companies to develop sustainable supply chain management (SSCM) approaches to minimise brand and financial damage (Lim and Phillips, 2008). Incorporating sustainability objectives into supplier selection decisions offers companies the opportunity to minimise supply chain risk, which has increased due to the inter-global nature of networks (Finch, 2004). SSCM is a rapidly evolving area for both the academic and practitioner communities seeking to understand and manage the potential issues that can arise from the supply base (Seuring and Gold, 2013). Research on this topic has historically focused only on the economic dimension such as product price, product delivery and service, lead time required, and product quality, providing little information or insight into the environmental and social aspects

(Genovese et al., 2013). In their 2012 systematic literature review on supply chain sustainability, Ashby et al. (2012) found that less than 18% of papers documented the economic, environmental, and social aspects together, compared to the one-way economic dimension or the one-way environmental dimension. For example, scholars such as Zhang et al. (2016) did not consider social aspects in their early research on environmental management. In the past, other researchers have also argued that only environmental issues are a subset of sustainability issues (Agle et al., 2001). The ambiguity of the definition of sustainability has led to a lack of research in this area (Klassen and Vereecke, 2012). The lack of clarity in the literature is reflected in the practise of organisations. For example, in the literature, the concept of sustainability emerged after that of business, and the same pattern can be observed in practise. In the past, managers believed that they covered all aspects of sustainability when they considered Green Supply Chain Management (GSCM) practises and adhered to CSR standards. Sustainability may not have been considered at all. Research has found that the challenges faced by managers who are supposed to ensure a sustainable supply chain are due to the confusion created by the interaction and misalignment of the green supply chain (Storey et al., 2006). Therefore, definitions and clarity of the concept are needed to achieve directly applicable and relevant outcomes. The development of standards to support the formation of a sustainable supply chain is in its early stages. Currently, there are a variety of guidance documents to help companies interpret the SSCM dimension; these include Global Reporting Initiative (Ismail et at., 2021), United Nations Compact (Bell and Morse, 2008), and International Organisation for Standardisation (ISO). These documents are a useful starting point, but they do not provide enough specific measures to help companies establish their sustainable supply chains. This impacts on the measurement of sustainability in the supply chain, which cannot be achieved if the measures against which they can be measured are not yet defined. This imbalance in research, based on the premise that all three dimensions of the Triple Bottom Line (TBL) (Hourneaux, et al., 2018), namely the economic, environmental and social dimensions, are equally important (Carter and Easton, 2011), is exacerbated when considering the initial stages of supply chain formation. The academic and managerial literature on the mechanisms for building sustainable supply chains in relation to purchasing and supplier selection is very limited, but the activities involved are the starting point for developing a platform for interdependent organisations to work together (Carter and Jennings, 2002). Today, companies need to consider the sustainability of their operations and decisions along the entire length of the supply chain and expand the scope of procurement beyond the traditional remit of quality, cost, and delivery (QCD) to include all aspects of the three-bottom line. Therefore, the development of delivery support mechanisms and the use of criteria to assess supplier capabilities and skills is required to meet the buyer's requirements (Gimenez and Sierra, 2013). Metrics such as food miles, carbon footprint, and air quality have emerged as metrics to support buyers in building a green supply chain. Corresponding metrics in sustainable supply chains are more problematic as some aspects need to be measured in terms of societal well-being, such as 'community impact'. Various stakeholders have an interest in improving sustainability standards in supply chains as they are likely to benefit from the agenda. SSCM is an important global issue, the improvement of which will significantly change the lives of people, both those directly and those indirectly involved with the supply chain. Suppliers will benefit by having the opportunity to demonstrate good behaviour, increasing their chances of being selected by buyers. As these criteria increasingly become a factor in decision-making, suppliers will need to increase their activity in areas where they need to improve. Transparency of supplier behaviour not only leads to winning new business, but also to more sustainable business relationships between parties in the supply chain (Leppelt et al., 2013). In addition, the supplier's local community benefits from better sustainability behaviour based on the type of criteria against which it is measured. For example, ensuring a fair living wage and no forced labour means that people in local communities have the opportunity to improve their lives in line with the expectations of global stakeholders, thus achieving a better quality of life for this group of people. Buyers benefit from a better reputation for sustainability as they can demonstrate that their supply chain meets consumer expectations. In addition, focused companies reduce their reputational risk and the risk of supply chain disruption by preventing a sustainability disaster from occurring (Zsidisin and Ellram, 2003). Consumers, policy makers, shareholders and academics also benefit from research on sustainable supplier selection. Some consumers demand more transparency in their purchases and benefit from more freedom of information regarding the supply of these goods. Policy makers will benefit from new insights into supplier behaviour in an area plagued by measurement problems. For example, the GRI framework and UN Global Compact have not provided metrics for their sustainability criteria (which are very broad). Academics have also struggled to keep up with the environmental metrics provided in the publication pipeline. In 2014, Sarkis and Dhavale first proposed trying to do this for sustainability. Therefore, the research will contribute to an academic field that is underdeveloped in researching metrics and best practises (Zorzini et al., 2015). However, sustainability initiatives require some form of investment that impacts on the economic bottom line and is scrutinised by stakeholders who have a financial interest in the business. Nonetheless, arguably, a shared value approach where all three aspects are important because it is better for your business to take care of the three-bottom line (TBL) is worth the effort for higher returns (Porter and Kramer, 2011). The involvement of new suppliers in the supply chain puts the decision on supplier selection at the centre of purchasing activities. Companies today need to take more responsibility for the behaviour and actions of their suppliers due to pressure from stakeholders and potential investors, as well as the durability of their company's survival (Miemzyck et al., 2012). Therefore, the implementation of sustainability relies heavily on the procurement function through the use of sustainable procurement (Schneider and Wallenburg, 2012). Consequently, investigating the systemic issues at the interface of sustainability, purchasing and procurement is an area for research to address (Linton et al., 2007).

In many other industries, for example automotive industry, production of TFT-LCD display, pharmaceuticals industry, telecommunications company, watch production, food industry, electronics and appliances industry, and packaging production, sustainability has become a growing concern for all manufacturing sectors. In recent years, sustainability practises have become a major topic of conversation for automobile manufacturers around the world. The automotive industry has had to shift its focus to adapt to this trend. In addition, the automotive industry is under significant pressure from governments and society to pursue a more sustainable growth model (Vasiljevic, et al 2018). Researchers show that sustainability requires significant investment, yet only 3% of executives and experts in the automotive industry say that most companies invest sufficiently beyond what is required (Jain, et al 2018). In the automotive industry, "Original Equipment Manufacturers (OEMs)" require a variety of components and parts to assemble the final product. Therefore, they need a strong and extensive supply chain with a large number of suppliers. This fact makes the automotive industry one of the most important industries compared to other industries when it comes to selecting suppliers for the supply chain (Lin, 2004). One of the necessary components of a car is tyres, and the most important raw material for the production of car tyres is rubber. Although there is a lot of research on other car parts from an academic perspective such as gearbox (Fallahpour et al., 2017), car seat manufacturer (Phumchusri and Tangsiriwattana, 2019), digital technology (Hasan and Nihan, 2022), and battery (Jayant et al., 2019), tyre rubber still lacks comprehensive knowledge on sustainability. Moreover, tyres are rapidly becoming a new environmental issue, which will affect the automotive industry. For this reason, the researcher is motivated to explore the decision-making process for sustainable supplier selection at all levels of Thai tyre manufacturers as there is a lack in the available research on this topic. Appropriate supplier selection processes help companies to increase their productivity and customer satisfaction. However, selecting a supplier is a problem that involves many factors and criteria, including both subjective and predictable factors. A balance among these factors is necessary to ensure the selection of the most suitable supplier (Fu-Jiang et al., 2006). Therefore, a company must ensure that its strategic processes include supplier decision making. As a company becomes more and more dependent on its suppliers, the process of supply chain management becomes more and more important to avoid possible consequences of a wrong decision.

1.2 Overview of Tyre Rubber Industry

The global demand for rubber was 9.9 million tonnes in 2010 and is expected to increase to 14.3 million tonnes by 2022, with an average annual growth rate of 3.7% compared to production the previous year, as shown in Figure 1-1.

Strong growth in the global rubber industry is expected due to increased vehicle production and demand for rubber-based components, development of new rubber-based materials that improve performance and durability, and government regulations aimed at reducing emissions and improving fuel efficiency, which can lead to the use of more rubber-based components in vehicles. Additionally, the shift towards electric vehicles is expected to further increase demand for rubber-based components in the global automotive industry, with particular demand for rubber from China, India, South Korea and regions in South America (TRA 2012b).

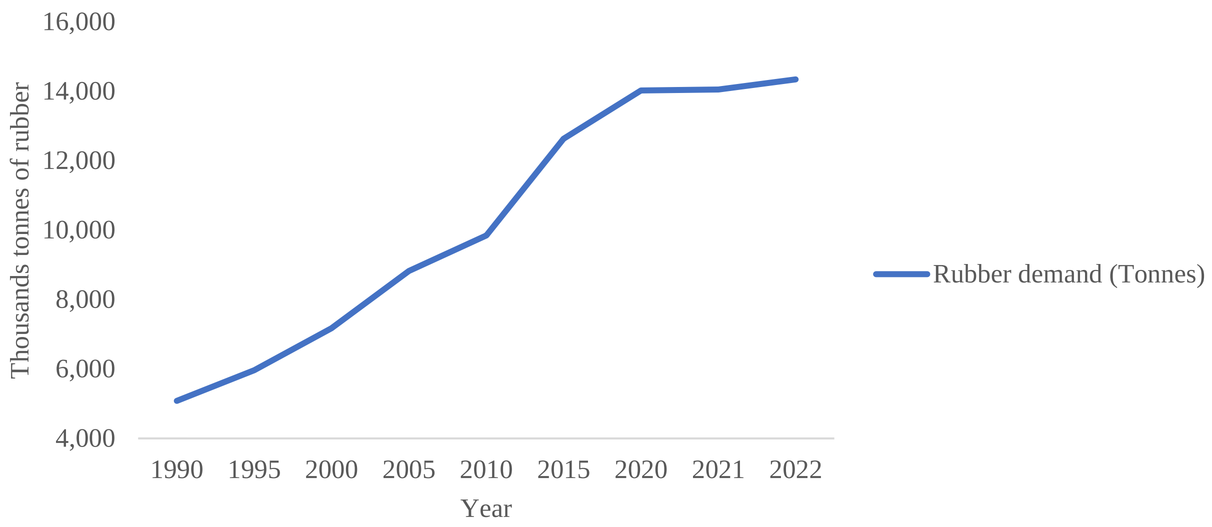


Figure 1- 1 Rubber demand (The Association of Natural Rubber Producing Countries)

The tyre industry dominates rubber consumption, accounting for about 70% of total demand. Thailand is currently the largest natural rubber producer in the world with a global market share of 32% (OAE, 2021) (see Table 1-1). Indonesia, Vietnam, India, and Côte d'Ivoire follow in second to fifth place.

Table 1- 1 Global tyre rubber production: unit 1,000 tons (OAE, 2021)

Country/Year	**2018**	**2019**	**2020**
Thailand	4,923	4,849	4,860
Indonesia	3,630	3,449	3,366
Vietnam	1,138	1,182	1,226
India	956	960	963
Côte d'Ivoire	624	780	936
China	824	840	688
Malaysia	603	640	515
Guatemala	391	397	436
Philippines	423	432	422
Cambodia	220	288	349
Others	1,144	1,157	1,240
Total	14,877	14,973	15,001

The Office of Agricultural Economics in Thailand (OAE 2021) displays the highest rubber production from 2018 to 2020. Rubber production is expected to reach more than 16 million tonnes by the end of 2021. Thailand is expected to remain the leading rubber producer, followed by Indonesia and Vietnam. Malaysia is expected to lag behind Vietnam, which is ranked fourth in ASEAN and sixth in the world.

1.3 An Overview of The Tyre Rubber Industry in Thailand

Starting with the Thai rubber supply chain, Figure 1-2 illustrates the rubber supply chain and production process. There are three main components:

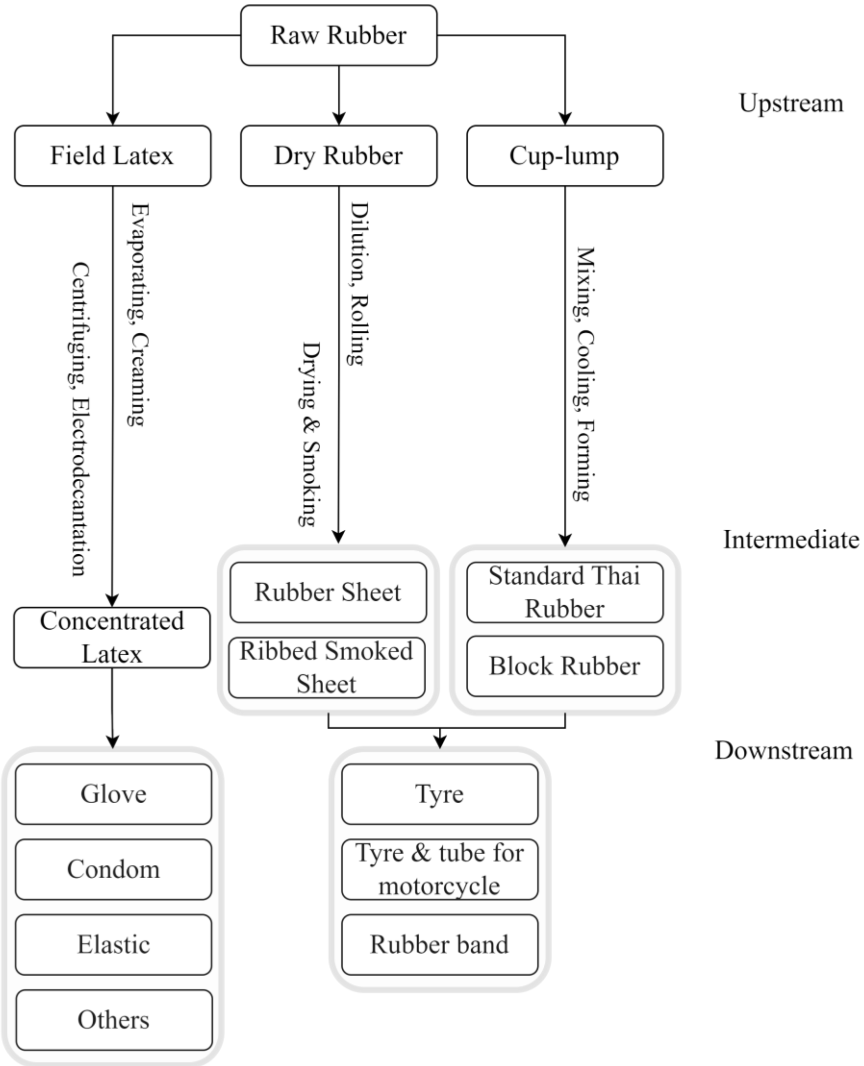


Figure 1- 2 The Rubber Supply Chain and Production Process

(1) Upstream industries involve the growing and harvesting of rubber on plantations by growers and tappers, but to add value to primary production, some producers engage in basic processing of their field latex to produce dried rubber products, such as cup lump, scraps, raw sheet and crepe rubber. Almost all upstream production in Thailand is consumed as inputs into domestic midstream industries.

(2) Intermediate or midstream industries, or rubber processors, take rubber produced on plantations and convert this into semi-finished products, such as ribbed smoked sheet (RSS), technically specified rubber (TSR), concentrated latex, compound rubber and skim rubber, which variously have the qualities and properties required as inputs to downstream production.

(3) Downstream producers, which is this Thesis focus on research, include manufacturers of items such as automobile tyres, latex gloves, condoms, elastics, and so on. Meanwhile, synthetic rubber, which has been developed by the petrochemical sector, may be used in place of natural rubber in applications where its qualities make it more suitable. Tyre manufacturing consumes 49% of all rubber producers as shown in Figure 1-3 (Sowcharoensuk, 2021).

Figure 1- 3 Downstream of Thailand rubber industry (Sowcharoensuk, 2021)

Apart from being a major international automobile manufacturer, Thailand is a major part producer. The part production is also in line with automobile production. According to Figure 1-4, the autoparts export consists of Electronics and Electrical Appliances (E&E), Motorcycle Parts (MC Parts), Motor Vehicle Parts (MV Parts), Transmission, Engine and parts, Tire (Tyre), and other autoparts. However, most export auto parts are motorcycle and motor vehicle parts, tyre rubber, and engine and parts respectively.

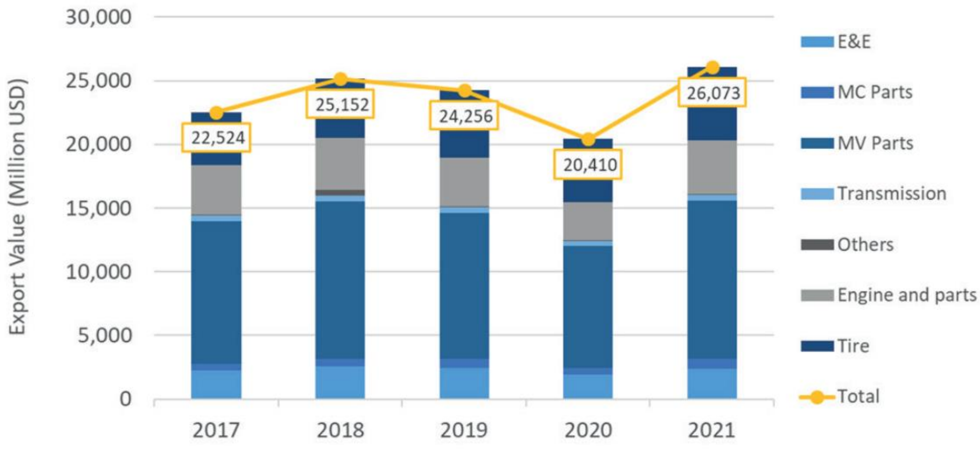


Figure 1- 4 Auto parts export value in Thailand (Thailand Automotive Institute Annual Report 2021)

In addition, important factors affecting this sector include the direction of government support (e.g., use of rubber by public sector organisations), loans to support a sustainable rubber industry in Thailand, and decisions by overseas investors to relocate production bases, especially Chinese investors in the tyre industry. Tyre rubber industry is also supported by the following: Michelin opening a new factory to produce off-road tyres for distribution in Thailand and to export to Asia, Africa and the Middle East, as well as to be a hub to produce tyres for Ford, Isuzu, Mazda and Toyota, The US-China trade war had prompted some Chinese tyre manufacturers to shift production to Thailand (Thailand Automotive Institute, 2020). As a consequence, exports to the US increased, and Thailand overtook China as the top exporter of tyres to the US for the first time, capturing 18.8% of the market by value (the Chinese market share declined from 16.7% in 2018 to just 8.5% a year later). In terms of tyre exports, Thailand rose to third place after China (18.7%) and Germany (7.2%), thanks to its 7.0% share of the worldwide market. The US (46.2% of the value of Thailand's tyre exports), the ASEAN region (13.9%), and the EU (8.9%) are the country's three most significant export destinations. (Yongpisanphob, 2020).

Sowcharoensuk (2021) indicated that the supply was 12.9 million tonnes worldwide in 2020. Thailand, which continues to be the world's major supplier of rubber, supplied 38.2% of this, or 4.4 million tonnes. Thailand is followed in significance by Indonesia, Vietnam, China, Malaysia, and India. In all, Asia is the source of 93% of the world's rubber. As a result, Indonesia, Malaysia, and the CLMV group are Thailand's major rivals among ASEAN manufacturers (Cambodia, Laos, Myanmar, and Vietnam) (Figure 1-5).

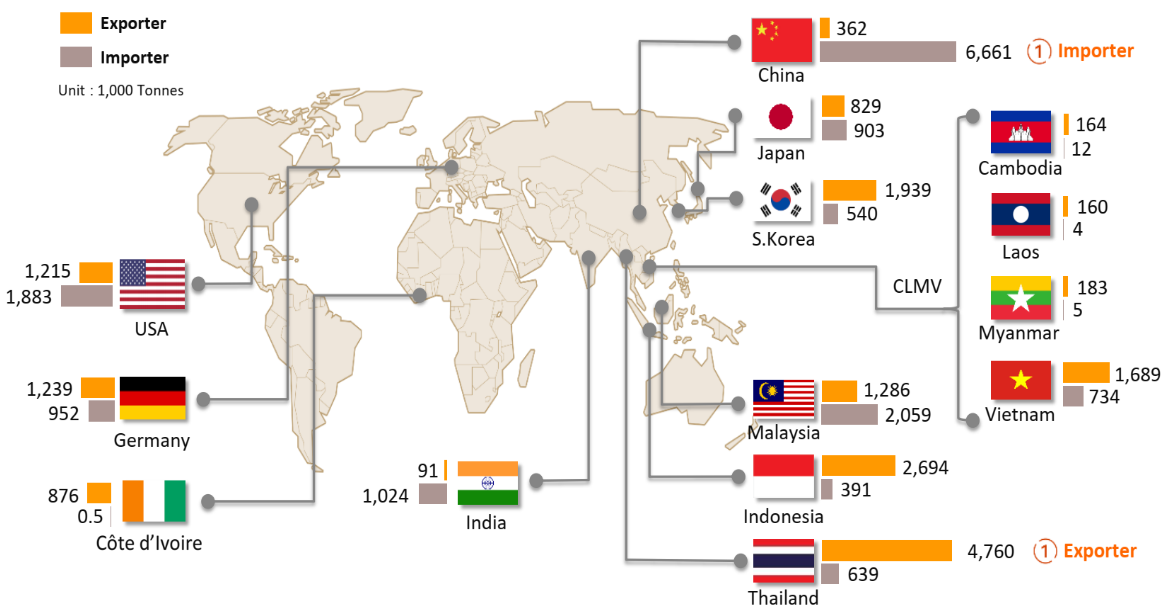


Figure 1- 5 Major Natural Rubber Exporters and Importers (Sowcharoensuk, 2021)

1.4 An Overview of Thai Autoparts Industry

The Thai autoparts industry has been receiving government support since 1963 (Niyomsilpa, 2008). Initially, state efforts to encourage investment in the domestic production and use of auto parts consisted of raising import duties on ‘complete built-up’ autos and ‘complete knock-down’ units (Tai and Ku, 2013). Later, as the government tried to attract foreign companies to establish production facilities in Thailand, Warr and Kohpaiboon (2017) stated that the Board of Investment introduced several investment incentives, including tax breaks for investors and waiving duties on imported machinery. These policies have encouraged Thai and overseas investors to set up autoparts manufacturing facilities in Thailand. Thailand now has a significant autoparts industry. The most important joint-ventures and Thai-only operations include Thai Summit Auto Parts, Summit Auto Parts, Somboon Advance Technology and Thai Auto Press Parts. The major international players active in Thailand include Robert Bosch, Denso, Magna, Continental, ZF and Aisin Seiki (Warr and Kohpaiboon, 2018). Most manufacturers have received some form of support from the government for the manufacture of parts made from rubber (which depend on domestic production of rubber inputs), including tyres.

In terms of the market for auto parts, the domestic Thai market is the most important and it provides around 65-70% of the sector’s total income (Leenutaphong et al., 2021). The most commonly exported goods are including tyres and rubber products. Thanks to the extensive and developed supply chains, Thailand’s auto parts industry is able to generate economies of scale. Coupled with the ability to produce parts that meets auto manufacturers’ specifications, Thai auto parts producers are competitive on world markets. Thailand’s strategic geographical location also allows the country to be an auto parts manufacturing hub for the ASEAN zone and other industries. These factors have helped Thailand to turn into a major supplier of autoparts globally.

Thailand ranked 14th globally and first in the ASEAN region for exports of car components in 2019, and it is the third-largest exporter of tires globally (Yongpisanphob, 2020). The most common destination for these exporters is production facilities elsewhere in the ASEAN zone, including Indonesia, Malaysia, Vietnam and the Philippines. However, labour cost in Thailand is higher than in Indonesia and Vietnam, and the level of research and development in the industry is low compared to Malaysia (Thailand Automotive Institute, 2020).

At present, there is a total of 1,735 operators active in the autoparts sector in Thailand (Jermsittiparsert et al., 2019) as shown in Figure 1-6. The Tier-1 manufacturers are those which produce high-quality products that meet vehicle manufacturers’ specifications. Currently, there are 709 tier-1 operators, of which 54% are foreign-owned, 23% are joint ventures, and 23% are Thai owned (Jermsittiparsert et al., 2019). Also, 1,000 Tier-2 and tier-3 manufacturers are generally Thai-owned SMEs. These usually have lower levels of investment in research and development and employ lower levels of manufacturing technology than tier-1 operators do and so they are therefore at a disadvantage when competing in the OEM market.

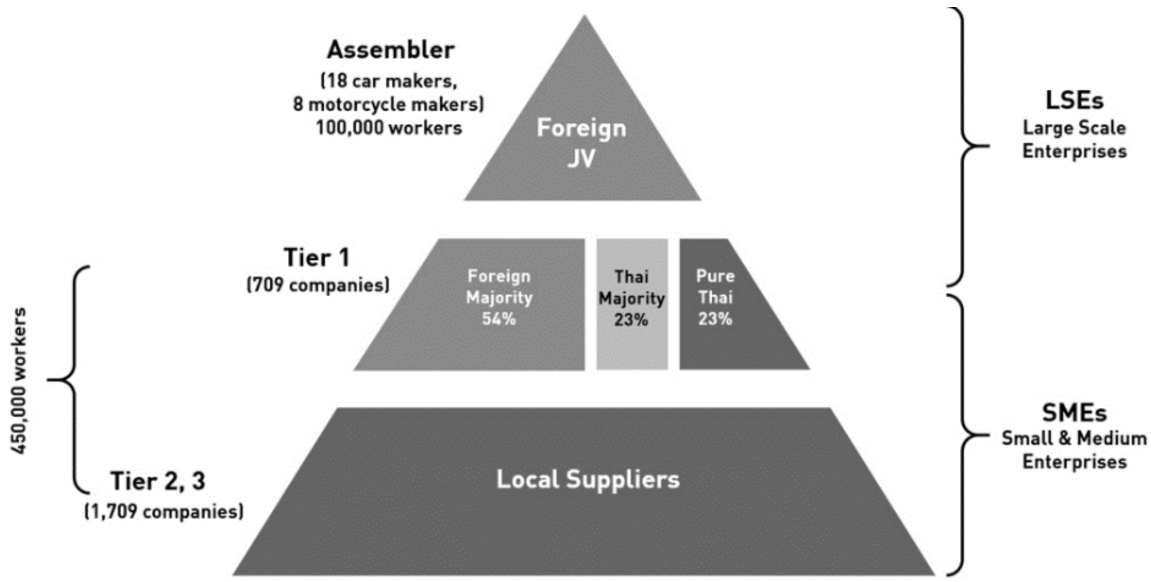


Figure 1- 6 Structure of Thai automotive industry (Jermsittiparsert et al., 2019)

1.5 Sustainable supplier problem in Thailand

Although Thailand has benefits from the price of rubber which rose to historic highs Global demand for rubber rose sharply, especially from China and India, which at this time saw their economies grow quickly. As the tyre rubber sector developed rapidly, environmental and social issues have also drawn considerable attention over the decade. In Global Sustainability Index Thailand get ranked 154th from 180 countries. For environmental standards, the number of ISO 14001 (environment) certificates among Thai rubber producers is lower than that of other rubber producers in Asia. In addition, there is none of ISO26000 (social) certificates used in organisations. There could be several potential explanations, firstly, lack of awareness or understanding. It is possible that Thai producers and organizations are not aware of the importance and benefits of ISO14001 and ISO26000 certification. Thai producers and organizations have the resource constraints to dedicate towards obtaining these certifications. Then, the regulatory environment in Thailand is not stringent or enforced to companies, which reduce the perceived need for certification. This means that companies concentrated most on the economic dimension whereas, environment, and social aspect were not much explored. The main issue for companies and organisations is how to choose the most appropriate supplier with regard to sustainability.

1.5.1 Environmental supplier selection problem

Green management, in Thailand, has been widely implemented in multiple sectors, including the tyre rubber products sector. Rubber is a necessary raw material for producing products such as car tyres. The demand from the automotive industry in Thailand has risen continuously (Chanchaichujit et al., 2016). Several manufacturers, who demand tyre rubber for their manufacturing, are increasingly engaging in green supplier selection. There are several reasons. Firstly, consumers are becoming increasingly aware of the impact of their purchasing decisions on the environment. As a result, manufacturers are under pressure to ensure that their supply chains are sustainable and environmentally friendly. Secondly, many companies have established sustainability policies that require them to consider the social and environmental impact of their operations. Thirdly, companies that rely on suppliers for critical inputs, such as tyre rubber, face supply chain risks that can impact their operations. By selecting suppliers who are committed to sustainable and environmentally friendly practices, companies can reduce their exposure to supply chain risks, such as environmental disasters, regulatory penalties, and reputational damage. Typically, the firm carefully assesses relevant green criteria when choosing a supplier of tyre rubber. Nonetheless, utilizing environmental criteria are not certainly in the final evaluation because there are trade-offs between environmental, social, and economic factors that need to be considered in the decision-making process. In some SMEs companies, decision-makers prioritize other factors such as cost, time, or regulatory compliance over environmental considerations. Besides, a green assessment may adversely impact between upstream and downstream in ambiguous condition. In such cases, conducting a green assessment may have unintended consequences, such as penalizing suppliers who have made efforts to improve their environmental performance but are unable to fully demonstrate their progress due to incomplete or ambiguous data. Additionally, this may cause negative effects on the relationship between upstream and downstream partners in the supply chain. And finally, the reputation of business results in negative impacts, particularly regarding corporate social responsibility.

1.5.2 Social supplier selection problem

The social dimension was not much explored due to complexity of human behaviour in workplaces (Carter and Easton, 2011). According to the very complex human problems, very little has been achieved on social sustainability in the supplier selection (Chai et al., 2023). In recent years, the awareness of social sustainability has enhanced not only in private companies, but also in public companies (Badri et al., 2017). An ethically questionable behaviour of suppliers has a major influence on brand image and business (Ehrgott et al., 2011). For instance, in South Africa, Mmereki et al. (2019) argued that waste tyres production led to health problems in communities. Another issue emerged in the automotive industry where Mansouri (2016) analysed the impacts leading to unethical action in emission tests.

In the Thai industry, the firms are currently selected and evaluated only on economic criteria when choosing a supplier of tyre rubber. Bonfanti and Bordignon (2017) described various aspects from a big international company which forced labours from Thai suppliers in terms of human rights, human trafficking, safety, health and hygiene in fisheries industry. In the Thai apparel sector, some companies recruited illegal women immigrant workers from neighbourhood areas because they accepted lower wages (Kusakabe and Pearson, 2013). The majority of these circumstances underline the weakness of the upstream elements of supply chain affecting suppliers. The previous studies solely focused on conventional business and economic factors. A few studies concentrated exclusively on the selection and assessment of suppliers' social sustainability.

1.6 Significance of the Research

There is a large number of automobile companies that do not all follow the same strategy, do not have the same reputation in the market and do not have the same financial status. The growing competition forces the companies to make various resources and efforts to improve the companies' purchasing process and evaluate the suppliers considering all the risks associated with each supplier. Each company has a different process for selecting suppliers; there are some companies that do not follow any formal process for evaluating suppliers as only the records of reputed suppliers are considered, while there are other companies that follow a highly complex process with professional help (Anderson et al., 2008). As the suppliers have different strengths and weaknesses, the departmental managers need to carefully evaluate the suppliers before finally selecting them. Relying solely on experienced managers to make supplier decisions may lead to personal preferences and biases, potentially leading to suboptimal choices. However, in this research, multi-criteria decision-making methods provide a structured approach for analysing and comparing supplier options based on multiple criteria, reducing subjectivity and bias. Several studies analysing the customer-supplier relationship have highlighted the need to pay special attention to improving the quality of the products and services that companies offer to their customers. Nowadays, purchasing decisions have become central activities. Therefore, the process of supplier evaluation plays a crucial role (Sarkar and Mohapatra, 2011). In particular, supplier selection plays an important role in deciding the competitiveness of major customers (Boran et al., 2009). From this point of view, supplier selection is the subject of ongoing scrutiny (Kamann et al., 2004).

1.7 Research Aim and Objectives

1.7.1 Research Aim

To propose a combined multi criteria decision making model for assessing and selecting sustainable suppliers within the Thai tyre rubber industry.

1.7.2 Research Objectives

In order to achieve the above aim, the following list of objectives are proposed:

(1) Identify the set of main- and sub-criteria in sustainability for supplier evaluation and selection in Thai tyre rubber industry.

(2) Prioritise the order of main- and sub-criteria for evaluating and selecting sustainable suppliers.

(3) Perform a sensitivity analysis on a decision-making model of sustainable supplier evaluation and selection.

1.8 Scope of the Thesis

The scope of this study consists of foreign assemblers, Tier-1 autoparts suppliers and Tier-2 local autoparts suppliers of tyre rubber industry in Thailand. Small- and medium-size tyres suppliers are included in this research. This does mean that they have impact on the Thai tyre rubber industry, or that the sustainability evaluation of these suppliers is important. In addition, it is assumed that the respondents involved in the questionnaire and exploratory survey are acquainted with every tier of the industry.

1.9 Contributions to Knowledge

In summary, the main contributions of this research are as follows:

(1) The endeavour of this research is to investigate the supplier selection decision-making process in Thai tyre rubber industry companies, also the presence and usage of sustainable criteria to support the decision-making process. The research provides an in-depth understanding of the decision-making process and the most relevant main and sub-criteria for sustainable supplier selection. This research identifies Thailand as a key player and a developing country, that contributes to the global tyres production. It focuses on a new supplier selection decision-making process in sustainability, thus providing a contribution to knowledge.

(2) A thorough investigation of the extant literature that has been found that studies sustainable supplier selection decision-making in multi-criteria decision-making models. So far, they have mostly been conducted using a single-criterion approach model. However, the approach of this study is a novel quantitative combined decision-making model based on case-study approach.

(3) Another contribution of this research is the discussion of the awareness of sustainability concerns that different companies use practically to support their supplier selection decision-making process in Thailand.

1.10 Novelty of the Thesis

The novelty of this research is that it includes economic, environment and social criteria as the triple bottom line that is explored in the sustainable supplier evaluation and selection criteria model within the tyre rubber industry in Thailand. This is the first study to examine the Tyre rubber companies' industry using the advantages of the fuzzy analytic hierarchy process (FAHP) and fuzzy technique for order performance by similarity to ideal solution method (FTOPSIS) approaches.

In addition to this research, a combined approach in multiple criteria decision-making model is proposed and applied.

1.11 Other considerations

The study is conducted in Thailand, the population sample is limited to major assemblers, Tier-1 autoparts suppliers and Tier-2 local Auto parts suppliers in the tyre rubber industry in the country.

Criteria which influence the results of this study may practically be applicable in the Thai business context. Therefore, results of the study may not be generalised without changes at the global level because tyre rubber suppliers in other parts of the world that may be operating in different business climates.

1.12 Structure of the Thesis

This research is presented in six chapters, the details of which are outlined in brief below:

Chapter 1: Introduction

An introductory chapter is to discuss the background and scope of the study, as well as significance of research, stating aims and objectives, limitations involved in the contribution to the study.

Chapter 2: Literature Review

A review of the existing literature on supply chain management, sustainable supply chain management, sustainable criteria for supplier evaluation and selection, and the existing research within sustainable supplier selection decision-making. It does so by considering all research published in academic journals. This chapter identifies all of the shortcomings of the various studies undertaken so far, and identifies the void in sustainable supplier evaluation and selection.

Chapter 3: Methodology

This includes the research approach and design, respondent sampling and population, data collection, data analysis procedure, pilot study, and the analysis method. The data collection section is described including data collection, sample selection and participation, developing the survey questionnaire, item measurement scales and pilot study.

Chapter 4: Findings

This chapter presents the main study, analysis and findings. It contains a survey questionnaire, data analysis and the outcomes of multiple criteria decisions making.

Chapter 5: Discussion

This chapter discusses and reviews the result of the findings discovered in combination with the literature review.

Chapter 6: Conclusion

The final chapter will conclude the Thesis with a summary and the limitations of the study, contribution and, novelty of the study. In addition, recommendations can be found for practitioners and academics.

2. Literature Review

This chapter begins with a discussion of the different general concepts. This specifically includes sustainability, sustainable supply chain management, definitions and characteristics of traditional and sustainable supplier selection criteria, and modelling approaches in sustainable supplier selection.

The focus of this chapter is the review of literature on the sustainable supplier selection criteria and its modelling approaches. It will examine the contents of related studies in supplier selection influencing factors and criteria such as: quality and technologies, price, delivery and responsiveness, supplier relationship management, decision making tools and techniques, government procurement policy, and business ethics.

2.1 Sustainability and The Three Bottom Line

Recently, there has been an increased awareness of sustainability issues in both the management and the research fields. On the one hand, many large companies have started to report on their social and environmental performances. On the other hand, the concept of sustainability has also begun to appear in the literature of disciplines such as operations or supply chain management (SCM) (Carter and Rogers, 2008). The term "sustainability" was first coined by the World Commission on Environment and Development (WCED) (1987) and it is defined as: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs". However, this definition has been described as too general and difficult for companies to apply (Linton et al., 2007). In that sense, the way sustainability is usually operationalised in the operations and SCM fields is through the Three Bottom Line (TBL) (Elkington, 1998). The TBL concept includes environmental, social, and economic dimensions as measures of corporate performance. The tyre rubber industry is no exception, as it is a resource-intensive sector that has a significant impact on the environment and society. This literature review aims to explore the current state of sustainability in the tyre rubber industry in Thailand, with a particular focus on the environmental, social, and economic dimensions of sustainability. The environmental impacts of the tyre rubber industry in Thailand have been well-documented in the literature. For example, a study by Negash et al. (2021) found that the industry is a major contributor to air pollution, water pollution, and deforestation in the country. The authors suggest that reducing emissions from the industry and promoting sustainable land use practices could help mitigate these impacts. From an environmental standpoint though, the booming rubber industry is a cause for concern given that rubber production is energy-intensive and which also contributes to several environmental pollutions (Chanchaichujit et al., 2020). The tyre rubber industry also has significant social impacts, particularly in terms of labour rights and community relations. A study by Saksorngmuang et al. (2019) found that many workers in the industry face poor working conditions, low wages, and limited opportunities for career advancement. In addition, the industry has been criticized for its land use practices, which have often led to conflicts with local communities. The authors suggest that promoting social responsibility and stakeholder engagement could help address these issues. The economic sustainability of the tyre rubber industry in Thailand has been the subject of much debate in the literature. On the one hand, the industry is a significant contributor to the country's GDP and provides employment opportunities for many people (Phoungthong et al, 2021). On the other hand, the tyre industry is highly dependent on natural resources and vulnerable to fluctuations in global commodity markets. A study by Wongsuwat et al. (2021) suggests that promoting innovation and diversification in the tyre industry could help enhance its economic sustainability.

2.2 Sustainable Supply Chain Management

The increase in sustainability awareness can be clearly observed in the SCM discipline, whose focus has recently moved from considering cost and operational issues such as service improvement or quality, to also include environmental and social aspects (Jiang, 2009) as a way to pursue sustainability along the entire supply chain. Sustainable SCM (SCM) embodies the firm's plans and activities that integrate both environmental and social issues into SCM to improve the firm's sustainability performance as well as that of its suppliers and customers (Seuring and Muller, 2008). Based on this definition, two important aspects need to be highlighted. On the one hand, to achieve sustainability, firms should engage on both environmental and social issues. Firms should not only concentrate on the green supply chain but also make more socially responsible. On the other hand, sustainability extends the boundaries of the firm and includes not only the implementation of internal sustainable practices (e.g., use of clean technologies and/or the implementation of work/life balance policies) that improve the firm's sustainability performance but also the extension of sustainable practices to other partners in the supply chain (e.g., training suppliers on environmental risks). With the aim of having a positive impact on their sustainability performance, firms will mainly focus on this second set of practices (i.e., practices that aim to extend sustainability to suppliers) and will analyse and study their role on extending sustainability along the supply chain.

2.3 Supplier Selection and Evaluation Overview

To assess current practices of supplier evaluation, a selection of both academic literature and industry practices was reviewed for general content, depth of the content, and the general approach being taken to supplier assessment. A large body of literature centred on evaluating suppliers on a financial basis. More recent work relates to assessing environmental aspects of interactions with a supplier. In a few cases there are environmental and societal items considered together, but the literature is lacking with respect a comprehensive approach to all three of the TBL criteria at the supplier level. There has been work addressing the TBL at the enterprise supply chain level (Badurdeen et al., 2010), however the literature is still lacking at addressing the relationship with individual suppliers.

In his work "A Review and Critique of Supplier Selection Process and Practices", Sonmez (2006) reviewed 147 academic journal articles. In this work the articles were classified into five categories: decision criteria that should be used, use of decision making / support techniques and tools, buyer /

seller relationships, international supplier section practices, and e-procurement. It was noted that the evaluation of suppliers is a multiple criteria decision making (MCDM) problem that can have the complexity of having both qualitative and quantitative criteria. In this work, it is noted that the general trend on supplier selection is a five-phase process: 1) realisation of the need for a new supplier, 2) determination and formulation of design criteria, 3) prequalification (initial screening and drawing up a shortlist of potential suppliers from a large list), 4) final supplier selection, 5) monitoring whether the suppliers selected is feasible.

Zimmer et al. (2016) also categorize the types of models used in supplier selection literature, as seen in Figure 2-1. They provide a list of the corresponding methods used for each category of model that was reviewed.

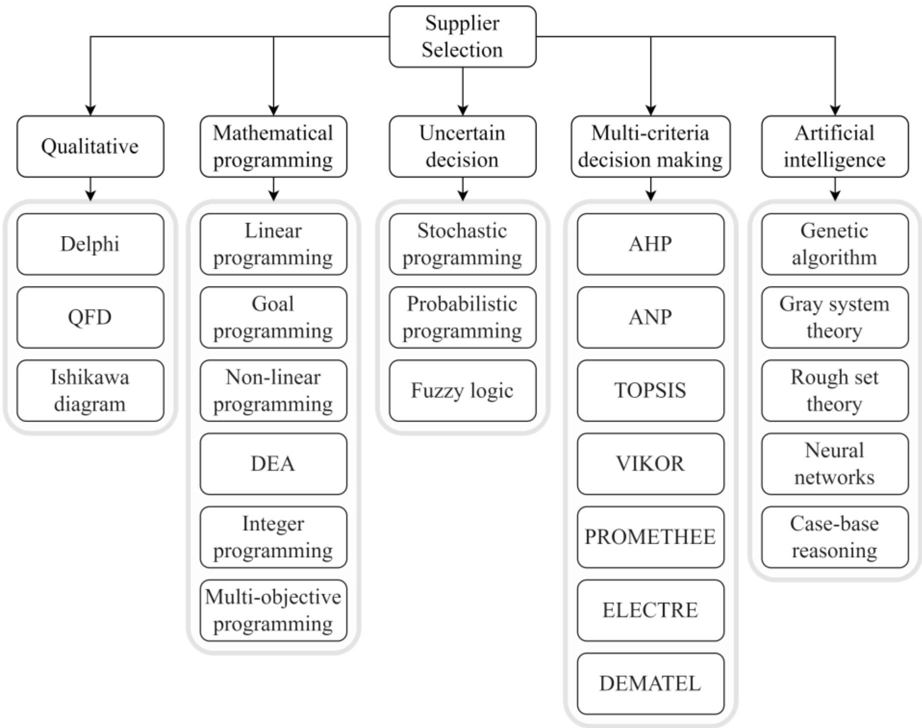


Figure 2- 1 Supplier Selection Methods

Figure 2-1 illustrates the different methods that have been employed for supplier selection, which can be broadly categorised into five groups. In order to identify the most suitable suppliers, a qualitative approach is commonly used, such as Delphi and QFD, which involve gathering input from multiple stakeholders and determining the specific criteria that are most pertinent to the organisation and its customers. The second group encompasses mathematical programming models, including data envelopment analysis (DEA) and multi-objective linear programming (MOLP) models. Fuzzy logic approaches constitute the third group, which evaluate suppliers in situations of uncertainty. The fourth group consists of methods based on the analytic hierarchy process (AHP) and analytic network process (ANP), both of which are multi-criteria decision-making (MCDM) techniques, as cited in the work by

Govindan et al. (2013). The fifth and final group involves the use of artificial intelligence models, such as artificial neural networks (ANNs).

Zimmer et al., (2016) also noted that supplier selection, like all decision-making problems, has two main tasks: the process of evaluation and assessment and summarising this information to allow for the choice to be made.

As in most of the supplier selection literature, Choi and Kim (2008) propose a hybrid e-Procurement decision support model that combines the selection of the appropriate suppliers by Multi-criteria Decision Making (MCDM) and optimization modelling by rule-based reasoning. This work classifies the criteria into two major categories: qualitative and quantitative. Choi and Kim's work is significant to the research done in the work here, due to the emphasis placed on the final selection of a supplier being 'multi-objective' in nature. The multi-objectives that are being considered by Choi and Kim's work are all relative to what can be called economic criteria, but nonetheless it places significant emphasis on the MCDM discussed previously. Zhang (2010) proposes a multi-attribute utility (MAU) model approach to selecting suppliers, but the work only provides a detailed mathematical method for performing this evaluation and has no criteria or metrics reviewed or listed.

2.3.1 Economic Metrics for Supplier Evaluation

Academic literature reviewing the financial impact of supply chain and supplier relationships tends to be detailed and quantitative in nature (Pagell and Gobeli, 2009). A variety of criteria have been used for supplier selection and the most common include cost, delivery, and product quality (Jain et al., 2009).

The economic health and fiscal security are crucial for any supplier relationship (Bryne, 1992) as a financially unhealthy supplier can cause significant disruptions in the supply chain and business in general. Bryne (1992) proposes generating four types of ratios to access the financial health of a given supplier. These ratios are liquidity ratios, leverage ratios, activity ratios, and profitability ratios.

All of these ratios are defined as coming from readily available information. The liquidity ratios measure a company's ability to meet the immediate financial needs of the business and include factors such as salaries, interest on debt, and taxes. Leverage ratios indicate the extent to which a company's funds are provided by creditors. These leverage ratios give an approximation of the financial risk of a company. The activity ratios show the correlation between sales and assets of a given supplier. It is a way of quantifying the revenues generated from its resources. The profitability ratios are a way of accessing whether a company generates enough profit to have long term viability. It is also significant to note that Bryne (1992) stresses the importance of comparing these ratios to industry specific standards and to perform a year-to-year comparison to establish a trend line. Significant work has been done to document and control both the supply chain and individual supplier relationships (Lambert and Pohlen, 2001), but these works do not consider the TBL objectives and view the relationships as strictly financial in nature. Economic dimensions are detailed in Table 2-1.

Table 2- 1 Economic Criteria

Main criteria	Sub-criteria
Cost	Cost and price
Delivery	Reliability of service
Product quality	Quality management
Finance	Economic performance
	Financial stability

2.3.2 Environmental Metrics for Supplier Evaluation

There have been both academic and professional literature generated which address the issue of suppliers being required or asked by their customers to become "green". A significant piece of relevant academic literature incorporating some TBL aspects into the supplier selection process is that of Humphreys et al., (2003). Humphreys et al. (2003) create a decision support system to evaluate suppliers based on seven environmental categories separated into two categories: environmental costs 'pollutants effects', and environmental costs 'improvement' with five metrics listed for each category. For environmental costs 'pollutants effects' the metrics are solid waste, chemical waste, air emission, water waste disposal, and energy, while the five metrics for environmental costs 'improvement' are buying environmentally friendly material, buying new environmentally friendly equipment, redesign of product, staff training, and recycling.

From an industry perspective "most green supply chain initiatives are the result of customer requests or government regulation" (Katz, 2009) and tend to look for compliance after the decision to have a supplier-customer relationship already been determined. This compliance is not insignificant and can be expensive, as it is estimated that $3 billion is spent annually by the electronics industry alone to conform to the European Union regulations (Katz, 2009). These categories and metrics are detailed in Table 2-2.

Table 2- 2 Environmental Criteria

Main criteria	Sub-criteria
Environmental costs 'pollutants effects'	Solid waste
	Chemical waste
	Air emission
	Water waste disposal
	Energy
Environmental costs 'improvement'	Buying environmentally friendly material
	Buying mew environmentally friendly equipment
	Redesign of product

	Staff training
	Recycling

2.3.3 Societal Metrics for Supplier Selection

When considering the societal aspects of the TBL, there are few academic resources as far as it relates to suitable metrics. A significant amount of literature on the societal sustainability aspects for suppliers comes from the Journal of Business Ethics. This literature however tends to look at what can be called brand protection, being concerned with the image portrayed (Amaeshi et al., 2008) or look at the pressures which cause a company to review its suppliers from a societal point of view (Ehrgott et al., 2011). According to the work of Ehrgott et al. (2011), there are six reasons that companies choose to be responsible from a societal standpoint in selecting suppliers: intensity of customer social pressures, intensity of government social pressures, intensity of social middle management pressure, supplier strategic capabilities, buying firm reputation, and extent of organisational learning in supplier management. There has been work which has attempted to quantify some of the societal aspects of business models (Darby et al., 2006), but the research is broad in nature and does not go into the metric level. Darby et al. (2006) state that there are six "accounts" that need to be reviewed in evaluating what is called the "social accounting" of a given entity. The six social metrics consist of a report on performance against stated objectives, an assessment of the impact on the community, the views of stakeholders on objectives and values, a report on environmental performance, a report on how equal opportunities are implemented, and a report on compliance with statutory quality and procedural standards. The 2002 United Nations Johannesburg Summit – Global Challenge Global Opportunity provides a framework from which metrics can be derived (Summit, 2002). This framework accomplishes this by reporting on what The Summit believes to be the most critical issues facing the future of the planet: population growth, poverty and inequality, food and agriculture, freshwater, forests, energy, climate change, health as it relates to water, and health as it relates to air pollution. The most comprehensive academic literature on societal metrics is contained in a working paper titled "ESAT: A Framework and Metrics for Corporate Sustainability Assessment" (Badurdeen et al., 2013). Unlike the previous works discussed in this section, their works present very detailed metrics and provides computational methods for calculating a value for each metric while indicating the desired trend for each metric to improve societal sustainability. The metrics are structured into nine performance criteria which are anti-corruption/anti-bribery, supplier development and training practices, employee development and training, customer satisfaction, customer awareness, compliance and product responsibility, employee well-being, community development, and diversity and equal opportunity. The paper does not define an acceptable level for metric scores. This is typical when reviewing environmental and societal metrics, as they tend to be specific to a particular industry or facility. The qualitative societal criteria are divided into five categories and these categories and metrics are detailed in Table 2-3.

Table 2- 3 Societal Criteria

Main criteria	Sub criteria
Employment stability	Job opportunity
	Employment compensation
Employment practices	Employee contracts
	Equity
	Labour sources
Health and safety	Health and safety practices
	Health and safety incidents
Capacity development	Research and development
	Career development
Human capital	Health
	Education
Productive capital	Housing
	Services infrastructure
	Mobile infrastructures

2.4 Sustainable Supplier Selection and Evaluation

As we have already mentioned, one challenge firms face when managing sustainability in its extension to other partners in the supply chain (i.e., suppliers) since firms are held responsible not only for their actions but also for their suppliers' environmental damages or unethical behaviours. As pointed out by Faruk et al. (2002) suppliers' poor environmental management can harm the buying firm's environmental performance. This is also true in the case of social issues. For instance, companies such as Nike (Lucchini and Moisello, 2019), Gap (Smith et al., 2011) or Apple (Sandoval, 2013) have been vilified because some of their suppliers were employing child labour in their facilities. As firms realize that customers and stakeholders do not distinguish between the lead company and its partners in the supply chain (Large and Gimenez, 2011), the need to develop governance mechanisms that allow them to extend sustainability along the supply chain becomes clear (Kytle and Ruggie, 2005). Many companies implement codes of conduct, supplier assessment practices and/or collaboration with suppliers in order to make their suppliers become more sustainable (Keating et al., 2008). In the SCM field, the set of practices aimed at improving suppliers' performance is known as supplier development (Krause et al., 2000). To improve suppliers' performance, buying firms can implement supplier development strategies such as assessing suppliers, providing suppliers with incentives, instigating competition among them or working directly with them (e.g., training suppliers' personnel) (Andersen and Skjoett-Larsen, 2009). In the context of sustainable SCM, two main sets of supplier development practices have been studied: supplier assessment and collaboration with suppliers (e.g., Gualandris and Kalchschmidt, 2014, Lee and Klassen, 2008, and Vachon and Klassen, 2006). Supplier assessment efforts by buying firms represent in-depth evaluations of the suppliers' performance (Krause et al., 2000). These activities can take the form of questionnaires, non-regulatory standards, or third-party audits (Min and Galle, 1997; Walton et al., 1998) and suppliers' company visits (Large and Gimenez, 2011). This evaluation process allows the buying firm to determine whether the supplier meets current and future business needs. The buying firm needs to quantify and communicate the results of the evaluation to suppliers so that they are aware of the possible discrepancies between their current performance and the buying firm expectations (Prahinski and Benton, 2004). Therefore, an essential part of the assessment process includes providing evaluative feedback to suppliers. This way, suppliers are given directions for improvement (Krause et al., 2000). Supplier collaboration entails the direct involvement of the buying firm in the supplier development effort. The buying firm's direct involvement includes investments in the supplier through training and education of supplier's personnel and/or dedicating buying firm personnel temporarily to the supplier (Krause et al., 2000). Examples of collaborative activities are providing training programs to suppliers, sponsoring meetings for suppliers in order to share information and experience, and undertaking joint applied research regarding alternative materials or processes (Lee and Klassen, 2008). This supplier development strategy represents transaction-specific investments in the supplier by the buying firm (Williamson, 1991). In the sustainable SCM literature, there is a growing body of empirical research that has studied these practices. Some papers have focused on their antecedents (Reuter et al., 2010) and others on their impact on different dimensions such as the management of sustainability (Ciliberti et al., 2008; Klassen and Vachon, 2003), environmental capabilities (Lee and Klassen, 2008), environmental investments (Klassen and Vachon, 2003, and Vachon, 2007), the successful implementation of codes of conduct (Lim and Philips, 2008), commitment (Simpson et al., 2007) and performance (Green et al., 2012). Table 2-4 provides a classification of the literature that has been studied. It includes papers that have analysed the antecedents of assessment and/or collaboration. In that sense, the literature has been classified according to the methodology used, the sustainability dimensions under study and the scope of the antecedent(s) considered (i.e., internal or external). Internal antecedents cover factors within the boundaries of the firm. External antecedents include factors beyond the firm's boundaries which are, in general, related to the environment in which the firm operates. Additional information related to the name of the antecedent(s), the countries in which the study has been performed and the results of each paper have also been included. Based on this literature review the following points need to be highlighted. First, most of the papers have analysed the antecedents of green supplier development practices, neglecting the antecedents for social ones. In fact, from the 10 papers identified, 9 papers have exclusively looked at antecedents of green practices, 4 have considered both economic and green practices, while only 1 paper focused on environment and social. However, there is no paper considered three dimensions together. Second, most of the papers have considered internal antecedents (7 out of 10). That is, most of the papers have looked at the influence that factors such as the firm's orientation towards sustainability or the provision of training have on the adoption of assessment and collaborative practices. Only 5 papers have considered the role of factors coming from the external environment in which the firm is embedded. It is also important to highlight that from these 10 papers, 2 have looked at both internal and external antecedents. Finally, in the literature there is no in agreement with respect to which factors influence the adoption of these practices. While some papers have found that external factors such as pressures coming from the government exert a positive influence on their adoption (Sarkis et al., 2010) others did not (Mathiyazhagan et al., 2014). One possible cause of these mixed results can be explained by differences in country. Most of the papers have been conducted in single countries. From the remaining papers, 3 have considered regions Europe, 1 in South America, and 4 include Asia countries in their samples. However, these papers have not considered the country level in their analysis. In other words, these papers have not studied differences in the influence of practices' adoption due to differences in countries.

Table 2- 4 Classification of the papers that analyse the antecedents of sustainable supplier development practices with "✓" = applies and "O" = does not consider

Author (Year)	**Method**		**Sustainability dimensions**			**Scope**		**Country**
	Survey	**Case**	**Economic**	**Environment**	**Social**	**Internal**	**External**	
Sarkis et al. (2010)	✓	O	✓	✓	O	✓	✓	Spain
Large and Gimenez (2011)	✓	O	✓	✓	O	✓	O	Germany
Hsu et al. (2013)	✓	O	O	✓	O	O	✓	Malaysia
Zhu et al. (2013)	✓	O	O	✓	O	O	✓	China
Gualandris and Kalchschmidt (2014)	✓	O	O	✓	✓	✓	O	Italy
Kannan et al. (2014)	✓	O	✓	✓	O	✓	O	Brazil
Mathiyazhagan et al. (2014)	✓	O	✓	✓	O	✓	✓	India
Jabbour et al. (2015)	O	✓	O	✓	O	✓	O	Brazil
Srinual et al. (2019)	O	✓	O	✓	O	O	✓	Thailand

Srinual et al. (2020)	O	✓	O	O	✓	✓	O	Thailand
Arvind et al. (2020)	O	✓	O	O	✓	O	✓	United Kingdom
Oey et al. (2020)	O	✓	✓	✓	O	O	✓	Malaysia
Beiki et al. (2021)	O	✓	O	✓	O	✓	O	Russia
Tayab and Sarkar (2021)	✓	O	✓	O	O	O	✓	Pakistan
Li et al. (2022)	✓	O	✓	✓	O	O	✓	China
Caristi et al. (2022)	O	✓	✓	O	O	O	✓	Italy
Cinnirella et al. (2022)	O	✓	✓	✓	O	✓	O	Italy
Mishra et al. (2022)	O	✓	✓	O	✓	O	✓	India
Acerbi et al. (2023)	O	✓	O	✓	✓	O	✓	Italy
Chai et al. (2023)	O	✓	O	✓	O	O	✓	China

2.5 Criteria in Sustainable Supplier Selection and Evaluation

In the literature and various publications dealing with the same or similar problems as in this paper one can find a large number of criteria for evaluating suppliers. However, the question arises how to choose the right and optimal solution from a certain set. Dickson (1966) was the first to study supplier selection and evaluation, Then, in his work, Ellram (1990) tried to increase the importance of qualitative criteria which should ensure long-term cooperation between the company and suppliers. He shared criteria in four groups: financial aspects, organizational structure and strategic issues, technological factors, and other factors (Table 2-5).

Table 2- 5 Ellram (1990) Criteria for Supplier Evaluation

Main Criteria	**Sub Criteria**
Financial aspects	Economic performance
	Financial stability
Organisational culture and strategic questions	Trust

	Management attitude
	Strategic plans
	Leadership ability
	Cooperation services between customer and supplier
	Supplier's organizational structure and staff
Technological issues	Assessment of production capability and capacity
	Assessment of prospect production capacity
	Supplier's design capability
	Supplier speed of development
Other factors	Safety and security at work
	Business references
	Supplier customers

The criteria shown in Table 2-5 are intended to encourage creation long-term partnerships between the company and suppliers, as well as to create an opportunity securing sources of supply for a longer period. To be able to apply this approach to supplier evaluation, the company must develop a different strategy for supplier performance evaluation. The authors tried to give an answer to the previously asked question at the end of the past century, and Webber et al., (1991) investigated the criteria for selecting suppliers in production and retail environment in 74 studies published from 1966 to 1991. Table 2-6 shows a presentation of the criteria established by the mentioned authors.

Table 2- 6 Summary of Criteria

Criterion	Importance of criterion
Net price	Great importance
Delivery	
Quality	
Production plants	
Geographical location	
Technical skills	
Management and organisation	Little importance
Reputation and position in the industry	
Financial position	
Historical performance	

The group of authors (Webber et al., 1991) concluded that the criteria of quality, delivery and price prevail as dominant, while geographical location, financial position and production capacities belong to a secondary group of factors. The criteria defined by Dickson and later modified by Webber are still broadly accepted in various studies. However, although the time and importance of individual criteria changes, this has been confirmed by the work of (Cheraghi et al., 2004) in which the authors included over 110 works who considered the issue of supplier selection. Verma and Pullman (1998) conducted research with 58 managers including operations managers or the managers with purchasing/supplier in order to examine how they compromise when choosing a supplier. Their research indicated that managers pay the most attention to quality as well the most important attribute of the supplier, followed by delivery and price. Impact research criteria in the supply chain continues at the beginning of this century, so Karpak et al., (2001) took reliability of delivery as a selection criterion, while Kraus et al., (2001) in their research saw the need to add innovation as a new equal criterion. According to Birch, (2001), before starting to define the most important criteria on the basis on which suppliers need to be evaluated, the approach involved must first define a customer-supplier relationship. Therefore, procurement managers must first execute certain agreements with suppliers and determine the conditions for negotiations. According to the same author, criteria for selecting suppliers can be classified into five different categories: costs, logistics, quality, development, and management. Bhutta and Huq, (2002) used four in their research criteria for supplier evaluation: price, quality, technology and service. In a study by Biebi and Bayraktar (2003), they addressed similar criteria as in the case in Birch (2001) and here the criteria are classified as: logistics, technology, business and business cooperation (Table 2-7). The goal was to create a model that makes a difference between qualitative and quantitative criteria.

Table 2- 7 Supplier evaluation criteria

Main criteria	**Sub criteria**
Logistics	Delivery time
	Lot support
	Flexibility in changing orders
	Reliability of delivery
Technology	Capacity to meet demand
	Products creation
	Product and process improvement
	Problem-solving ability
Business	Reputation and position
	Financial stability
	Management capability and compatibility

Relationships	Simple communication
	Previous experiences
	Business references and competence

The following authors, like most of the previous ones, used four criteria in their research: Guneri et al. (2009) quality, reputation, closeness of relations with suppliers and reliability, Shen and Yu (2009) technical capacity, quality, warranty period and innovation, and Boran (2009) quality, price, delivery on time and closeness of relations with suppliers. Büyüközkan and Çifçi (2011) used several criteria such as technical capacity, quality, price, financial position, production performance, etc., while Junior et al. (2014) in their research used quality, price, delivery that includes time and reliability, supplier profile which includes reputation and financial position and relationship with the supplier. Financial indicators, quality and delivery are present in almost all surveys as criteria for supplier selection (Fallahpour et al., 2017). These criteria can be considered as the main criteria which are further subdivided into sub-criteria if a larger number is considered, or as criteria without sub-criteria when it comes to evaluating suppliers on the basis of a smaller set of criteria.

2.6 Modelling Approaches for Sustainable Supplier Selection and Evaluation

There are diverse decision-making approaches for ranking suppliers based on different preferences. Although absolute categorisation is not possible for these approaches, some researchers have classified these modelling approaches into various categorises. One of the earliest attempts to review supplier selection approaches, Weber et al. (1991) identified and categorised sustainable supplier selection modelling approaches into three classifications. 1) Linear weighting models, 2) mathematical programming models, and 3) statistical/probabilistic approaches. In linear weighting models, the model assigns a weight to each criterion that is normally determined subjectively and aggregates the supplier's performance on each criterion based on the assigned weights. Finally, the suppliers are ranked based on the aggregated scores. In mathematical programming models, the supplier selection problem is formulated as a mathematical objective function that can be either maximised or minimised depending on managerial preferences. In addition, some constraints are embedded in the model to consider real-world limitations and increase the reliability of the results. The statistical/probabilistic approach considers the stochastic uncertainty that decision makers face in supplier selection; for instance, uncertainty in internal demand or order lead time may fluctuate or vary from one period to another. De Boer et al. (2001) extended the above classification by Weber et al. (1991) by embedding the total cost of ownership and artificial intelligence-based approaches into the above categorisation. Total cost of ownership models deals with all quantifiable and related costs the company needs to pay for purchasing an item. In other words, the cost of goods and services is not limited to their final price; it also includes other types of cost, such as maintenance cost and spare parts cost, that are considered in the supplier evaluation. The second group of models is artificial intelligence-based models, which enable decision makers to extract invaluable information for a new supplier selection problem based on computer-aided systems. In these methods, the computer aided systems are trained and developed by purchasing experts as well as by using historical data from previous purchasing instances. This trained system can provide invaluable information to non-experts dealing with similar purchasing situations. Chai et al. (2013) provided a new group of supplier evaluation techniques, known as a multi-criteria decision-making approach and stated that these techniques can be considered an independent group of models in addition to mathematical programming and artificial intelligence (AI) techniques. A multi-criteria decision-making approach provides a ranking for a set of alternatives based on several criteria chosen by experts. The field of multi-criteria decision-making has been in great development, before thanks to the large number of publications that deal with making certain decisions on basis of applied methods belonging to this area. This area is one of the fastest growing areas of operational research primarily because many methods have been developed and are still evolving (Stanujkic et al., 2013). Table 2-8 shows the recent developments methods of multi-criteria decision-making.

Table 2- 8 Overview of recent development in single multi-criteria analysis methods

Authors	**Method**
Luanghan et al., (2022)	SAW
Li et al., (2020)	DEMATEL
Kumar and Barman, (2023)	AHP
Zhang et al., (2019)	ANP
Atthirawong, (2020)	TOPSIS
Tong et al., (2021)	PROMETHEE
Fei et al., (2019)	ELECTRE
Dodevska et al., (2023)	VIKOR

Many papers have been recently published, which according to Zavadskas et al., (2016) apply various multi-criteria decision-making techniques to solve engineering problems. Everyday use of multi-criteria decision-making methods (Gul et al., 2016) certainly contributed to the growth of the popularity of this area (Zavadskasi, 2014). There are many single models of multi-criteria decision making that have been proposed for solving various problems in engineering. Akkaya et al., (2015) is proposed AHP model for solving problems in the field of industrial engineering. Chen and Yang, (2011) used limited AHP and TOPSIS for selection suppliers. These single methods have also been used to solve the following problems: for the selection and development of a logistics partner in return logistics (Prakash and Barua, 2016), ranking industrial alternatives for portfolio investment (Dincer et al., 2016), for the selection of equipment for handling (Yazdani, 2014), for the choice of mining method in a zinc production company in Iran (Yazdanii, 2014), or a single approach of multi-criteria decision-making with QFD method for supplier selection in the green supply chain (Yazdani et al., 2016), AHP for evaluation in return logistics (Acar et al., 2015), a VIKOR method for supplier selection (Mohaghar et al., 2013).

Taking into account all the above, it can be concluded that this area has recently, especially in the last few years, experienced expansion, and a large number of supplier selection problems arise to solve using methods that belong to the specified area. They are used to solve problems of different nature and have found great application in the field of management and logistics, where certain decisions are made on the basis of multi-criteria methods. There are a number of methods which belong to the area of multi-criteria decision-making, which is shown in Table 2-8. The most used, at least when it comes to supplier selection, are the AHP and TOPSIS methods, which can be observed from Table 2-8 where an overview of the most used multi-criteria methods is given decision-making in the field of evaluation and selection of suppliers, which will be used in within this paper. Recently, fuzzy methods are being developed (Fuzzy AHP, Fuzzy TOPSIS) in this field which are beginning to play a major role in research in different areas, including the area that is the subject of research. The study by Kumar et al. (2022) applied fuzzy TOPSIS method for supplier selection in the automotive accessories manufacturing industry are being increasingly used in supplier selection because they can handle imprecise and uncertain information better than traditional methods. Since Sharma et al. (2023) also found that the fuzzy approach improved the accuracy and flexibility of the decision-making process in supplier selection, highlighting the potential benefits of fuzzy methods in this context. The frequency of application of the Analytical Hierarchical Process method is also visible in the last decade. It is used to solve the problem of choosing a supplier, either in conventional form or combined with fuzzy logic, (Stević et al., 2015), selection of suppliers in industry (Barbarasoglu and Yazgac, 1997), selection suppliers for a textile company (Ertugrul and Karakasoglu, 2006), production areas (Chan I Kumar, 2007), supplier selection for TFT-LCD manufacturer (Lee, 2009), electronic procurement (Benyoucef and Canbolat, 2007), in a washing machine company (Kilincci and Onal, 2011), in a company motor gears (Ayhan, 2013), a supplier for a white goods manufacturer (Kahraman et al., 2003). Ho et al. (2010) reviewed the literature for application multi-criteria analysis in this area. There are a considerable number of publications that deal precisely with the comparison of classic AHP and fuzzy AHP such as (Aggarwal and Singh, 2013, and Stević et al., 2015).

AHP is often used in combination with other methods, as testified by (Stević et al., 2015), where the authors in the work of AHP use it to assess the weight of the criteria, and the TOPSIS method to obtain the final rank of alternatives (Balli, 2009, Mahmoodzadeh et al., 2007), a fuzzy AHP or fuzzy TOPSIS (Zeydan et al., 2011), to evaluate the performance of suppliers in the manufacturing company several types of electronic cards (Eraslan and Atalay, 2014). Shukla et al., (2014) show how one can perform these methods in fuzzy form in order to provide greater consistency in valuation in the prioritization of supply chain partners. Bronja and Bronja (2015) use these methods to select an aluminium sheet metal supplier.

These multi-criteria decision-making methods, such as AHP, ANP, or TOPSIS are very commonly used to determine the significance of the criteria and are an integral part of the analysis for the selection of suppliers and when they are ranked by some methods that do not belong to this area. It is used to perform the supplier evaluation process within the doctoral dissertation precisely a combination of several methods of multi-criteria decision making. To determine significance criteria this Thesis uses a fuzzy analytical hierarchical process (FAHP) that compares the criteria based on a fuzzy comparison scale, while some of the alternatives can be used to rank of the methods. In addition, the DEMATEL method for determination uses relative weighting criteria. As already emphasized in the previous section, Table 2-9 shows of methods for evaluation and selection of suppliers.

Table 2- 9 Overview of evaluation methods and supplier selection

Authors	**Industry**	**Methods**
Zeydan et al., (2011)	Automotive Industry	Fuzzy AHP
Lee, (2009)	Production Of TFT-LCD	Fuzzy AHP
Asamoah et al., (2012)	Pharmaceutical Industry	AHP
Önüt et al., (2009)	Telecommunications Company	Fuzzy ANP
Parthiban et al., (2012)	Automotive Industry	AHP
Liao and Kao, (2011)	Watch Production	Fuzzy TOPSIS
Liao, (2010)	The Food Industry	AHP
Junior et al., (2014)	Automotive Industry	Fuzzy TOPSIS
Chamodrakas et al., (2010)	Electronic Industry	Fuzzy AHP
Jamil et al., (2013)	Automotive Industry	Fuzzy TOPSIS
Roostaee et al., (2012)	Automotive Industry	Fuzzy VIKOR
Kang et al., (2012)	Packaging Production	Fuzzy ANP
Alimardani et al., (2013)	Automotive Industry	VIKOR
Azar et al., (2011)	Automotive Industry	TOPSIS

2.7 Knowledge Gap in the Application of Multi-criteria Decision Making on Sustainable Supplier Selection

Most of the previous research deals with specific problems, and the criteria that are used in them vary depending on the area in which they are applied. Lack all that has been said so far represents the non-existence of a universal general model which implies a set of criteria that, with very little modification depending on the area applications, could be used in different areas. In addition, a shortcoming is evident with respect to research in this area in the field of this research, which would indicate the current situation on the domestic market and the conditions that need to be met for the efficient conduct of all activities and processes in the procurement subsystem. Some authors in the region have dealt with the

field of procurement (Bronja and Bronja, 2015), but as said on the basis of a specific case, not taking in considering the differences that exist in the supply chain from the aspect of companies' activities.
Despite numerous new models that have been developed in multi-criteria decision making, the question arises as to which method or approach to apply. The goal is to enable decision makers as clearly as possible to express their preferences, reduce subjectivity and the uncertainty that exists in every decision-making process. Accordingly developed in this thesis is a new approach that takes advantage of hybrid multi-criteria decision-making method. Hybrid methods represent a modification of traditional approaches and take into account uncertainties in the stakeholder decisions that most often occur when assessing the importance of alternatives or criteria. Rough the numbers take into account the stated uncertainties through the possibility of expressing preferences for each alternative or criterion. Such preferences are further converted into fuzzy intervals, thus closer and with greater precision determines the preference.

2.8 Justification of the choice of Thailand for this study

Thailand is a newly industrialised market economy and has presented itself as one of the fastest growing economies in Asia (Wade, 1990, Bloom et al., 1998, and Ozawa, 1992).
The economy is relatively open, and state oriented just like most of the Asian economies, which makes this interesting. The tyre rubber industry is a significant contributor to the economy of Thailand, making it the leading producer in South East Asia, ahead of more populous Indonesia and Vietnam. In terms of GDP per capita value, Thailand ranks eighth among South East Asian countries (Vadra, 2015). In terms of GDP per capita, which is a measure of a country's economic output per person, Thailand ranks eighth among Southeast Asian countries. This suggests that while Thailand's economy is significant in the region, it is not the wealthiest in terms of per capita income. The Thai economy is hugely driven by manufacturing and is one of the most competitive in the world (Quinn, 1992). Moreover, it is important to indicate that the country’s economy is hugely dependent on manufacturing SMEs, and this sector has contributed massively to the success of the country’s external trade (Meyer, 2004). The industry sector accounts for more than 36.8%, which is more than a third of the country’s GDP and employs 36% of the labour force according to statistics released by the Department of Statistics in 2012. However, the industrial sector is mostly contributed to by the automotive industry, construction industry, and electronic industry. The highlighted facts justify the reason why Thailand is an important area of study when it comes to manufacturing process and operation. The gradual but consistent growth of the country’s industrial sector and the role of large enterprises and small-medium enterprises in this development are intriguing and can act as a benchmark through which developing countries can stimulate industrialised economic growth.

3. Research Methodology

The previous chapter focused on identifying a gap in the literature through thorough secondary research into current theories on incorporating sustainability criteria into sustainable supplier selection models and the criteria used to make these decisions.

This chapter presents an overview and understanding of the research methodology that is applied in this study. The purpose is to document the rationale behind the research design, data collection and data analysis methods chosen. The methodological approach was designed to address the research objective and the underlying questions in an effective way. The first section, which discusses the research philosophy of this project, will help to shape the research methods discussed in section 3.2, where both the advantages and limitations of the survey questionnaire and case study methods will be considered in order to explain the final research methods chosen for this research project. In the following sections, the procedures used for the questionnaire preparation, data gathering, and data processing will be explained. In Figure 3-1, This research consisted of five main phases. The phases were interlinked. These phases were necessary steps to achieve the objectives of the current research.

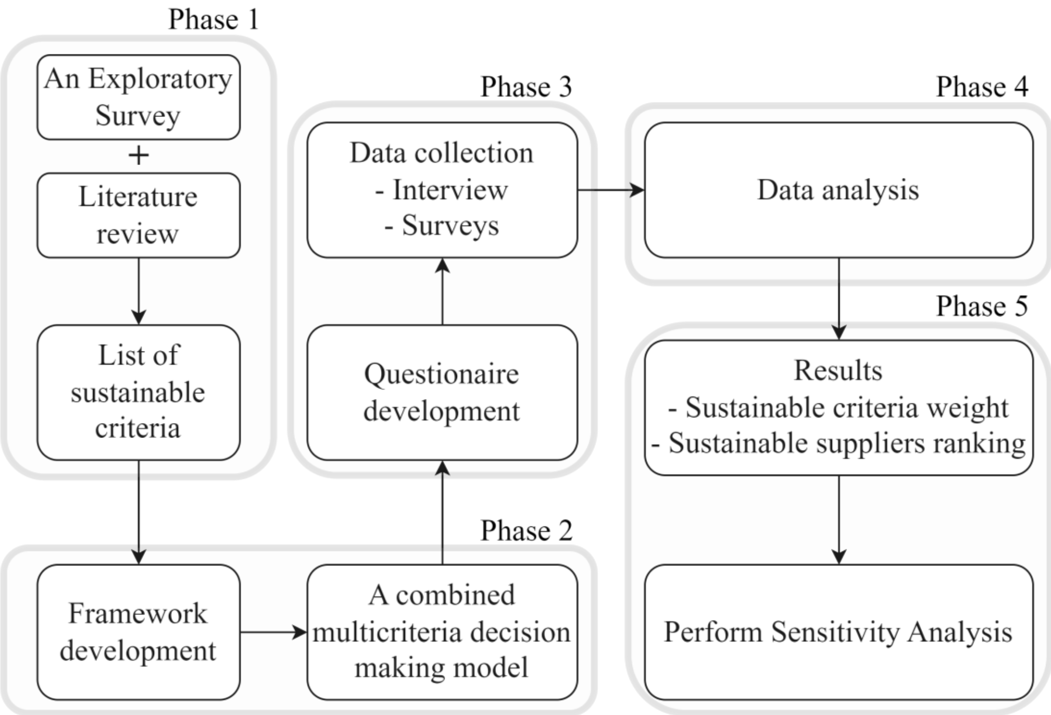


Figure 3- 1 Flowchart of the research process

3.1 Research philosophy

“Research philosophy” can be defined as an overarching term that relates to the development of knowledge and the nature of that knowledge with regards to particular research (Saunders et. al., 2009). The adoption of a research philosophy includes critical assumptions about the how the researcher views the world, and those assumptions will determine the choices of research strategies and methods.

Although it is an abstract term, “research philosophy” is of great importance to the research strategy design because it has a significant impact on the way the research is conducted, and the understanding of the research findings. Therefore, different philosophies adopted in research processes obviously lead to different findings and views on the same issue. Furthermore, according to Saunders et al. (2009), no one philosophy is better than another. The “best” way to carry out research only depends on the research reality – that is, obtaining answers to the research questions. Saunders et al. (2009) also pointed out that ontology and epistemology are two major ways to think about research philosophy, and these are often used in the science context.

With regards to this particular research, the epistemological research philosophy will be considered. Epistemology is the study of knowledge which tries to answer “what” questions. According to Bryman and Bell (2007), epistemology is about issues having to do with the creation of knowledge for particular concerns. This research focuses on the sustainability in supplier selection of large enterprises and small-medium enterprises within a particular territorial area in Thailand, and thus epistemological considerations are helpful in research design and the process of carrying out the research. According to Gephart (2004), based on the underlying research epistemology there are three categories of research paradigms or philosophical research perspective: positivist and post-positivist, interpretive, and critical postmodernism. In the present research, positivist and post-positivist, as well as interpretive, methodologies are used in this research.

Positivist and post-positivist methodology focus on realism, which refers to the objective realities that can be understood with reference to science (Lincoln and Guba, 2000). This methodology seeks to uncover the truth. Moreover, by using this methodology, the factual depictions of the world can be collected and analysed to reveal the definitive or probabilistic truths or realities, and to evaluate, verify or falsify hypotheses (Gephart, 2004). In addition, it usually uses precise, objective measures and is associated with quantitative data.

Interpretive methodology focuses on relativism, which refers to the inter-subjective realities composed of both subjective and objective meanings (Gubrium and Holstein, 2000). The goal of this methodology is to uncover, describe, and theoretically interpret actual meanings that people use in real settings. Furthermore, it is usually associated with qualitative methods, such as case studies, interviews, observational methods, grounded theory and textual analysis (Gephart, 2004).

Thus, considering the limitations of both quantitative and qualitative research methods, a multi-method strategy is chosen here to reject the narrow analytical paradigms in favour of breadth of information, which can be provided by using more than one method. Quantitative research allows the collection of a large amount of data from a sizable population in a highly economical way, while qualitative research provides detailed information to explain social phenomena in depth; therefore, the combination of these two approaches is a popular strategy at present, especially in business and management research (Morgan, 1998). Based on the discussion the research method used in this study can be summarised as shown Figure 3-2.

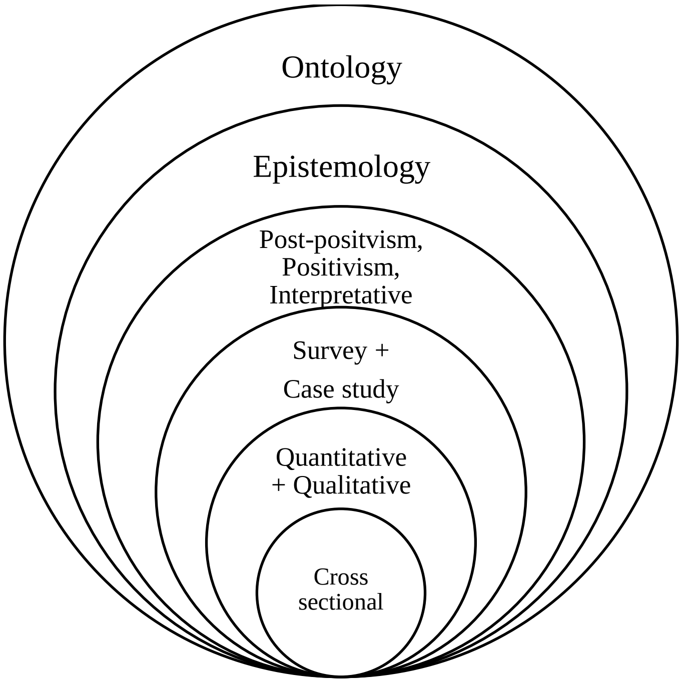


Figure 3- 2 The research methodology used in this study

3.2 Research design

Research design is a general plan of how the researcher intends to answer the research questions that have been set (Saunders et al., 2007). Research design entails defining the nature of the methodology to be implemented, as well as the spatial location, industry and unit of analysis selected. In other words, the research design is a statement written before any data is collected which explains and justifies what data is to be gathered, how and from where it will be collected. At a later stage, it will require the researcher to explain how the data will be analysed and how this will provide answers to the research questions. A research design is a formula or simply the basic directions to carry out the project as stated by (Hair et al., 2010).

Morgan (1998) has identified the Priority-Sequence model in the mixed method research strategy in combining the qualitative and quantitative methods. The selection of either a quantitative or qualitative approach as the principal method is the priority of the two methods. The preceding step is to determine the sequence whether the complementary method will function as either a follow-up or an initial to the principal method. A way to decide which method should be applied is to develop on the decision in regard to which method will be chosen to be principal. The research designs where a preliminary qualitative study gives complementary aid in developing a larger quantitative study was adopted in this study based on Morgan (1998) sequence. These studies are normally principally quantitative research, but initially they utilize some of the qualitative techniques to develop or better the effectiveness of the quantitative research that follows. These two decisions give away four fundamental research designs: (a) preliminary qualitative methods in a quantitative study, (b) preliminary quantitative methods in a qualitative study, (c) follow-up qualitative methods in a quantitative study, and (d) follow-up quantitative methods in a qualitative study. The Figure 3.2 shows the priority sequence decision adopted from the Morgan study.

Thus, this study chooses cell 1 strategy (see Figure 3-3) to be adopted in the mixed method research design. Since, in this study, the beginning of a survey with a qualitative method such as, focus groups including different types of employee positions in each selected tyre rubber company to develop the content of a survey of sustainable criteria on the topic of supplier selection. The discussion from the initial survey is used to generate the questionnaire items related to the topics of importance sustainable criteria, decision making methods, size, and type of ownership in tyre rubber industries.

In this study the research design involves mixing qualitative and quantitative approaches. The study showed that more weight was given to the decision makers by quantitative phase and the qualitative and quantitative phases were happening sequentially. As a result, the researcher proposes to conduct qualitative research first in order to gain some insight and investigate the studied occurrence (Zikmund, 2003). This was very helpful in aiding researchers to get familiar with the subjective dimension of the supplier selection criteria.

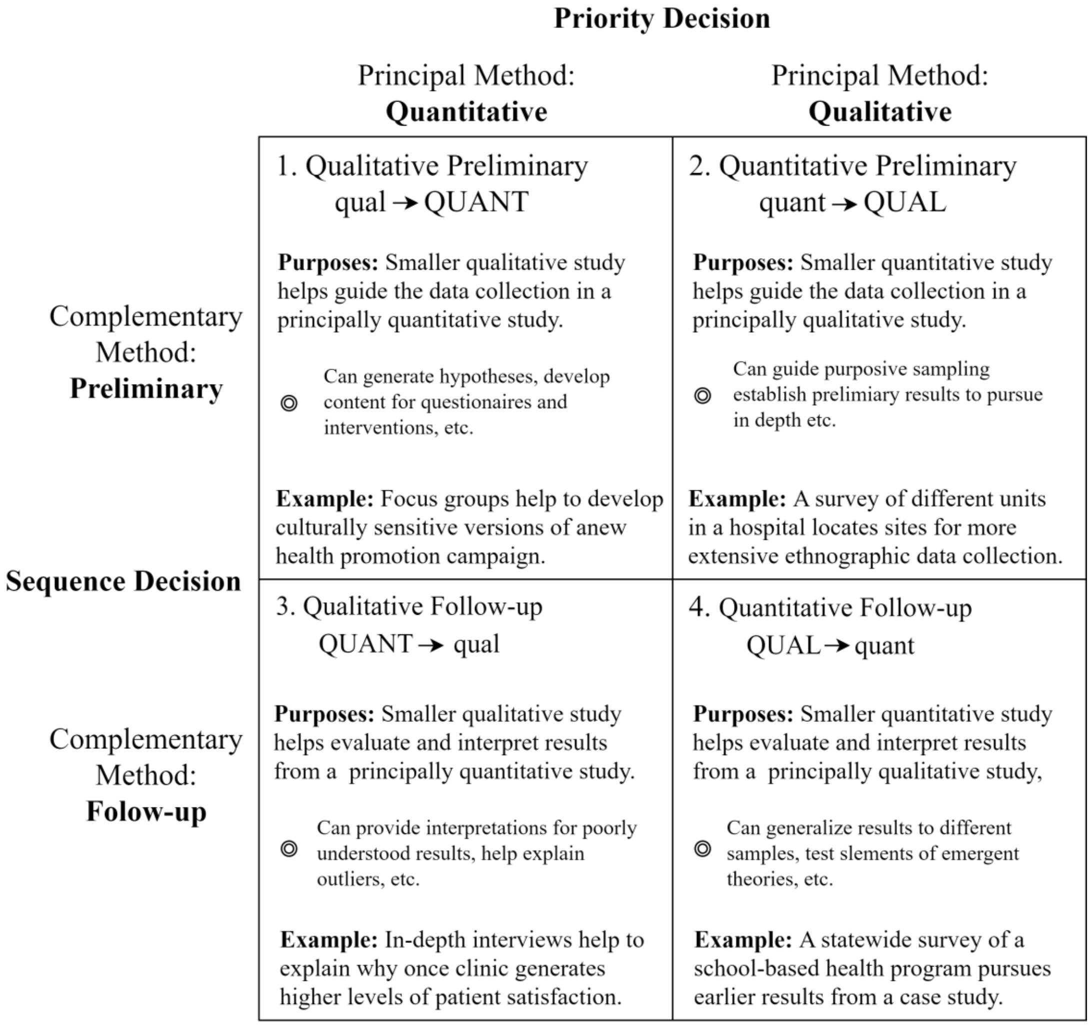


Figure 3- 3 Priority-Sequence Model (Adopted from Morgan's,1998)

3.2.1 Qualitative Approach

As mentioned in the research design, the first stage of the empirical study involved the conduct of qualitative research. Patton (2002) defined qualitative enquiry as going into the field or into the real world of organisations, programs, neighbourhoods, street corners and getting close enough to the circumstances and people there to capture what was taking place (Patton, 2002).

Qualitative research has become a conventional and valid type of inquiry in the social sciences. Its value in generating valuable contextualised information is widely recognised (Creswell et al., 2003). The present study puts considerable emphasis on the industrial context (i.e., higher education), requiring qualitative enquiry made valuable. In this study, content analysis, which involves analysing qualitative data sources, such as documents or interviews, are applied to identify criteria and decision making methods from tyre rubber firms. This approach is useful for identifying sustainable criteria related to sustainable supplier selection and evaluation in the tyre rubber industry in Thailand.

3.2.2 Quantitative approach

Quantitative studies are generally interested in testing on why and how phenomena can differ. However, this 'why and how' is different from the 'why and how' in qualitative studies. Statistics and mathematical models are used in quantitative studies for data analysis. Additionally, in quantitative studies, the results explain relationships and provide categorical answers such as satisfactory, good, bad or excellent relationships, without quantifying these relationships (Tavakol and Sandars, 2014). Primary quantitative data were collected by the current researcher for the quantitative part. According to Tayur et al. (2012), to provide the best answer for a quantitative study, a clear expression should be ensured in the collected data. Hence, the researcher had an interest in finding out about different kinds of relationship among the proposed key criteria. For instance, the current researcher examined a positive/negative relationship among the criteria of quality, price, and delivery. This approach is in line with the explanations of Brandenburg et al. (2014), who stated that the magnitude of the relationships between the variables needs to be established in the quantitative studies.

A combined multi-criteria decision-making model was used in the current research as its main quantitative instrument. The application of the MCDM method was selected to provide a ranked list of the chosen criteria. It structures decision-making problems in a hierarchical model consisting of quantifiable components with their relationships and the alternatives, to achieve a specific target (Saaty, 1980). One of the most important advantages is that it enables researchers to measure the results of the study more effectively and thus deliver an appropriate scale of ranking for the criteria (Lirn et al., 2004). This model helps to convert the criteria from qualitative to quantitative data for more accurate and simpler measurement and analysis. A quantitative method, in this study, involves analysing data from questionnaires completed by tyre rubber managers. The scores were analysed using statistical analysis and numerical modelling, which is a combined decision-making model used to select and evaluate potential suppliers based on their sustainability scores.

3.3 Research methods

According to Yin (2003), different research methods help to answer different forms of research questions.

3.3.1 Questionnaire survey

The quantitative questionnaire survey method is used in this study. Surveys are a fairly popular research strategy within business and management research (Saunders et al., 2009), and there are several possible reasons for this. Firstly, surveys are quite helpful to obtain straightforward information from respondents (McIntyre, 2005). They enable respondents to directly clarify their answers to the researchers. Secondly, this method provides a cost-effective way for the researchers to obtain data from a large number of samples (Easterby-Smith et al. 2002). In addition, it is highly economical to sample rather than to target the whole population, as the findings from a survey sample can represent the whole population (Saunders et al., 2009). Another interesting point, according to Saunders et al. (2009), is that surveys are always regarded as authoritative, as they are relatively easy to explain and to understand in comparison to other data collection techniques. For this study, a questionnaire is used for the survey, and the measurements and data collection process will be introduced in the following sections.

The questionnaire survey method does also have limitations which need to be addressed. Firstly, closed-ended questions are incapable of identifying any points that participants have misinterpreted as a result of inappropriate wording and placement of questions, or misunderstanding, which will probably lead to biased results (Choi and Pak, 2005). Secondly, poor internal validity can arise because standardised questions cannot reveal detailed information such as why something happens (Mitchell and Jolley, 2010). In light of these limitations, and to obtain more detailed information within the investigated phenomenon, the case study method can be used to overcome the possible disadvantages generated by single-method strategy.

3.3.2 Case study

Case study enables a researcher to closely examine the data within a specific context (Saunders et al., 2009). The method that has been applied extensively by researchers in many fields, including education (Gulsecen and Kubat, 2006), sociology (Grassel and Schirmer, 2006), community-based problems (Johnson, 2006), law (Lovell, 2006), medicine (Taylor and Berridge, 2006) and management (Saunders et al., 2009). There are several reasons for its popularity. For example, the data collected from a case study can be examined and analysed in context (Yin, 2008). In other words, the data does not need to be analysed by other tools or in other ways. Moreover, the detailed information from a case study can help not only to understand what is happening in real life at that moment, but to explain the complexities of contemporary real-life environment, which may not be possible using experimental or survey research (Zaidah, 2003).

However, there are several disadvantages of the case study method. The first relates to its generalisability (Silverman, 2009), which is limited by its dependency on a single case or a few cases.

In addition, researchers can have biased views, which can affect the findings and conclusions (Yin, 2003).

3.3.3 Research methods for the Thesis

Given the limitations of both methods, as discussed above, this study will combine the findings from a case study with quantitative survey data in order to provide a more detailed explanation of sustainable criteria in economic, environment, and social among LEs and SMEs with the supplier selection of sustainability. The questionnaire survey will be used to test the hypotheses by collecting a relatively wide range of data, while the case study represents the intersection of theory by attempting to fit theoretical methodology with reality. This study’s contribution to knowledge lies in its employment of proven techniques in new environments, as well as contributing to industry by deploying the new framework in the real world amidst the dynamism of reality.

3.4 Guidelines on data collection

The primary data used in this study comes from questionnaire responses from managers in LEs and SMEs that have a profound impact on the sustainability in tyre rubber industry and are located within Thailand. The questionnaire contains four sections. The first section is composed of questions which aim to obtain basic information of the enterprises, including “how old” the enterprises are, which sectors they operate in, and their location. It will also ask for information on the number of employees. The remaining three sections are made up of criteria affecting implementation to sustainability in tyre rubber industry in Thailand. Section two contains economic criteria. Section three contains questions on environmental criteria. The last section questions concern social criteria. All questions from the latter three sections are measured on a five-point Likert-type scale, as follows: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

3.5 Sample selection

According to Gilbert (2001), a study population is a set of the entire elements eligible for the study. In an effort to gather data that can represent the whole target population, samples are chosen from the total population. It was revealed by Sekaran (2006) that sampling offers in depth information that deals with a small number of units. In this analysis, the characteristics of sample selection are in the central, eastern, and north-eastern part of province in Thailand since most of tyre rubber companies are in those areas, types of ownership including from foreigner and Thai and, no. of employees in each tyre rubber company. The total population is also defined as all full-time employees of tyre rubber company in Thailand. The characteristics of employee’s sample are the position relating to purchase, procure, produce, and involve the process about tyre rubber in the company. Therefore, the total population ranges from non-executives to senior management staff of the companies. However, in order to get meaningful data which is directly related to the subject under study, the target population only comprises executives and management staff from concerned departments/divisions/units namely procurement, purchasing, finance, and technical engineering department.

3.5.1 Targeted samples

The sample is referred to as the section of a population that has been chosen for the present research. Given that large experts panel result in a high degree of uniformity, decision-making becomes impractical (Pun and Hui, 2001). It is widely agreed that any study sample should have more than 20 participants in order to provide reliable data (Bryman and Bell, 2007).

In this research, the sampling method chosen was a non-probability sampling method. A non-probability sample is a study sample whereby units in the population are not selected at random; meaning not all units in the total population have an equal opportunity of being chosen for the study. In other words, some units of the population have more chances of being selected compared to others (Bryman and Bell, 2007). Bryman and Bell (2015) also state that stratified random sampling guarantees that specific subgroups within the population are included in the sample with proportions that mirror their size in the population. This method reduces the risk of under-representing certain subgroups in the sample, which can lead to biased or inaccurate results. In this study, the selection of respondents was conducted based on stratified random sampling where the researcher had a clear idea what sample unit was needed. Only employees of selected department or division such as purchasing, procurement, finance, and engineering division became the target sampling population.

As well as how to choose organisational cases and research participants, sampling is also used to determine the appropriate number of interviewees. In a qualitative study, the number of interviewees is not as critical as in a quantitative one. According to Patton (1990), "there are no rules for sample size in qualitative inquiry. Sample size depends on what you want to know, the purpose of the inquiry, what's at stake, what will be useful, what will have credibility, and what can be done with available time and resources". By using a non-probability purposive sampling technique, it can be ensured that appropriate informants are selected, who can provide plentiful information which can be considered more important than the number of interviewees. Using this perspective, informants with sufficient knowledge and experience in the field of supply chain vendor selection decisions and sustainability interests will be selected as appropriate interviewees for this study.

The selection of related departments in this study was on the basis of job function and reference towards previous literature. Strauss (1962) identified departments that are normally involved in the purchasing process and selection of the supplier were production, purchasing, engineering, and scheduling departments while Duncan (1965) stated that engineering, production, and purchasing as functional departments holding major influence in the purchasing process. Buckner's (1967) research showed that purchasing, operations management, and management level were most frequently involved in supplier selection and purchase decisions.

3.5.2 Sampling frame

In selecting a study sample set from the tyre rubber industry companies in Thailand, the sample frame was gathered from the companies' online websites, company database and direct contact with officers from the selected companies via email or telephone. The samples were then selected based on the employees' job functions which were related to supplier selection activities within the organisations. The sampling frame of this study comprised 22 enterprises randomly selected from the top-level management who are in the tyre rubber industry in Thailand which included OEM, Tier1 and Tier 2 suppliers. The sectoral categories were listed as option for the questionnaire respondents to choose from tyre rubber industry firm classifications. From Table 3-1 to Table 3-3 shows the distribution of sampled companies in Thai tyre rubber companies.

Table 3- 1 Distribution of sampled companies in terms of Thai tyre rubber industry

Type of sampled companies	Number of sampled companies	Percentage of sampled companies (%)
OEM	2	10
Tier 1 Suppliers	10	45
Tier 2 Suppliers (Local)	10	45

Table 3- 2 Types of company and ownership in this research

Types of companies	Types of ownership					Total number of companies
	Foreign JV	Foreign Majority	Thai Majority	Pure Thai	Local suppliers	
Assemblers	2	-	-	-	-	2
Tier 1 Suppliers	-	3	4	1	-	10
Tier 2 Suppliers	-	-	-	-	10	10

Table 3- 3 Types of Thai rubber suppliers

Tyre rubber supplier	Province	Type of ownership	Company size (employees)	Authorised capital (USD)
T1.1	Rayong	Foreign majority	> 1,500	168,197,142.86
T1.2	Samutsakorn	Thai majority	1,001–1,500	36,571,428.57
T1.3	Prachiburi	Pure Thai	>1,500	42,857,142.86
T1.4	Samutprakarn	Thai majority	1,001–1,500	18,812,408.57
T1.5	Bangkok	Pure Thai	1,001–1,500	16,000,000.00
T1.6	Nakornpathom	Thai majority	1,001–1,500	59,000,000.00
T1.7	Bangkok	Foreign majority	> 1,500	169,057,142.86
T1.8	Samutsakorn	Pure Thai	1,001–1,500	11,428,571.43

T1.9	Chonburi	Thai majority	1,001–1,500	15,356,290.74
T1.10	Rayong	Foreign majority	> 1,500	340,000,007.31
T2.1	Ratchaburi	Local SMEs	<1,000	142,857.14
T2.2	Rayong	Local SMEs	<1,000	85,714.29
T2.3	Samutprakarn	Local SMEs	<1,000	21,428.57
T2.4	Lopburi	Local SMEs	<1,000	285,714.29
T2.5	Bangkok	Local SMEs	<1,000	171,428.57
T2.6	Chonburi	Local SMEs	<1,000	28,571.43
T2.7	Bangkok	Local SMEs	<1,000	571,428.57
T2.8	Nakornpathom	Local SMEs	<1,000	142,857.14
T2.9	Samutprakarn	Local SMEs	<1,000	428,571.43
T2.10	Samutsakorn	Local SMEs	<1,000	857,142.86

The total estimated sample was 50 respondents throughout the whole of Thailand. A detailed description of the interview sample profile is presented in table 3-4 below.

Table 3- 4 Interview sample profile

Participants' details	Number of samples	Percent (%)
Procurement/Purchasing	21	42
Finance	9	18
Production/Quality	3	6
Logistics/Engineer	11	22
General Manager	6	12
Total number of participants	50	100

3.5.3 Case selection

Qualitative research, like case studies, can provide more detailed information to contribute to the discussions and conclusions within a study. Therefore, LEs and SMEs from the questionnaire respondents were selected as a case study in order to more deeply explore the sustainability in Thailand. The selection was based on certain criteria such as their size, capital, and geographical location, among others. Moreover, together with the findings of the investigation into the specific enterprise, a combined decision making model was built based on the results of the quantitative survey; this model would not only be helpful for the specific enterprise investigated with respect to improving its sustainable development in the long run, but would also have significance for companies in the same industrial sector, and may even serve as useful as an example for LEs and SMEs across industries nationally and internationally.

3.6 Preparation for data collection

As part of the exploratory stage of the research, a pilot test was carried out in order to test the validity and practicality of the questionnaire. The pilot test was targeted at the Thai tyre rubber industry in Thailand. The sample population for the study included 50 LEs and SMEs, and these were contacted by email, together with a covering letter, with the allotted time for returning the questionnaire set within four months. A total of 22 questionnaires were returned by the deadline, which provides a response rate of 44% for the exploratory survey.

A small sample of 78 respondents participated in the exploratory survey. However, out of the total sample of 75 respondents only 50 responded to the exploratory survey. Prior to sending the questionnaire to be tested, the researcher communicated with the participants regarding the exploratory survey. Subsequently, the questionnaires were personally handed to them during personal visits.

The structure for each of the interviews for this project was as follows: firstly, the introduction of the interviewer and the purpose of the interview and the study. Secondly, brief outline of the possible areas to be discussed; thirdly, asking questions and recorded information from interviewees by note-taking; finally, seeking feedback from interviewees on the interview itself and also confirmation of the data collected.

Data gathered from the exploratory survey was then analysed using the SPSS statistics software (version 15.0 for Windows). The questionnaire items were already coded in the SPSS programme beforehand.

Data analysis of the feedback gathered was carried out to obtain an initial indication of the items' reliability. At this point, the items' reliability is evaluated. It is necessary to establish item reliability as a condition for validity in order to ensure that the measures are error-free and thus able to provide consistent results (Peter, 1979).

The reliability of the items produced was evaluated by means of a questionnaire which contains the items taken from the qualitative study and literature. The scale was then further reduced by the researcher by examining the coefficient of the inter item correlation by evaluating the result of the "corrected item to total correlation" for every single item from each construct. Since the Cronbach's alpha (Tabachnick and Fidell, 2007) is widely used by most researchers, the internal consistency reliability was evaluated using the coefficient alpha method. The Cronbach's alpha shows how different characteristics of a construct are purportedly measured by the different items (Hair et al., 2006). Several researchers suggested various threshold levels for Cronbach's α coefficient. Alpha values closer to 1 indicates higher consistency of data reliability. Cronbach's alpha value of 0.6 is generally taken as the minimum threshold value of data reliability (Nunnally, 1978). Sekaran (2003) believed that Cronbach's alpha value less than 0.6 is considered poor, in the range of 0.7 to be acceptable, and more than 0.80 to be good (Sekaran, 2003). Hair et al., (2006) concurred that the minimum level for Cronbach's α coefficient is 0.70, In exploratory research, the value may decline to 0.6. The rule of thumb on the coefficient value as suggested by Hair, Babin, Money and Samouel (2003) is shown in Table 3-5.

Table 3- 5 Rule of thumb for using Cronbach's alpha

Alpha coefficient range	Strength of association
< 0.6	Poor
0.6 to < 0.7	Moderate
0.7 to < 0.8	Good
0.8 to < 0.9	Very Good
0.9 to 1.0	Excellent

Based on the result of this pilot study, the Cronbach's alpha for all the constructs was above the minimum threshold of 0.60. The result recorded that the lowest Cronbach's alpha was 0.634 and the highest was 0.966. The following table are the sample detailed Cronbach's alpha for each independent construct in sustainable supplier selection criteria.

Table 3- 6 Sample main criteria of Cronbach's alpha coefficient

Main Criteria	Cronbach's alpha coefficient
Government policy	0.954
Financial position	0.966
Quality management	0.947
Process performance	0.930
Cultural factors	0.334
Green practice	0.947
Cooperate social responsibility	0.847
Business ethics	0.755

Based on the result of the pilot study, there are some criteria that would need to be purged due to low item correlations (individual score less than 0.4) which did not meet the reliability criteria. Leech and Barret (2010) indicated that items with moderately high to high correlation value (i.e., 0.4 and above) will become good components of a summated rating scale. On the contrary, items with score of lower than 0.4 should be removed.

3.7 Data collection

The final questionnaires were sent out to every respondent, together with a personalised official covering letter as shown in Appendix 1. To make sure that a full coverage of the respondents was achieved, a guide was utilized when the distribution of questionnaires was conducted listing all the current records of employees' names and emails that was obtained from the companies Human Resources Division. Some of the respondents in the headquarters were personally given a questionnaire by hand. Regional and state office respondents were contacted by telephone and questionnaires were sent afterwards via email. This effort made sure that all respondents understood the significant of the survey. A total questionnaire was distributed to all personnel from purchasing and procurement, finance and engineering department in 22 tyre rubber companies in Thailand. This study adopts the positivist philosophy and deductive approach. Thus, it employed the mixed method of research design which combined the qualitative and quantitative methods. Therefore, this study is principally quantitative research, but initially some qualitative input from the interview was used at the beginning in order to improve the effectiveness of the quantitative research. The item and variable development were mainly based on the existing literature and the main data were collected from the survey.

3.8 Summary of research approach

Table 3-7 displays the summary of the research approach for this study.

Table 3- 7 Summary of research approach

Focus	**Selected approach**
Philosophies	Positivist
Choices	Deductive
Strategies	Survey and Case study
Approaches	A mixed method (Quantitative + Qualitative)
Time horizon	Cross sectional study
Technique and procedures	
Unit of analysis	Suppliers in tyre rubber industry in Thailand
Population	Large and small-medium tyre rubber companies in Thailand (from 50 companies)
Sampling frame and target	22 companies with procurement, purchasing, finance, engineering, and related departments
Sampling method	Non-probability sampling (5 groups) and stratified random sampling (50 respondents from 78 respondents)
Data collection method	Interviews, online questionnaires

4. A Combined Decision-Making Model and Development of the Current Research Mathematical Model

This chapter outlines the first of two decision-making models employed in this Thesis. A schematic representation of the approach using the two parts is presented below in Figure 4-1.

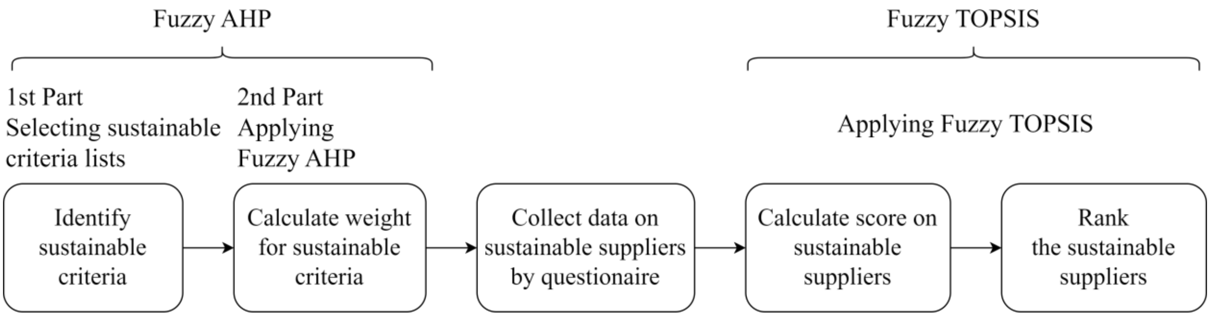


Figure 4- 1 Steps of Fuzzy AHP and Fuzzy TOPSIS

The first part is used to determine the significant factors which influence the choice to select and evaluate suppliers in sustainability ways where apply to the Tyre Rubber industry in Thailand. The second part of the chapter presents from a theoretical point of view the Fuzzy AHP method which has been applied to weight factors previously selected. Finally, the combined method application to achieve the final rank of factors from the most to the least important one for interviewed managers. This result is essential to apply, in the next chapter, the Fuzzy TOPSIS method which discovers the companies where it is most selected to implement for Thai Tyre rubber companies.

4.1 Sustainability factors for supplier selection and evaluation problem

In the recent past, attempts have been made to incorporate sustainability criteria into the supplier selection and evaluation process. Strategic benefits achieved by firms through the sustainability program are centrality, specificity, voluntarism, and visibility (Spangenberg, 2004). Consideration of sustainability issues in this problem also helped organisations attain other benefits such as improvement in their economic financial performance (partly in an economical dimension), fairness to the suppliers and customers, corporate reputation, social change, good human relations, and inter-organisational learning (partly in a social dimension).

Studies on the Dutch firms, Graafland and Ven (2006) found no significant relationship between the management's strategic and moral view of sustainability aspects and the actual sustainability of a firm's practice with respect to supplier selection. Murphy and Poist (2002) identified the strategies that have been used by managers for managing social responsibility issues in the logistics discipline. Anderson and Larsen (2009) presented a conceptual framework for analysing the corporate social responsibility practices in global supply chains. They also explained how IKEA involves in implementing and managing corporate social responsibility practices at the suppliers' end. Rodriquez et al. (2006) cautioned that suppliers must implement sustainable issues rigorously, rather than put up mere symbolic implementation, to get certification. Aguilera et al. (2007) emphasized that firms are pressured to engage in social responsibility initiatives by multiple contributors, each driven by instrumental, relational, and moral motives. Laws protect the employees from discrimination and harassment in the workplace based on elements including race, colour, religion, sex, sexual orientation, marital status, nation, disability, and age. Discrimination includes sexual harassment, hate speech, verbal abuse, and obscene telephone calls (Jay, 2010). Abuse of human rights includes health and safety violations in the workplace, murder, torture, and forced displacement at the hands of military and security forces protecting company facilities (Caroline, 2008). To prevent child labour, manufacturers and suppliers should follow policy and procedure for identifying workers below the minimum age, taking corrective actions, and maintaining personal records (including evidence of the birth date of each worker).

Sustainability is the development approach that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (WECD, 1987). Corporate sustainability is defined in terms of aspects such as economics, product-responsibility, human rights, labour practices, decent work, society and environment (GRI, 2010) which are in turn expressed by various criteria. A list of the aspects and their corresponding criteria in shown in Table 4-1.

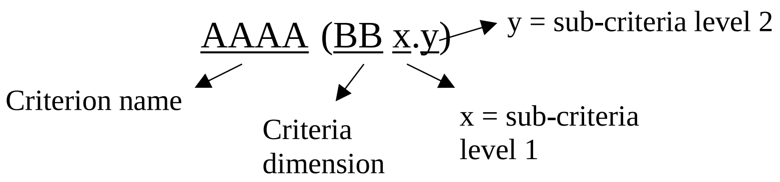
Table 4- 1 Sustainability criteria and sub criteria

Main Criteria	Sub Criteria level1 (Code)	Sub Criteria level2 (Code)
Economic dimension (EC)	Cost and price (EC1)	Bid price (EC1.1) Discounts (EC1.2) Logistics cost (EC1.3) Product cost (EC1.4) Ordering cost (EC1.5)
	Financial stability (EC2)	Profits (EC2.1) Cashflow issues (EC2.2) High loan capital (EC2.3) Takeover potential (EC2.4) Clients' dependency (EC2.5)
	Service (EC3)	Reliability of delivery service (EC3.1) Lead time (EC3.2) Accuracy of product and quantity delivered (EC3.3) Warranty/Returns (EC3.4)

		Responsiveness communication (EC3.5)
	Quality (EC4)	Control of products defect (EC4.1) Return rate (EC4.2) Certificate of quality (EC4.3) Quality management capability (EC4.4)
Social dimension (SC)	Employee's health and safety (SC1)	Health care delivery (SC1.1) Safety measures (SC1.2)
	Employee's welfare and right (SC2)	Equity (SC2.1) Gender discrimination (SC2.2) Equality (female vs male wages) (SC2.3) Job security (SC2.4) Child labour (SC2.5)
	Working condition (SC3)	Wages (SC3.1) Working hours (SC3.2) Contract labour (SC3.3) Training programs (SC3.4)
	Ethics (SC4)	Supplier ethics (SC4.1) Ethical environment (SC4.2) Disclosure of information (SC4.3)
	Social commitment (SC5)	Support for the local community (SC5.1) Stakeholder involvement (SC5.2)
Environmental dimension (ENV)	Green product (ENV1)	Recycle/reuse (ENV1.1) Green packaging (ENV1.2)
	Green competencies (ENV2)	Green design of products (ENV2.1) Green technology capability (ENV2.2)

	Environmental management (ENV3)	Environmental standard certifications (ENV3.1) Regulatory compliance (ENV3.2)
	Pollution control (ENV4)	Waste disposal schemes (ENV4.1) Pollution reduction capability (ENV4.2) Energy consumption (ENV4.3) Hazardous substances (ENV4.4) Air emissions (ENV4.5)
	Green image (ENV5)	

From Table 4-1, The code name in various sustainable criteria it can explain in the following.



For example, Bid price (EC1.1)

Criterion name = Bid price

Criteria dimension = EC (Economic dimension)

x = 1 (sub-criteria level 1 in 1st main criteria or economic dimension)

y = 1 (sub-criteria level 2 in 1st sub-criteria level 1)

Several studies have included environmental criteria in supplier selection and evaluation decisions (Handfield et al., 2002). Sekhar et al. (2017) found that social diversity, safety, and human rights as part of the sustainability criteria for supplier selection in the healthcare industry. Roa (2002) described insights in the greening process that inspire government and business communities in the region of Thailand. Some studies have also examined the relationships between green supply chain management, environmental and economic performance, using statistical techniques (Zhu and Sarkis, 2004). The results of these studies suggest that the main criterion, which positively correlates with environmental concern, is pollution. Pollution is generally understood as the introduction of contaminants into an environment that causes instability, disorder, harm, or discomfort to an ecosystem. In this Thesis, discrimination, abuse of human right, child labour, long working-hours, unfair competition, and pollution are used as indicators of industry sustainability.

4.2 The Fuzzy Analytical Hierarchy Process Model

Yahya and Kingsman (1999) examined different methods for decision-making problems and from the analyses in their study, they found that the Analytic Hierarchy Process (AHP) method is more practical and flexible than any other method for solving complex decision-making problems. Due to the complexity of the current world system, Wong and Li (2008) stated that there is a need to arrange priorities to be able to deal with unstructured and complex problems/systems and to have a clear agreement that one objective exceeds another in its importance. However, according to Kabir and Hasin (2001), the AHP model has some shortcomings. It is mainly used in crisp definition applications and AHP ranking is sometimes imprecise. In addition, two other weaknesses are necessary to mention. On the one hand, uncertainty of subjective preferences of the decision maker is not considered, even if they have a great influence on the AHP results and, on the other hand, human assessment on qualitative attributes is sometimes imprecise, containing vagueness. Since these elements have a considerable impact in AHP results, the conventional method is not able to reflect human thinking style and capture decision makers' impressions (Onay et al., 2016). In traditional AHP, the weights assigned to criteria and the scores assigned to alternatives are based on the judgment of the decision maker. However, the subjectivity of the decision maker's preferences introduces bias and uncertainty into the decision-making process, potentially leading to suboptimal decisions. Fuzzy AHP can help to address this issue by allowing decision makers to incorporate the uncertainty and vagueness of their preferences into the decision-making process. Fuzzy numbers can be used to represent the decision maker's preferences, allowing for a more flexible and nuanced representation of their judgments. This can help to ensure that the decision-making process is more accurate and robust, particularly in cases where the decision involves a range of qualitative attributes that are subject to human judgment. In addition, fuzzy AHP can help to account for the imprecision of human assessment on qualitative attributes by allowing decision makers to assign fuzzy scores to the alternatives. This can help to ensure that the imprecision and vagueness of the human assessment are accounted for in the decision-making process, resulting in more accurate and reliable decisions. To model this kind of uncertainty, fuzzy set theory can be incorporated as an extension of AHP. The Fuzzy AHP (FAHP) provides a more accurate description of the decision-making process in cases of uncertainty. From a procurement perspective or in green supply chain management, the main sources of uncertainty in supplier selection can include:

(1) Inaccurate or incomplete information. Decision makers may not have access to complete or accurate information on criteria and alternatives, leading to uncertainty in the decision-making process.

(2) Subjectivity and bias: Decision makers may have different perspectives or preferences, leading to subjective and potentially biased judgments.

According to Srichetta and Thurachon (2012), there are five main phases for applying Fuzzy AHP. These steps are briefly explained below:

(1) Identify the criteria that can be used as evaluators for supplier selection purposes, then

rearrange the decision problem factors into a hierarchical representation,

(2) Create the pairwise comparisons of the criteria relative to their importance to achieve the research objective,

(3) Calculate the weights of the criteria based on these data to prioritise them,

(4) Test the degree to which each supplier meets the selection criteria. Then, check the satisfaction with the input data, then commit the data to the test of consistency to ensure that they reflect a systemic pattern. If the consistency test is not satisfied, repeat the pairwise comparisons.

(5) Ranking the criteria

The whole process of Fuzzy AHP is shown as the following flowchart in Figure 4-2 Fuzzy AHP flowchart.

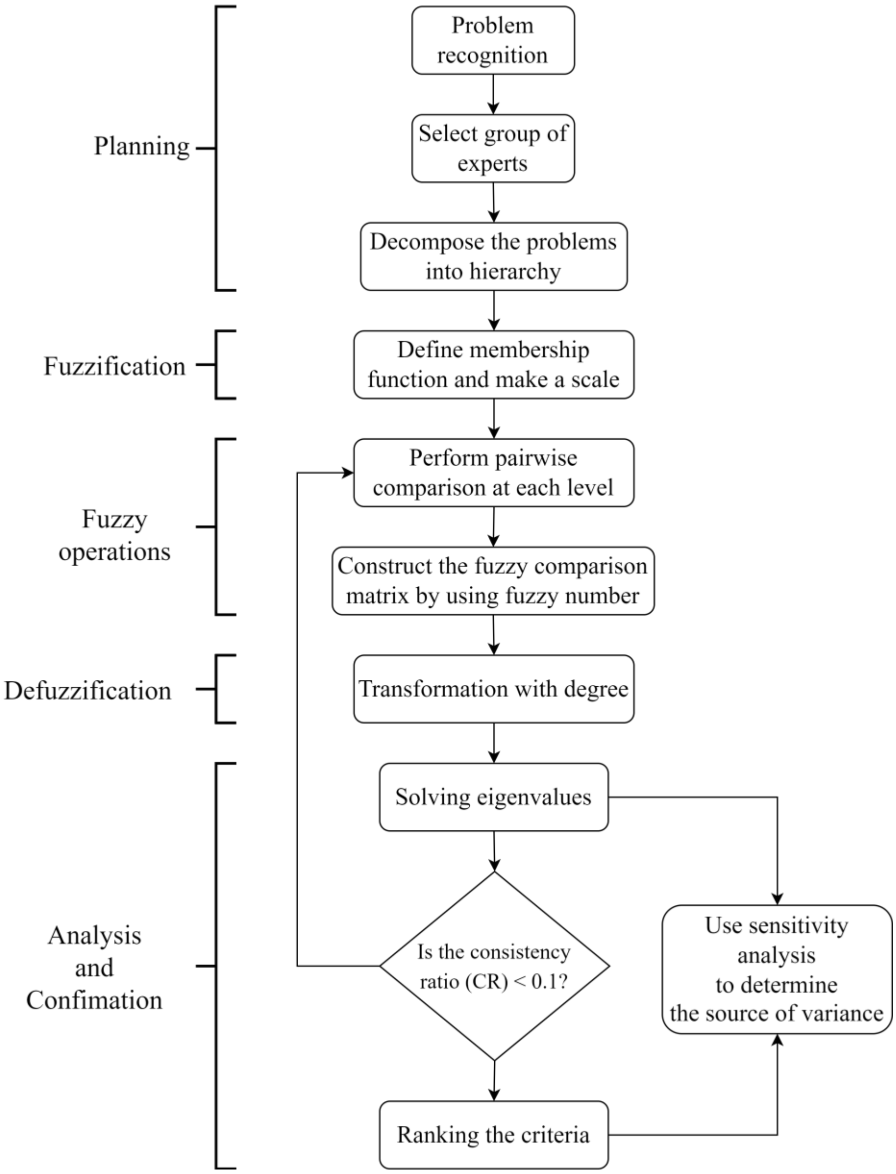


Figure 4- 2 Fuzzy AHP flowchart

With respect to the above processes, the current research started FAHP by establishing hierarchies. The first hierarchy derived the overall objective of the research. Then, the next level in the hierarchy contained the main criteria and the hierarchy descended to the sub-criteria and so on, until the lowest level in the hierarchy was established. According to Saaty (1990) and Bello (2003), there is no specific rule or standard for constructing a hierarchy. Meanwhile, these scholars stated that using FAHP, the complex decision-making problem is rearranged in a way that all the important factors and alternatives are listed first; they are then arranged in a hierarchy to conduct a comparison of the factors of the lower levels with some or all the factors in the next level up.

Chang (2010) explained that one of the advantages of Fuzzy AHP is that it is a creative method that enables the decision maker to simplify the problem by splitting it into basic elements consisting of the overall goal, the criteria, and the alternatives. This arrangement allows large quantities of data to be incorporated into the problem structure, thus building up a complete system for the decision-making problem. Figure 4-3 shows the FAHP structure.

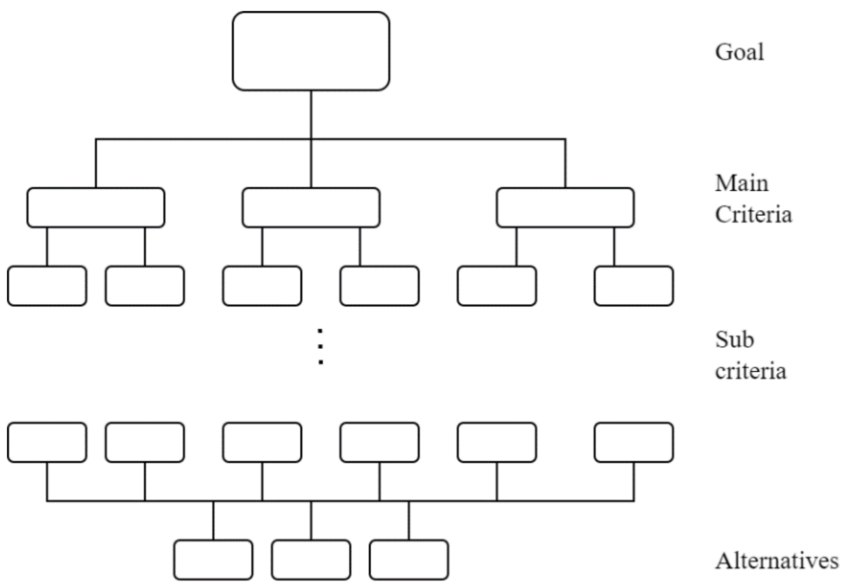


Figure 4- 3 Guidelines for Constructing Hierarchy (Adopted from Chan and Chan, 2004)

In general, the person’s experience and their understanding of the subject control the overall FAHP hierarchy. Based on that, they can select what is to be included and where to include it in the hierarchy. Likewise, identifying the attributes that contribute to the solution and the contributors related to the problem are important steps in developing an FAHP hierarchy (Saaty, 1996). The FAHP hierarchy of the current research as developed by the researcher for main criteria, sub-criteria level 1, and sub-criteria level 2 is shown in the following Figure 4-4.

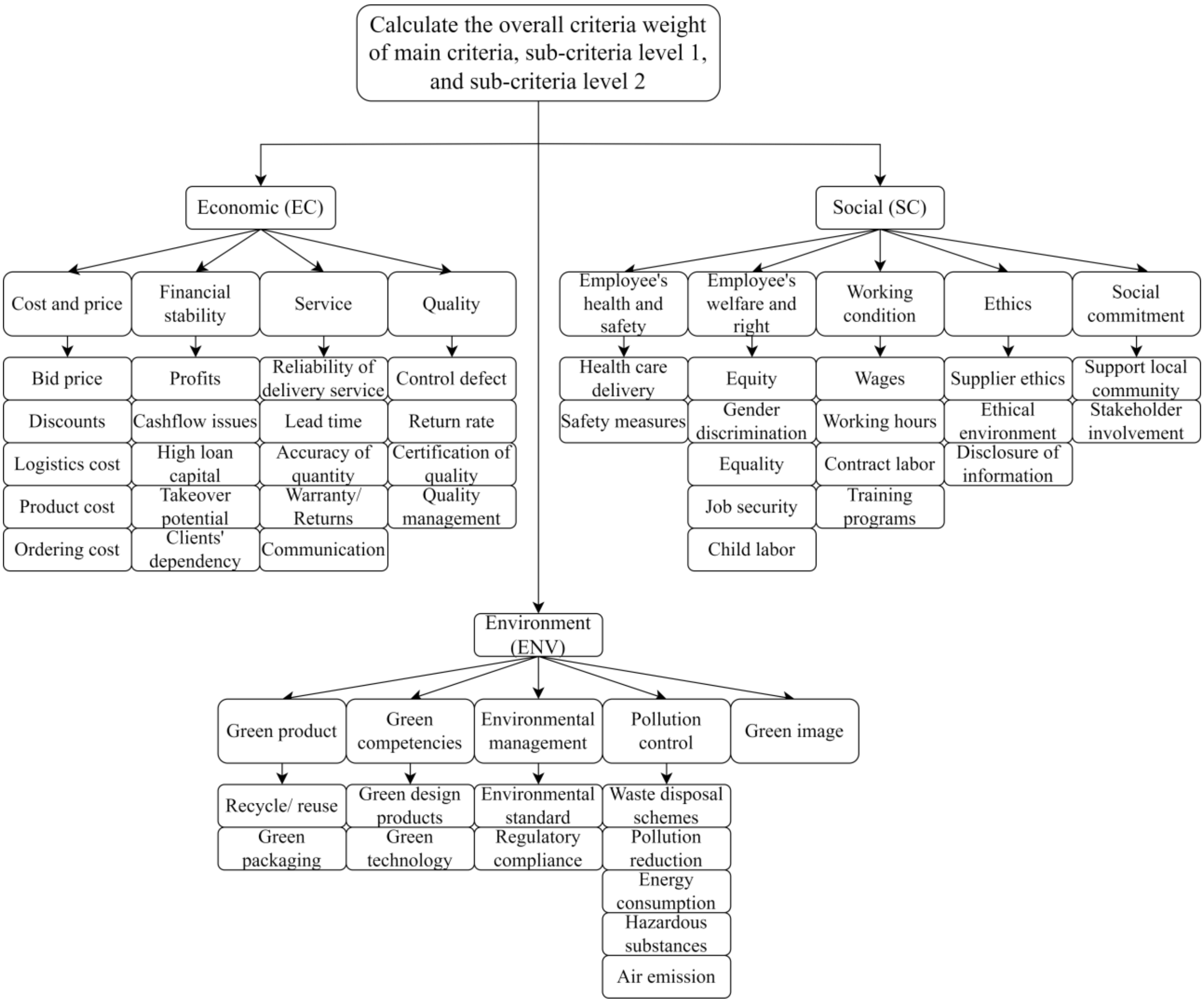


Figure 4- 4 The current research hierarchy with main criteria and sub criteria level 1 and 2

After creating the above FAHP hierarchy, the questionnaire based on pairwise comparisons were developed. As presented before, the final FAHP hierarchy for the current study includes three main criteria, 14 sub-criteria level 1 and 46 sub-criteria level 2. The questionnaire, therefore, contains a table for the comparison of the main criteria and the sub-criteria. Figure 4-4 displays the sub level of each criterion below.

In the current research questionnaire, the objective was to establish the relative importance of the different criteria which affect different decision makers in their supplier selection and evaluation. In doing so, the decision makers (the research participants) were asked to give a pairwise intensity of importance number, which reflects the relative importance of any two criteria or sub-criteria. However, for tackling the issues of vague and uncertainty in traditional pairwise comparison , the use of triangular fuzzy numbers in pairwise comparison matrices in fuzzy decision-making has been shown to improve the accuracy and consistency of decision-making processes, particularly when dealing with complex and uncertain decision problems. One study by Wang and Lee (2009) compared the performance of triangular fuzzy numbers with traditional pairwise comparison methods in a supplier selection problem.

The results showed that the use of triangular fuzzy numbers led to more consistent and accurate decisions, particularly when dealing with multiple criteria and uncertainties. Another study by Khan et al. (2017) also compared the performance of triangular fuzzy numbers with traditional pairwise comparison methods in a healthcare decision-making problem. The results showed that the use of triangular fuzzy numbers improved the accuracy and consistency of decision-making, particularly when dealing with incomplete and uncertain information. The reason for this improvement is that triangular fuzzy numbers allow decision-makers to express their preferences in a more flexible and nuanced way, by allowing for the possibility of partial agreement or disagreement between criteria. This can be particularly useful in decision problems where criteria are interdependent or where there is a high degree of uncertainty or ambiguity. Overall, the use of triangular fuzzy numbers in pairwise comparison matrices has been shown to be an effective tool in fuzzy decision-making, particularly in complex and uncertain decision problems. The different intensities of importance are shown in the pairwise comparison scale in Table 4-2 below, with a specific explanation of each intensity.

Table 4- 2 The Scale of relative importance in the pairwise comparison matrix

Linguistic variables	Fuzzy number	Triangular fuzzy scales	Reciprocal fuzzy scales
Equally important	$\tilde{1}$	(1, 1, 1)	(1, 1, 1)
Weakly important	$\tilde{3}$	(2, 3, 4)	(1/4, 1/3, 1/2)
Fairy important	$\tilde{5}$	(4, 5, 6)	(1/6, 1/5, 1/4)
Strongly important	$\tilde{7}$	(6, 7, 8)	(1/8, 1/7, 1/6)
Extremely important	$\tilde{9}$	(8, 9, 9)	(1/9, 1/9, 1/8)
You can also assign $\tilde{2}$, $\tilde{4}$,$\tilde{6}$, and $\tilde{8}$ to express intermediate values.			

Following the above scale for pairwise comparison, the decision makers were asked to fill in the questionnaire tables with their preferences for the relative importance of the different criteria and sub-criteria that affected their choice of supplier. As the research was conducted across various regions of Thailand, it provided an opportunity to gain a clear understanding of the influence of decision makers' factors, such as type of ownership, company size, and authorized capital, on their supplier selection decisions based on the survey. For instance, the type of ownership affect the decision-making process, with public or state-owned companies potentially having different considerations than privately owned companies. Similarly, company size impact the ability to implement sustainable supply chain practices, with larger companies typically having more resources to devote to sustainability initiatives. Authorized capital can also be an important factor, as companies with higher authorized capital are in better positioned to invest in sustainable practices and have greater influence in the market. By exploring the impact of these factors on sustainable supplier selection decisions, this Thesis can provide decision makers with insights into the unique challenges and opportunities faced by different types of companies. This information can be used to develop more effective sustainable supply chain strategies that take into account the specific circumstances and requirements of different types of companies. In addition, this can help to promote greater collaboration between decision makers and suppliers, as decision makers can use the insights gained from the research to identify areas where they can work with suppliers to promote sustainable practices and address any challenges that arise. Overall, the exploration of the factors of type of ownership, company size, and authorized capital in the research conducted across various regions of Thailand can help to provide decision makers in the tyre rubber industry with a more nuanced understanding of the factors that influence sustainable supplier selection decisions, which can ultimately lead to more effective and sustainable decision-making in this important area.

It was noted that there is a possibility that there would be differences between the comparison results and the decision during the pairwise comparison process. Chang (2010) said that FAHP requires an inconsistency ratio, which is defined as the degree of consistency of the judgement of the decision maker. Therefore, the consistency is determined by using the Eigenvalue, λ_{max}, and by computing the consistency index (CI). According to Saaty (1980), the CI is calculated after finishing the FAHP matrix, using the following equation 4.1.

$$CI = (\lambda_{max} - n) / (n - 1) \quad (4.1)$$

where λ_{max} is the maximum Eigenvalue of the matrix and n is the number of criteria in the model (matrix size).

The CI value is compared with the same index obtained as an average over many mutual matrices of the same order that were entered randomly. After the CI, the consistency ratio (CR) is calculated to check the matrix’s consistency using the following equation 4.2.

$$CR = CI/RI \quad (4.2)$$

where RI is the random index shown in Table 4-3

Table 4- 3 The random consistency index (Saaty and Kearns, 1985)

Size (n)	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.48

According to Huang and Ho (2013), the accepted value for the CR is less than 10%. If the CR is greater than 10% then the consistency of the data collection result is not accepted, and the judgement matrix is inconsistent. Therefore, any results collected in this research with CR greater than 10% were removed before proceeding with the analysis. In the current research, consistency is enhanced by examining and repeating the judgements.

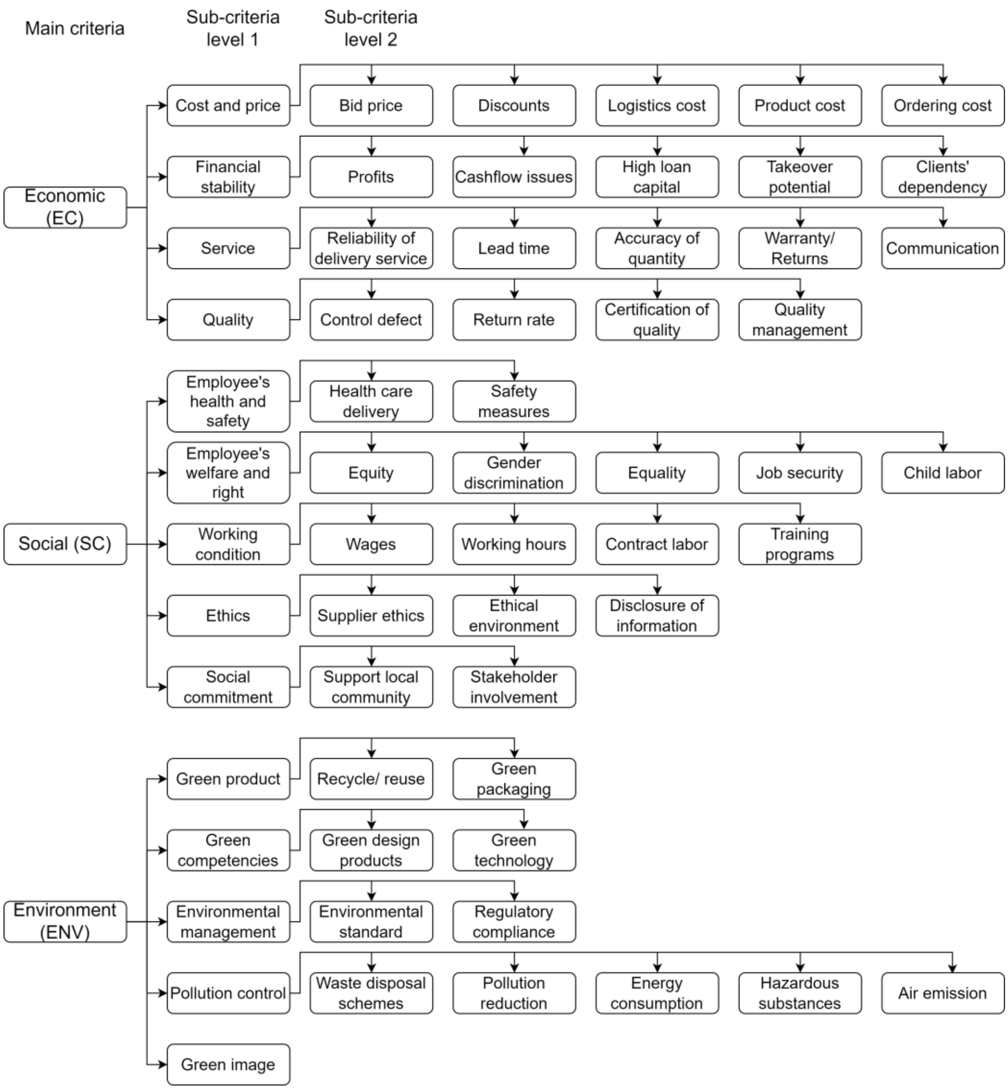


Figure 4- 5 Components of the main criteria and sub-criteria

4.2.1 Application of Fuzzy AHP method

To determine the importance criteria for selecting and evaluating sustainable supplier in tyre rubber industry in Thailand, the steps to achieve the result, through Buckley's methodology, are based on Ayhan (2013), Soberi et al. (2016) and Soltani et al. (2013) papers.

Step 1. Decompose the initial problem into goal, criteria, and alternatives to construct a hierarchical structure. Then determine the pair-wise comparison matrix. It is composed by d_{ijk} which indicates the k^{th} decision maker's preference of ith criterion over jth criterion, via the fuzzy triangular number. The "tilde" indicates the triangular number dimension. For example, $\tilde{a}_{12}$ represents the decision maker's preference of the first criterion over the second one.

$$\widetilde{A} = \begin{bmatrix} 1 & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \cdots & \tilde{a}_{nn} \end{bmatrix} \text{; } \tilde{a}_{ij} \text{ is represented a triangular fuzzy value} \quad (4.3)$$

If there is more than one decision maker, preferences of each decision maker are averaged.

Step 2. The geometric mean of fuzzy comparison values of each criterion is calculated through, where $\tilde{u}_{ij}$ still represents triangular values.

$$\tilde{u}_{ij} = \left(\prod_{i=1}^{n} \tilde{a}_{ij}\right)^{1/n} \quad (4.4)$$

Step 3. Find the fuzzy criteria weights.

$$\widetilde{w}_i = \tilde{u}_1 \text{ x } (\tilde{u}_1 + \tilde{u}_2 \; ... + \tilde{u}_n)^{-1} \quad (4.5)$$

Step 4. Applying defuzzified values method.

$$M_i = (\text{l}\widetilde{w}_i + \text{m}\widetilde{w}_i + \text{u}\widetilde{w}_i)/3 \quad (4.6)$$

Define l, m and u describe respectively the smallest, the most promising and the largest possible values related to a fuzzy event.

Step 5. Normalized preference or weight values.

$$N_i = M_i / \left(\sum_{i=1}^{n} M_i\right) \quad (4.7)$$

Once performed these five steps, criteria and alternatives normalized weights are found. In the end, each alternative weight is multiplied with the related criteria. Done this, it is possible to compute the scores for each alternative. One of them with the highest score is suggested to the decision maker.

To apply the above equation (Equation 4.3-4.7), the pairwise comparison results are used. From Table 4-4 to Table 4-6, they present N_i, N_{ij}, and N_{ijk} which are the weights achieved from the FAHP for selecting and evaluating supplier in tyre rubber industry in Thailand.
where: N_i is the weight criteria of i^{th} criteria,
N_{ij} is the relative weight of the sub-criteria j of the criteria i,
and N_{ijk} is the relative weight of the sub-criteria k of the sub-criteria j of the criteria i

The scores depend on the decision maker's judgements and needs, for example, if a criterion or a sub-criterion is important to the decision makers, they will give it a high score during the evaluation process and vice versa.

Table 4- 4 Main Criteria weights for Tyre rubber firms (FAHP Outputs)

Main criteria	Economic dimension (EC)	Social dimension (SC)	Environmental dimension (ENV)
Weight	0.41	0.27	0.32

Table 4- 5 Sub-criteria level 1 weights for Tyre rubber firms (FAHP Outputs)

Main Criteria	Sub-criteria level 1	Weight
Economic dimension (EC)	Cost and price (EC1)	0.36
	Financial stability (EC2)	0.27
	Service (EC3)	0.17
	Quality (EC4)	0.20
Social dimension (SC)	Employee's health and safety (SC1)	0.16
	Employee's welfare and right (SC2)	0.20
	Working condition (SC3)	0.19
	Ethics (SC4)	0.31
	Social commitment (SC5)	0.14
Environmental dimension (ENV)	Green product (ENV1)	0.19
	Green competencies (ENV2)	0.12
	Environmental management (ENV3)	0.41
	Pollution control (ENV4)	0.18
	Green image (ENV5)	0.10

Table 4- 6 Sub-criteria level 2 weights for Tyre rubber firms (FAHP Outputs)

Main Criteria	Sub-criteria level 1	Sub-criteria level 2	Weight
	Cost and price (EC1)	Bid price (EC1.1)	0.32
		Discounts (EC1.2)	0.17
		Logistics cost (EC1.3)	0.15
		Product cost (EC1.4)	0.20
		Ordering cost (EC1.5)	0.16
	Financial stability (EC2	Profits (EC2.1)	0.15
		Cashflow issues (EC2.2)	0.31
		High loan capital (EC2.3)	0.24
		Takeover potential (EC2.4)	0.18
		Clients' dependency (EC2.5)	0.12
	Service (EC3)	Reliability of delivery service (EC3.1)	0.40

Economic dimension (EC)		Lead time (EC3.2)	0.20
		Accuracy of product and quantity delivered (EC3.3)	0.17
		Warranty/Returns (EC3.4)	0.13
		Responsiveness communication (EC3.5)	0.10
	Quality (EC4)	Control of products defect (EC4.1)	0.31
		Return rate (EC4.2)	0.16
		Certificate of quality (EC4.3)	0.26
		Quality management capability (EC4.4)	0.27
Social Dimension (SC)	Employee's health and safety (SC1)	Health care delivery (SC1.1)	0.52
		Safety measures (SC1.2)	0.48
	Employee's welfare and right (SC2)	Equity (SC2.1)	0.15
		Gender discrimination (SC2.2)	0.06
		Equality (SC2.3)	0.17
		Job security (SC2.4)	0.51
		Child labour (SC2.5)	0.11
	Working condition (SC3)	Wages (SC3.1)	0.28
		Working hours (SC3.2)	0.16
		Contract labour (SC3.3)	0.34
		Training programs (SC3.4)	0.22
	Ethics (SC4)	Supplier ethics (SC4.1)	0.53
		Ethical environment (SC4.2)	0.12
		Disclosure of information (SC4.3)	0.35
	Social commitment (SC5)	Support for the local community (SC5.1)	0.43
		Stakeholder involvement (SC5.2)	0.57
Environmental dimension (ENV)	Green product (ENV1)	Recycle/ reuse (ENV1.1)	0.41
		Green packaging (ENV1.2)	0.59
	Green competencies (ENV2)	Green design of products (ENV2.1)	0.54

		Green technology capability (ENV2.2)	0.46
	Environmental management (ENV3)	Environment standard certifications (ENV3.1)	0.52
		Regulatory compliance (ENV3.2)	0.48
	Pollution control (ENV4)	Waste disposal schemes (ENV4.1)	0.20
		Pollution reduction capability (ENV4.2)	0.25
		Energy consumption (ENV4.3)	0.17
		Hazardous substances (ENV4.4)	0.18
		Air emissions (ENV4.5)	0.20

4.2.1.1 Main criteria weight from interviews

In order to test the decision-making model an interview guide was designed to gather input data to the top ranked criteria, see Appendix 2. After a comprehensive screening, which encompassed in 22 companies in the tyre rubber industry considered suitable for an interview about sustainable supplier selection, interviews were conducted either on site, via email or by telephone. Through the pair-wise comparison rounds carried out during the weightings for sustainable criteria were obtained, see Appendix 3. Figure 4-6 shows the relative weightings of the main categories as a result of the pair-wise comparisons. Traditional criteria, Economics, was still ranked significantly higher than any other category with a weight of 41% within Tier 1 Pure Thai suppliers and Tier 2 local suppliers while Foreign JV assembler, Supplier Tier 1 Foreign majority suppliers and Tier 1 Thai majority suppliers identified that environmental and social dimensions are more concerned for being sustainability. The second most important category according to the assigned weights was environmental dimension with 32% which increased rapidly. Least concern criteria was social dimension with a weight of 27%. However, this research investigates the supplier's in depth analysis not only with respect to economics, and environment, but also social aspects.

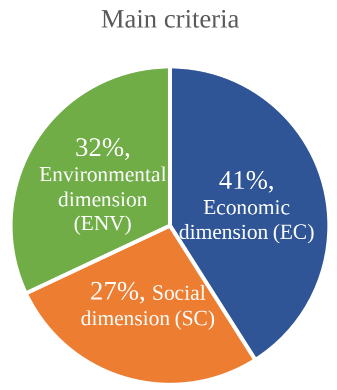


Figure 4- 6 Main criteria weights for sustainable supplier selection

4.2.1.2 Top priority in sub-criteria level weights from interviews

The below from Figure 4-7 to Figure 4-12 presents sub-criteria level 1 and 2 in the sustainable supplier selection for tyre rubber industry involved in this research.

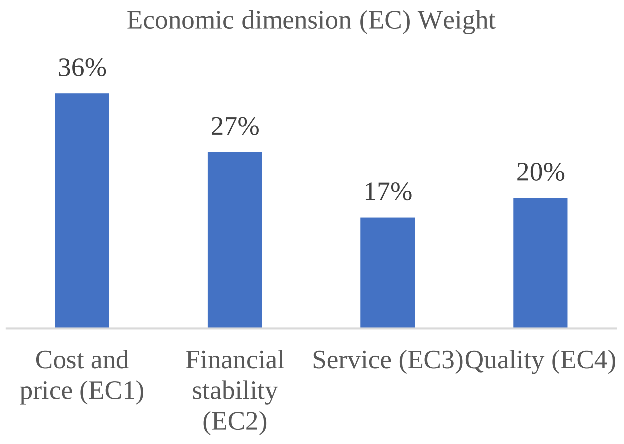


Figure 4- 7 Sub-criteria level 1 weights in economic criteria

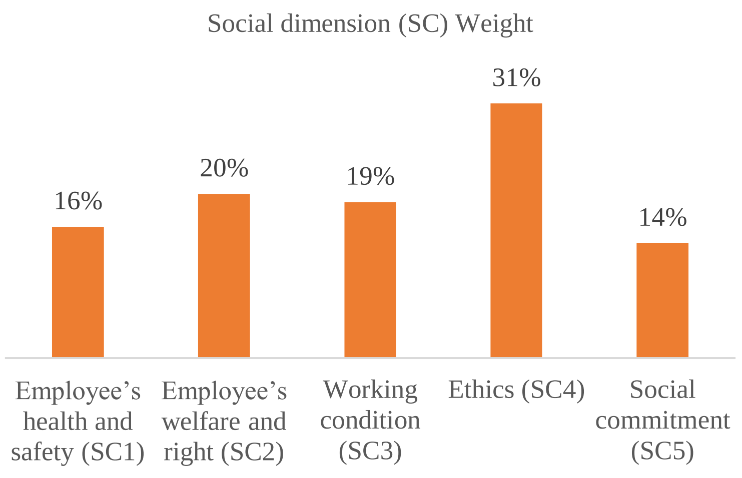


Figure 4- 8 Sub-criteria level 1 weights in social criteria

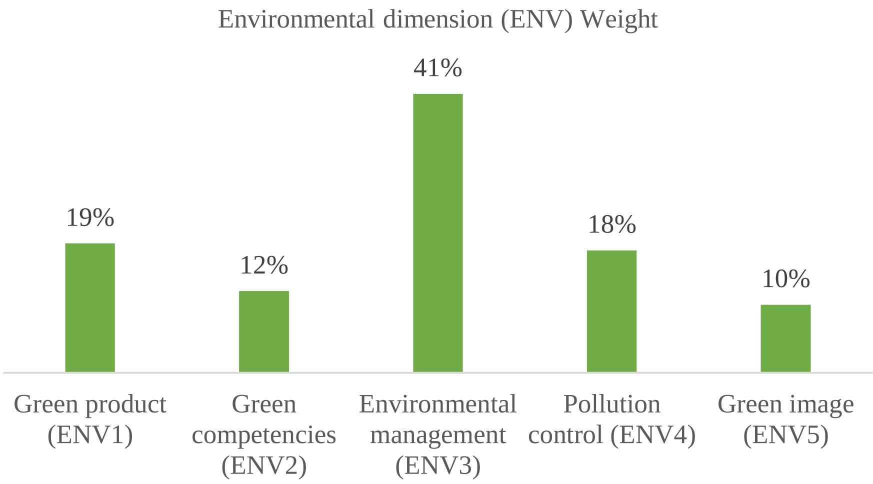


Figure 4- 9 Sub-criteria level 1 weights in environmental criteria

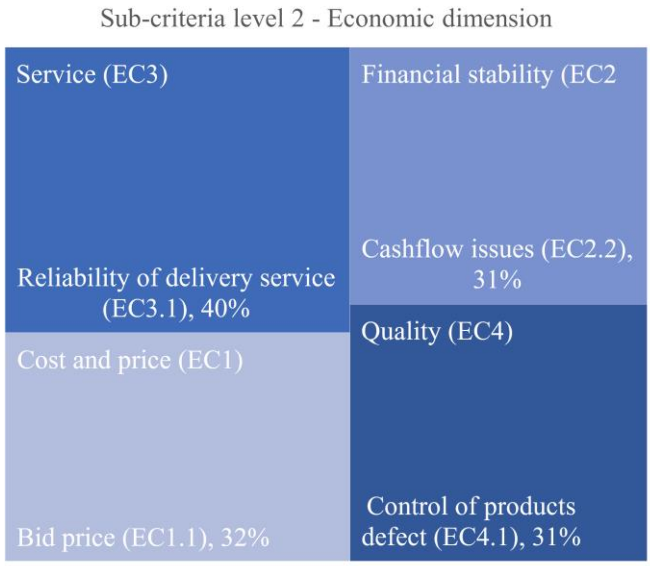


Figure 4- 10 Top sub-criteria level 2 weights in economic criteria

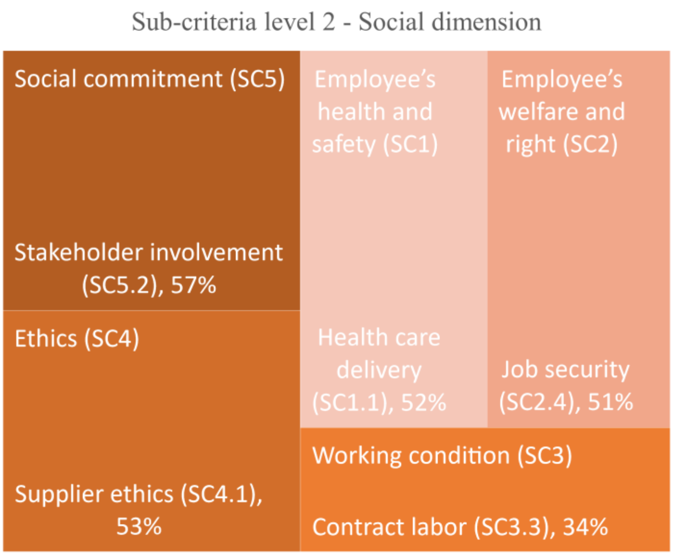


Figure 4- 11 Top sub-criteria level 2 weights in social criteria

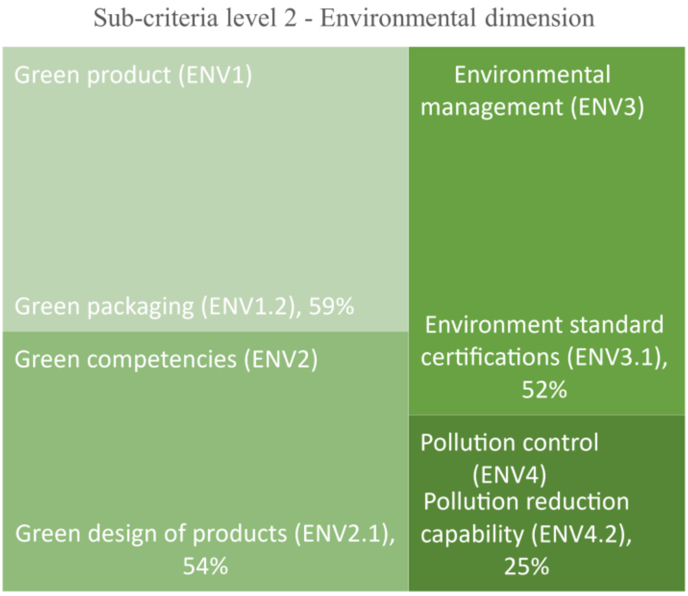


Figure 4- 12 Top sub-criteria level 2 weights in environmental criteria

4.2.1.2.1 Cost and price (EC1)

Cost and price has been identified as a pertinent supplier selection criterion in their decision-making process by all of the cases involved in this study. Tier 2 local suppliers states that cost is one of the most important factors when considering a supplier. Foreign majority, Thai majority, and Pure Thai supplier from Tier 1, are all identified as project based companies who all consider cost to be an important supplier selection criterion. They all state that the cost of rubber materials from the supplier impacts on their product with respect to the cost in which they sell to their manufacturers or customers. If the cost of the rubber material purchased from the supplier is high, the customer can then go to their competitor. However, for local suppliers, cost is seen as being as important as quality.

4.2.1.2.2 Financial stability (EC2)

Financial stability is identified as a pertinent supplier selection criterion in the supplier selection decision-making process for Tier 1 foreign majority suppliers and Tier 2 local suppliers. The other cases involved in this study do not mention financial stability as a pertinent criterion in the supplier selection decision-making process. For Tier 1 foreign majority suppliers, financial stability is referred to as company performance, and this criterion is related to the reliability of the company. This factor looks into the financial debt, and in general, to ensure that this supplier is a viable business partner for Tier 1 foreign majority suppliers. Tier 2 local suppliers, similar to Tier 1 foreign majority suppliers, also mentions financial stability as a pertinent criterion for the supplier selection decision-making process. Both cases, integrate assessing the financial stability of a supplier in their initial assessment during the supplier selection process. Tier 2 local suppliers assesses the financial stability in their nine stages of supplier selection. A supplier is required to submit financial reports for three years so that debt ratios and collection ratios can be assessed by Tier 2 local suppliers. Although this is a criterion for Tier 1 foreign majority suppliers, this structured process does not exist for Tier 1 Foreign majority suppliers. Tier 2 local suppliers, also explains that assessing a supplier's financial stability will result in knowing if a company is high risk or not. High risk suppliers are viewed as dependent, and this is not a supplier that Tier 2 local suppliers will shortlist for their approved supplier list.

4.2.1.2.3 Ethics (SC4)

Ethics is the most often mentioned criteria in social dimension as a pertinent supplier selection criterion for sustainability in the decision-making process for Tier 1 and Tier 2 suppliers. There was no mention of Ethics being a pertinent supplier selection criterion for Tier 1 Foreign majority suppliers and Tier 1 Thai majority suppliers. Tier 1 Pure Thai suppliers mentions that obeying to authority is a criterion that cannot be measured or assessed without conducted a large experiment on how people react when being obliged to act strictly as they are told without considering their own values and conscience, unlike pricing and pollution control, which is a factor that can be defined before purchase. Tier 1 Pure Thai suppliers also states that interpersonal behaviors is one of the factors that have the most problems in the supplier selection process, specifically purchasing manager or top management level behaves less ethical. Tier 1 Pure Thai suppliers uses reviews from interview questionaires to make an informed decision with regards to the service of the supplier, but in some cases, there is no information about this or the information is not consistent with the experience of Tier 1 Pure Thai suppliers. Tier 2 local suppliers is similar to Tier 1 Pure Thai suppliers that provides guidelines for code of conduct on how employees should behave under different circumstances. However, Tier 2 local suppliers will have to wait until after finishing the assessment tests to evaluate their behaviors. Similar to Tier 1 Pure Thai suppliers, if the track ethical risks are not acceptable, the supplier will not be used and will be placed in the inactive supplier list. It can be noted that this factor relates to the emerging theme of sustainability in social aspects. Tier 1 Thai majority suppliers speaks about rewards for ethical behavior and punishment of unethical behavior. Ethical behavior is mentioned as a legal factor with regards to Tier 1 Thai majority suppliers.

4.2.1.2.4 Employee's welfare and right (SC2)

Welfare and right has been currently identified as one of the main supplier selection criteria in the decision-making process for social aspects. Tier 1 and Tier 2 suppliers identify welfare measures with their suppliers to be an issue in their supplier selection process. The other suppliers in this study did not identify employee welfare as an issue or problem in their supplier selection process. However, in this study, Tier 1 tyre rubber suppliers express that for new employees, physical and mental health to workers is always a concern with regards to a healthy work environment.

4.2.1.2.5 Green product (ENV1)

Green product for a sustainable line of products are mentioned as a pertinent supplier selection criterion to the decision-making process by tyre rubber suppliers. Tier 1 Pure Thai suppliers did not mention technological attributes for designing reclycle and reuse of green products as supplier selection criterion considered in the decision-making process. Tier 1 foreign majority suppliers state that green product packaging is important, as their suppliers need to be knowledgeable of different requirements for products they require. Tier 1 foreign majority suppliers explained that this is important to them to operate in a niche market and for Supplier A to meet the needs and demands of their customers. Tier 1 Thai majority suppliers is similar to Tier 1 Foreign majority suppliers, in identifying green design as a sustainable supplier selection criterion in their decision-making process. Tier 1 Thai majority suppliers state that the research and development team is important to the purchasing process, as they need assurance that the rubber materials supplied by the supplier can produce the green product for the customer. The supplier must be knowledgeable so they can advise the department. Supplier F is similar to Tier 2 local suppliers in identifying sustainable attributes as a pertinent supplier selection criterion. The rubber materials supplied by the suppliers will need to be able to conform to different elements of the green design and packaging requirements. Tier 2 local suppliers's type of ownership is unlike Tier 1 foreign majority suppliers and Tier 1 Thai majority suppliers. However, technology in green product to reuse and recyle is still highlighted as a pertinent supplier selection criterion for the decision-making process. Although the type of the business differs, the reason for highlighting technical design is the same. It is necessary for their suppliers to have knowledge in how their products are capable of producing a sustainable product for Tier 2 local suppliers.

4.2.1.2.6 Environmental management (ENV3)

Tier 2 local suppliers did not mention any protocols and procedures adhered to environmental management system that corresponds to the sustainability of their product. Tier 1 suppliers state that they are ISO certified companies. Due to this, Tier 1 suppliers states that the ISO 14001 (environmetal standard certification) impacts on many processes in their business, for instance, their supplier evaluation process, their record keeping process, where a hard copy is required to be kept, and for every purchase order to suppliers is seen as a legally binding document, where a stamp needs to be placed. These processes allow them to follow the ISO 14001 requirements and allow Supplier B to preserve their ISO certification. Tier 1 Pure Thai suppliers mentions the importance of documentation as an important factor for the upkeep of the ISO 14001 standard. Similarly, to Tier 1 Thai majority suppliers, documentation is mentioned as an important factor for the ISO 14001 standard.

However, Tier 2 local suppliers did not mention the ISO 14001 standard as a part of their supplier evaluation process. Tier 1 Pure Thai suppliers, similar to Tier 1 Foreign majority suppliers and Tier 1 Thai majority suppliers, mentions the ISO 14001 certification and the impact on the processes of the company. Tier 1 Pure Thai suppliers state that this procedure impacts on the supplier selection process of some of their suppliers; it is according to the product or service that is being provided by the supplier. Tier 2 local suppliers also state that for some of their suppliers ISO 14001 certification is necessary and in some cases ISO certification is not necessary for some of their suppliers. Tier 2 local suppliers did not mention the ISO 14001 certification, unlike Tier 1 suppliers. Tier 1 Foreign majority suppliers mention legal agreements with their suppliers and their nine stages of the supplier selection process. It can be noted that due to the nature of their business and their relationship to their parent company, ISO 14001 is not mentioned or required. Tier 1 Pure Thai suppliers did not mention any protocols or procedures as part of their supplier selection process. It can be noted that the ISO 14001 is another method of ensuring a top quality product or service, and for Tier 2 local suppliers, as their suppliers are mostly friend or family association, this can be a reason for not incorporating the ISO 9001 certification as part of their supplier selection process.

4.2.2 Numerical Example of a combined decision making model (Fuzzy AHP)

A numerical example is presented to show how the weights of priorities for the criteria and sub-criteria are computed and to validate the mathematical model used in the current research.

For example, OEM Tyre company 1 compare among five sub-criteria level 1 in Social dimension. The following table highlights the pairwise comparison matrix and assigns fuzzy triangular numbers.

Table 4- 7 Pair-wise comparison between five sub-criteria level 1 in Social dimension

Social dimension	SC1			SC2			SC3			SC4			SC5		
Employee's health and safety (SC1)	1	1	1	1/6	1/5	1/4	2	3	4	1/9	1/9	1/9	1/4	1/3	1/2
Employee's welfare and right (SC2)	4	5	6	1	1	1	6	7	8	1/6	1/5	1/4	2	3	4
Working condition (SC3)	1/4	1/3	1/2	1/8	1/7	1/6	1	1	1	1/9	1/9	1/9	1/6	1/5	¼
Ethics (SC4)	9	9	9	4	5	6	9	9	9	1	1	1	6	7	8
Social commitment (SC5)	2	3	4	1/4	1/3	1/2	4	5	6	1/8	1/7	1/6	1	1	1

Then it is possible to continue with Buckley's (1985) steps.

For each company, calculate the geometric mean, $\tilde{u}_{ij}$. For example, for Social dimension:

$\tilde{u}_1 = \left[\left(1+\frac{1}{6}+2+\frac{1}{9}+\frac{1}{4}\right)^{\frac{1}{5}}, \left(1+\frac{1}{5}+3+\frac{1}{9}+\frac{1}{3}\right)^{\frac{1}{5}}, \left(1+\frac{1}{4}+4+\frac{1}{9}+\frac{1}{2}\right)^{\frac{1}{5}}\right]$ = [0.392, 0.467, 0.561]

Then, once computed the same passages for all sub-criteria level 1 in Social dimension, sum column values, take the reciprocal and finally sort the obtained values in increasing order. The geometric mean of fuzzy comparison values of each criterion is shown in Table 4-8

Table 4- 8 The geometric mean of fuzzy comparison values

Social dimension	$\tilde{u}_i$		
Employee's health and safety (SC1)	0.392	0.467	0.561
Employee's welfare and right (SC2)	1.516	1.838	2.169
Working condition (SC3)	0.225	0.254	0.297
Ethics (SC4)	4.547	4.904	5.223
Social commitment (SC5)	0.758	0.935	1.149
SUM	7.438	8.398	9.399
P(-1)	0.134	0.119	0.106
INCR (manually)	0.110	0.120	0.130

Compute the fuzzy weights of each criterion, $\tilde{w}_i$. For example, for Social dimension: Table 4-9 shows the result from comptuing this step.

$\tilde{w}_1$ = ((0.392*0.110), (0.0467*0.120), (0.561*0.130) = (0.042, 0.056, 0.075)

Table 4- 9 The fuzzy weights of each criterion

Social dimension	$\tilde{w}_i$		
Employee's health and safety (SC1)	0.042	0.056	0.075
Employee's welfare and right (SC2)	0.161	0.219	0.292
Working condition (SC3)	0.024	0.030	0.040
Ethics (SC4)	0.484	0.584	0.702
Social commitment (SC5)	0.081	0.111	0.154

The last two steps, on the one hand the calculation of non-fuzzy weight of each criterion (M_i) by taking the average of fuzzy numbers for each criterion SC and on the other hand the normalisation of them. For example, for SC1:

M_1 = (0.042+0.056+0.075)/3 = 0.058 and

N_1 = 0.058/1.018 = 0.0565 where 1.018 is the column summation of M_i in Table 4-10

Table 4- 10 Ranking sub-criteria weights from OEM Tyre company 1 in Social dimension

Social dimension	M_i	N_i	Rank
Employee's health and safety (SC1)	0.058	0.057	4
Employee's welfare and right (SC2)	0.224	0.220	2
Working condition (SC3)	0.031	0.031	5
Ethics (SC4)	0.590	0.579	1
Social commitment (SC5)	0.115	0.113	3

Finally, rank N_i assigns a specific weight to each firm based on its Social dimension in sustainable supplier selection and evaluation. Table 4-10 are ranked from the one with the highest weight to the least one. In particular, considering Social factors assessment as the next passage, questionnaire answers of OEM company 1 in SC4 will have a greater influence with regard to the others. The opposite happens for SC3 which has the lowest N_3 value.

4.2.3 Consistency Check

The consistency check is a significant consideration related to the quality of the final decision in terms of the consistency of judgements made by the decision maker during the set of pairwise comparisons. As discussed earlier in this chapter, five steps are followed to check the consistency of the final results:

Step 1. In the pairwise comparison matrix, the relative priority of the sub-criteria level 1 weights of Social sub-criteria level 1 in Table 4-11 is multiplied by each value in the first column in Table 4-12 and this is repeated for all other items.

Table 4- 11 The weighted sum for the selected sub-criteria in Social dimension.

Sub-criteria level 1	Weight sum
Employee's health and safety (SC1)	1.12
Employee's welfare and right (SC2)	1.03
Working condition (SC3)	0.97
Ethics (SC4)	0.97
Social commitment (SC5)	0.88

To find the vector of the values, calculate the summation of all values within the rows. This vector is called 'the weighted sum' (Table 4-13).

Table 4- 12 Priority sub-criteria level 1 weight in Social dimension

Sub-criteria level 1	Weight
Employee's health and safety (SC1)	0.16
Employee's welfare and right (SC2)	0.20
Working condition (SC3)	0.19
Ethics (SC4)	0.31
Social commitment (SC5)	0.14
Sum	1.00

Step 2. Calculate the average of the division of the weighted sum and the priority values. These values were found in the previous step. Table 4-13 displays the weighted sum divided by priority sub-criteria level 1 weights.

Table 4- 13 Weighted sum/Priority weights

Sub-criteria level 1	Values
Employee's health and safety (SC1)	7.05
Employee's welfare and right (SC2)	5.16
Working condition (SC3)	5.15
Ethics (SC4)	3.15
Social commitment (SC5)	6.29

The calculated average is expressed as λ_{max}, as shown below:

λ_{max} = (7.05+5.16+5.15+3.15+6.29)/5 = 5.36

Step 3. Calculate the Consistency Index (CI) using Equation 4.1:

$CI = (\lambda_{max} – n) / (n-1)$

Where n is the number of criteria, which 5. (eg. Sub-criteria level 1 in Social dimension)

CI = (5.36-5)/(5-1) = 0.091

Step 4. Calculate the Consistency Ratio (CR) using Equation 4.2:

CR = 0.36/1.12 = 0.081 or 8.1%

CR = 0.081, which is less than 10%, meaning that the consistency of the data result is accepted, and the judgement matrix is considered to be consistent.

4.3 The Fuzzy TOPSIS Decision Making Model

The combined decision-making model, Fuzzy TOPSIS is focused on the description of the Fuzzy and TOPSIS method, this method was applied to find the most suitable tyre rubber suppliers in Thailand using the implement sustainable criteria. Till now, on the one hand, Chapter three lists the numbers of Tyre rubber firms that were considered solving the Thesis problem and, on the other hand, Fuzzy AHP provides the weighted most influential sustainable factors vector. The Fuzzy TOPSIS (FTOPSIS) method consider these two results as the inputs for its application. This highlights the link between the two methods. The first paragraph starts with the description of the factors and in particular sub-factors (sub-categories of factors) needed to be considered. Next it continues with the presentation of the FTOPSIS method used in the Thesis case study. Then, FTOPSIS is applied to the collected data. As the last step, the final Tyre rubber firms ranking is presented between suppliers Tier 1 and Local Tier 2. Therefore, this part ends by identifying which should be the most selected to implement for Tyre rubber companies in Thailand. This section follows the evaluation methodology as describe in Figure 4-13 below.

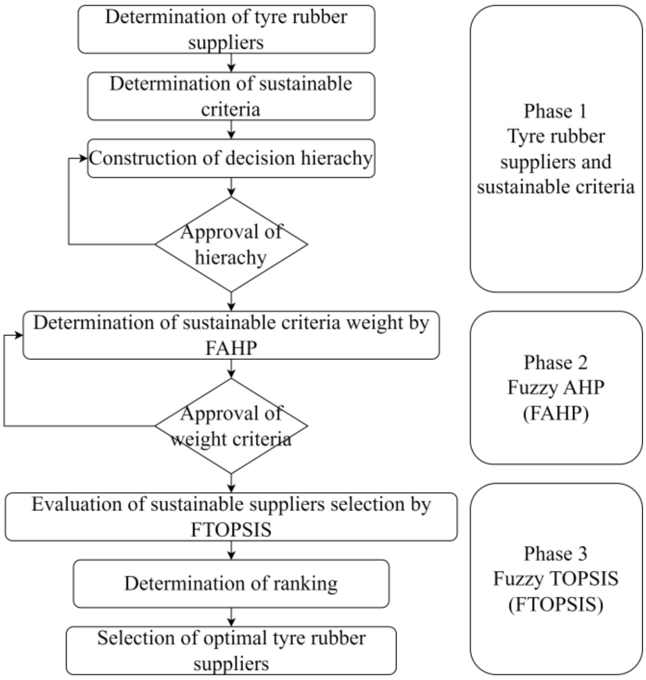


Figure 4- 13 Evaluation methodology of sustainable supplier selection

4.3.1 Sub-criteria description

The criteria list in the prior section has been analysed through the Fuzzy AHP model to understand which should be the criteria that influence a manager most in the case he/she would like to implement sustainability in tyre rubber suppliers and those that less influence the alternative.

Table 4-1 provides some examples of sustainable criteria; these examples can be categorised as sub-factors (sub-criteria) and turn out to be useful to conclude the analysis. Indeed, the Fuzzy TOPSIS model uses these sub-criteria to deliver the final solution of this Thesis case study.

Values and data collected from the surveys and questionaires for each sub-criteria are reported in Appendix 4. They will be necessary to apply the Fuzzy TOPSIS method in the next paragraph. For the moment, Figure 4-14 provides an overview of the sustainable supplier selection and evaluation problem, considering criteria, sub-criteria and alternative suppliers.

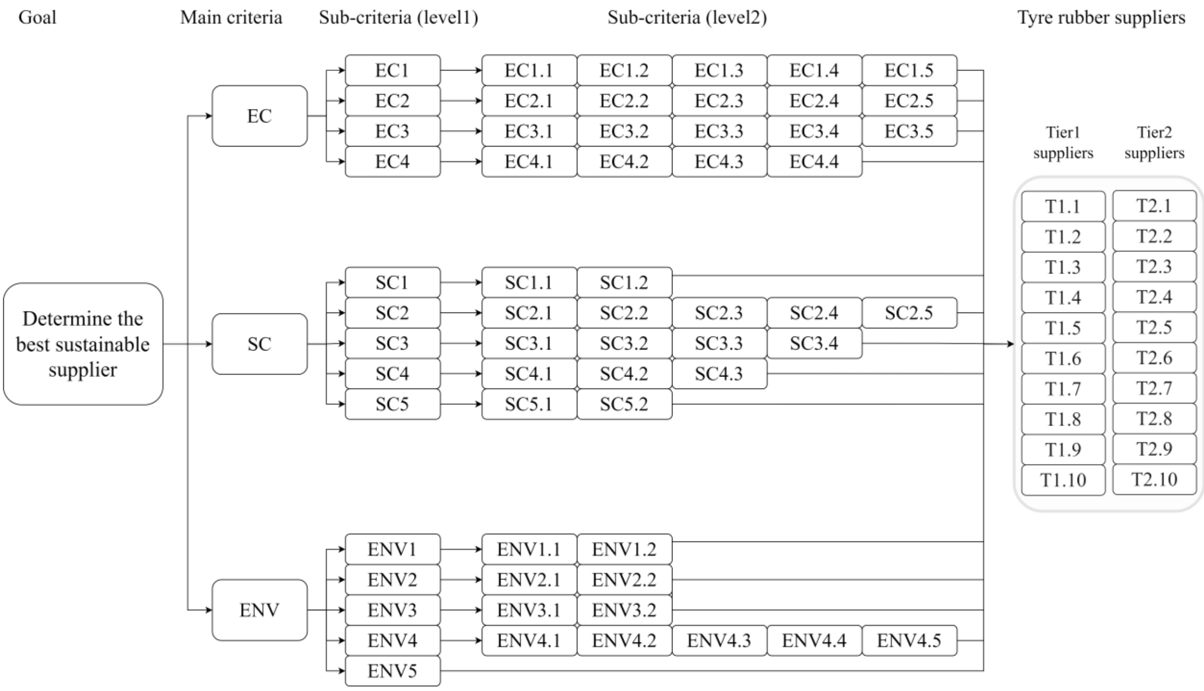


Figure 4- 14 Problem structure

4.3.2 The Fuzzy TOPSIS method for ranking of alternatives

The TOPSIS (technique for order preference by similarity to ideal solution) has wide applicability and is used for tackling ranking problems due to its simplicity. TOPSIS was developed by Hwang and Yoon (1981). Due to the presence of ambiguous and vague issues in the performance evaluation of friction composite materials, Fuzzy TOPSIS (FTOPSIS) is employed for performance evaluation which uses linguistic values rather than numerical values, which means that the rankings in the performance evaluation are evaluated by linguistic variables. Linguistic value can deal with ambiguities, uncertainties, and vagueness.

It is necessary to underline an important factor, i.e. cost, quality, finance, the aspect of the criteria differents among the criteria. Managers or stakeholders will look for suppliers with the lowest costs and highest benefits. For this reason, it is important to understand which sub-criteria should have a high numerical value (benefit/gain to the select a tyre rubber supplier). It is also necessary to identify which sub-criteria are costs or, which of them have reflect a negative view. “Min” stands for "less is better". These criteria are costs or have a negative effect on the procurement, so it is better if their values are as low as possible. “Max” stands for "more is better". The criteria are benefits or have a positive effect on the procurement, so it is better if their values are as high as possible.

The numerical values assigned to each sub-criterion in this thesis are confidential. As a result, a questionnaire has been developed to provide suppliers with alternative ratings based on linguistic values in relation to the sustainable supplier criteria. To convert the confidential numerical values associated with each sub-criterion into linguistic values, a linguistic rating system was employed. The researcher designed a questionnaire with a set of linguistic terms, such as "very high", "high", "medium", "low", and "very low", which were associated with specific numerical ranges. The supplier was asked to rate their performance in each sub-criterion by selecting the appropriate linguistic term that best described their performance, as per the given numerical range. For instance, a supplier may be asked to rate their environmental performance on a scale of 1 to 10, with 1 being the lowest importance and 10 being the highest importance. The supplier could then rate their environmental performance as "very high" if their numerical score was between 8 and 10, "high" if their score was between 6 and 7, "medium" if their score was between 4 and 5, "low" if their score was between 2 and 3, or "very low" if their score was between 0 and 1. This process allowed for the conversion of numerical values into linguistic values, making it easier for suppliers to provide ratings based on the sustainable supplier criteria. The selection of suppliers are transformed into linguistic variables which are given in the following Table 4-14. This gives the linguistic values in terms of fuzzy number.

Table 4- 14 Linguistics scale for each alternative (Jiang et al., 2008)

Linguistic variable	Numerical values (rating scale)	Triangular Fuzzy Numbers (TFNs) – (a,b,c)	Fuzzy Numbers [0,1]
Very low (VL)	0-1	(0, 1, 3)	(0, 0.10, 0.25)
Low (L)	2-3	(1, 3, 5)	(0.15, 0.30, 0.45)
Medium (M)	4-5	(3, 5, 7)	(0.35, 0.50, 0.65)
High (H)	6-7	(5, 7, 9)	(0.55, 0.70, 0.85)
Very high (VH)	8-10	(7, 9, 10)	(0.75, 0.90, 1)

4.3.3 Application of Fuzzy TOPSIS method

In this section, the FTOPSIS model as extended by Chen (2000) is used for ranking the alternatives or the suppliers. The linguistic assessment of the group decision makers on suppliers for each attribute applied fuzzy logic. The procedure is described below.

Step 1. A decision matrix is created after identifying the performance defining criterion and alternatives of the problem. If the number of alternatives is M and the number of performance defining criteria is N then the decision matrix has an order of M × N is represented in Eq. 4.8.

$$D_{M\times N} = \begin{bmatrix} a_{11} & \cdots & a_{1N} \\ \vdots & \ddots & \vdots \\ a_{M1} & \cdots & a_{MN} \end{bmatrix} \quad (4.8)$$

where an element a_{ij} ($a_{ij} > 0$) of the decision matrix $D_{M\times N}$ represents the actual value of i[th] the alternative (supplier) in term of j[th] attribute (sub-criteria).

Step 2. In order to transform the performance values to fuzzy linguistic variables, the decision matrix is converted into a normalised decision matrix (a_{ij}) by converting the performance values of the decision matrix into a range of [0, 1]. The normalized values of each element in the normalised decision matrix can be calculated by using Eq. 4.9.

$$r_{ij} = \frac{a_{ij} - \min\{a_{ij}\}}{\max\{a_{ij}\} - \min\{a_{ij}\}}, \text{ for benefit criteria, and } r_{ij} = \frac{\max\{a_{ij}\} - a_{ij}}{\max\{a_{ij}\} - \min\{a_{ij}\}}, \text{ for cost criteria} \quad (4.9)$$

Step 3. The linguistic values ($\tilde{a}_{ij}$, i= 1, 2... M, j = 1, 2... N) are chosen for M alternatives with respect to N criteria. These fuzzy linguistic values preserve the properties that the range of fuzzy numbers belongs to [0, 1].

Step 4. A weighted normalized fuzzy decision matrix is calculated by using Eq. 4.10.

$$\tilde{V}_{ij} = \tilde{a}_{ij} \times \widetilde{W}_i \quad (4.10)$$

Step 5. The determination of a fuzzy positive ideal solution (FPIS, $\tilde{A}^{+}$) and a fuzzy negative ideal solution (FNIS, $\tilde{A}^{-}$) is made by using Eq. 4.11 and 4.12.

$$\tilde{A}^{+} = (\tilde{V}_1^{+}, \tilde{V}_2^{+}, \quad \ldots, \tilde{V}_N^{+}), \text{ and } \tilde{A}^{-} = (\tilde{V}_1^{-}, \tilde{V}_2^{-}, \quad \ldots, \tilde{V}_N^{-}), \quad (4.11)$$

where

$$\tilde{V}_j^{+} = \begin{Bmatrix} (max\ i\ \tilde{V}_{ij}) & if\ j\ is\ benefits\ criterion \\ (min\ i\ \tilde{V}_{ij}) & if\ j\ is\ cost\ criterion \end{Bmatrix}, \text{ and}$$

$$\tilde{V}_j^{-} = \begin{Bmatrix} (min\ i\ \tilde{V}_{ij}) & if\ j\ is\ benefits\ criterion \\ (max\ i\ \tilde{V}_{ij}) & if\ j\ is\ cost\ criterion \end{Bmatrix}, \text{ for } j = 1,2, \ldots N$$

(4.12)

Step 6. The Euclidian distances between each of the alternatives and the fuzzy positive ideal solution and the fuzzy negative ideal solution are calculated by using Eq. 4.13.

$$\widetilde{D}_i^{+} = \sqrt{\frac{1}{3} \times \sum_{j=1}^{N} D\,(\tilde{V}_i^{+} - \tilde{V}_{ij})^2} \text{ , and}$$

$$\widetilde{D}_i^{-} = \sqrt{\frac{1}{3} \times \sum_{j=1}^{N} D\,(\tilde{V}_i^{-} - \tilde{V}_{ij})^2} \text{ , for i= 1, 2, 3 … M} \quad (4.13)$$

Step 7. Finally, the overall preference or fuzzy closeness index ($\widetilde{CC}_i$) of the alternatives is calculated with the help of Eq. 4.14.

$$\widetilde{CC}_i = \frac{\widetilde{D}_i^{-}}{\widetilde{D}_i^{+} + \widetilde{D}_i^{-}} \text{ , for i=1, 2, 3 … M} \quad (4.14)$$

The application of the Fuzzy TOPSIS method starts after weighting the criteria which collect the linguistic scale value for sustainable supplier alternatives from various department of Tyre rubber companies for each criterion. The linguistic values consist of five values such as very low (VL), low (V), medium (M), high (H), very high (VH). Table 4-15 and Table 4-16 show the summary of linguistic fuzzy evaluation matrix for the supplier alternatives Tier 1 and Local Tier 2 respectively.

Table 4- 15 The summary of linguistic fuzzy evaluation matrix for the ranking Tier 1 suppliers

Criteria	Sub-criteria 1	Sub-criteria 2	T1.1	T1.2	T1.3	T1.4	T1.5	T1.6	T1.7	T1.8	T1.9	T1.10
EC	EC1	EC1.1	VL	VH	H	M	H	L	H	L	VH	VH
		EC1.2	VL	H	L	L	VH	M	L	VL	VL	H
		EC1.3	H	M	H	M	VH	VH	VH	M	VH	M
		EC1.4	H	M	VL	M	M	VH	VL	M	VH	VL
		EC1.5	H	L	VH	L	M	M	VH	L	VH	VL
	EC2	EC2.1	M	L	L	L	L	VH	L	H	VL	VH
		EC2.2	L	L	VH	H	M	L	VL	L	H	L
		EC2.3	VL	H	VL	VL	H	H	H	M	M	VH
		EC2.4	L	M	VH	VH	VL	L	M	M	VL	L
		EC2.5	L	H	VH	H	VH	M	VH	H	VH	VH
	EC3	EC3.1	L	VL	VH	VL	VL	H	VH	VL	H	VH
		EC3.2	L	H	VL	VH	H	H	VL	L	L	H
		EC3.3	VL	L	VL	L	VL	VL	VL	H	H	H
		EC3.4	L	H	H	VL	H	H	M	VH	M	VH
		EC3.5	VH	M	VL	L	L	VL	VL	L	M	VH
	EC4	EC4.1	L	H	VL	M	L	H	M	M	M	VL
		EC4.2	H	M	H	M	VL	M	VL	VL	H	M
		EC4.3	VL	VL	VL	L	VH	L	M	M	L	M
		EC4.4	VH	M	L	M	L	M	M	VH	M	M
SC	SC1	SC1.1	VH	L	VL	H	VL	VH	L	H	L	VL
		SC1.2	VH	VH	M	L	H	VL	H	VH	VL	VH
	SC2	SC2.1	M	VL	VL	VH	L	H	L	H	M	VH
		SC2.2	H	H	VH	VL	M	H	L	M	VL	VH
		SC2.3	M	VH	VH	H	M	VH	M	VL	M	M
		SC2.4	H	VL	VH	L	H	H	H	M	VH	L

		SC2.5	H	L	VH	H	M	VH	VH	VL	M	M
	SC3	SC3.1	H	VH	VH	H	H	L	H	L	VH	M
		SC3.2	VH	M	H	VL	M	VH	L	L	L	H
		SC3.3	M	VH	H	VH	M	L	M	L	M	H
		SC3.4	VL	VH	H	H	M	L	H	H	M	VL
	SC4	SC4.1	M	M	VL	H	VH	VL	VL	M	L	H
		SC4.2	VH	H	VL	L	M	M	M	VH	H	M
		SC4.3	VH	L	VL	L	VH	VH	VL	VH	H	M
	SC5	SC5.1	M	VH	VH	M	VL	L	H	M	VH	H
		SC5.2	H	VL	VH	VH	H	VH	VL	VL	H	VH
ENV	ENV1	ENV1.1	H	VL	VH	VL	VL	H	H	H	L	M
		ENV1.2	L	L	H	VH	VH	VH	H	H	VH	H
	ENV2	ENV2.1	VH	H	VL	VL	H	H	L	VH	L	M
		ENV2.2	L	VL	VH	L	VL	H	VH	L	VL	VL
	ENV3	ENV3.1	L	L	VH	VL	H	VH	L	VH	L	L
		ENV3.2	M	M	H	VL	VL	L	L	H	H	M
	ENV4	ENV4.1	VH	M	VL	M	M	VL	L	H	VH	VL
		ENV4.2	M	VH	M	H	M	H	VH	L	VH	VL
		ENV4.3	L	M	VH	L	M	VL	L	H	VH	VH
		ENV4.4	H	H	M	H	VH	L	VH	H	L	M
		ENV4.5	VH	L	H	L	VH	H	M	H	M	M
	ENV5		H	VL	H	H	M	L	VH	H	H	L

Table 4- 16 The summary of linguistic fuzzy evaluation matrix for the ranking Tier 2 suppliers

Criteria	Sub-criteria 1	Sub-criteria 2	T2.1	T2.2	T2.3	T2.4	T2.5	T2.6	T2.7	T2.8	T2.9	T2.10
EC	EC1	EC1.1	M	H	L	M	H	VL	VH	VH	H	L
		EC1.2	VL	VH	VH	VL	L	L	H	VH	L	H
		EC1.3	VH	L	VL	VH	H	VL	M	H	VH	H
		EC1.4	L	VH	VH	VL	VL	VL	H	VH	L	VL
		EC1.5	L	L	M	VH	H	H	L	L	L	L
	EC2	EC2.1	M	H	L	H	L	L	M	VL	H	VL
		EC2.2	VH	VL	H	VL	VL	VL	VH	L	VH	VH
		EC2.3	VL	H	L	H	L	L	H	H	L	VL
		EC2.4	M	H	VL	VH	VH	M	M	VL	VL	M
		EC2.5	VH	VL	M	M	L	VH	L	VL	M	L
	EC3	EC3.1	H	VH	M	VH	L	VL	L	H	VL	VL
		EC3.2	VH	M	VH	VH	VH	L	H	VH	L	VL
		EC3.3	VL	H	VL	L	L	VL	L	M	L	L
		EC3.4	VH	L	H	M	VH	L	M	H	H	VL
		EC3.5	VH	H	VH	M	L	H	VL	H	M	VL
	EC4	EC4.1	L	M	VL	L	H	VH	M	L	L	VL
		EC4.2	VL	H	H	VH	M	H	M	M	M	H
		EC4.3	VH	M	VL	M	VH	L	M	L	H	VH
		EC4.4	VH	M	L	M	L	M	M	VH	M	M
SC	SC1	SC1.1	VH	L	VL	H	VL	VH	L	H	L	VL
		SC1.2	VH	VH	M	L	H	VL	H	VH	VL	VH
	SC2	SC2.1	M	VL	VL	VH	L	H	L	H	M	VH
		SC2.2	H	H	VH	VL	M	H	L	M	VL	VH

		SC2.3	M	VH	VH	H	M	VH	M	VL	M	M
		SC2.4	H	VL	VH	L	H	H	H	M	VH	L
		SC2.5	H	L	VH	H	M	VH	VH	VL	M	M
	SC3	SC3.1	H	VH	VH	H	H	L	H	L	VH	M
		SC3.2	VH	M	H	VL	M	VH	L	L	L	H
		SC3.3	M	VH	H	VH	M	L	M	L	M	H
		SC3.4	VL	VH	H	H	M	L	H	H	M	VL
	SC4	SC4.1	M	M	VL	H	VH	VL	VL	M	L	H
		SC4.2	VH	H	VL	L	M	M	M	VH	H	M
		SC4.3	VH	L	VL	L	VH	VH	VL	VH	H	M
	SC5	SC5.1	M	VH	VH	M	VL	L	H	M	VH	H
		SC5.2	H	VL	VH	VH	H	VH	VL	VL	H	VH
ENV	ENV1	ENV1.1	H	VL	VH	VL	VL	H	H	H	L	M
		ENV1.2	L	L	H	VH	VH	VH	H	H	VH	H
	ENV2	ENV2.1	VH	H	VL	VL	H	H	L	VH	L	M
		ENV2.2	L	VL	VH	L	VL	H	VH	L	VL	VL
	ENV3	ENV3.1	L	L	VH	VL	H	VH	L	VH	L	L
		ENV3.2	M	M	H	VL	VL	L	L	H	H	M
	ENV4	ENV4.1	VH	M	VL	M	M	VL	L	H	VH	VL
		ENV4.2	M	VH	M	H	M	H	VH	L	VH	VL
		ENV4.3	L	M	VH	L	M	VL	L	H	VH	VH
		ENV4.4	H	H	M	H	VH	L	VH	H	L	M
		ENV4.5	VH	L	H	L	VH	H	M	H	M	M
	ENV5		H	VL	H	H	M	L	VH	H	H	L

Then, the linguistic fuzzy evaluation matrix is created by decision makers and various departments. According to the scale we convert this linguistic value into the fuzzy number by the use of the scale in Table 4-15. This Table 4-15 is follows by Jiang et al. (2008) which is related to linguistic values and fuzzy number. So we also follow this fundamental in Table 4-15. Conversion of the linguistic values results in VL = (0,0.10,0.25), L = (0.15,0.30,0.45), M = (0.35,0.50,0.65), H = (0.55,0.70,0.85) and VH = (0.75,0.90,1).

By calculating from Eq. 4.10, Table 4-17 shows Tier 1 suppliers' sample of the fuzzy weighted evaluation matrix (T1.1 to T1.3) from the help of Table 4-6 multiplying weighted criteria in each row corresponding to criteria. For example, supplier alternative T1.1 (Tier 1 Supplier 1) the cost and price weighting criteria (EC1.1) is 0.32 and T1.1 cost and price value in terms of fuzzy is VL (0, 0.1, 0.25) then the value of fuzzy weighted evaluation matrix for T1.1 is calculated as [(0.32x0), (0.32x0.1), (0.32x0.25). The value for T1.1 supplier is [0, 0.03, 0.08]. The overall results are shown in Appendix 4.

Table 4- 17 Tier 1 suppliers' sample of The Fuzzy weighted evaluation matrix (T1.1-T1.3)

Sub-criteria 2	Weight	Suppliers T1.1	Suppliers T1.2	Suppliers T1.3
EC1.1	0.32	(0,0.03,0.08)	(0.24,0.29,0.32)	(0.18,0.22,0.27)
EC1.2	0.17	(0,0.02,0.04)	(0.09,0.12,0.14)	(0.03,0.05,0.08)
EC1.3	0.15	(0.08,0.11,0.13)	(0.05,0.08,0.1)	(0.08,0.11,0.13)
EC1.4	0.2	(0.11,0.14,0.17)	(0.07,0.1,0.13)	(0,0.02,0.05)
EC1.5	0.16	(0.09,0.11,0.14)	(0.02,0.05,0.07)	(0.12,0.14,0.16)
EC2.1	0.15	(0.05,0.08,0.1)	(0.02,0.05,0.07)	(0.02,0.05,0.07)
EC2.2	0.31	(0.05,0.09,0.14)	(0.05,0.09,0.14)	(0.23,0.28,0.31)
EC2.3	0.24	(0,0.02,0.06)	(0.13,0.17,0.2)	(0,0.02,0.06)
EC2.4	0.18	(0.03,0.05,0.08)	(0.06,0.09,0.12)	(0.14,0.16,0.18)
EC2.5	0.12	(0.02,0.04,0.05)	(0.07,0.08,0.1)	(0.09,0.11,0.12)
EC3.1	0.4	(0.06,0.12,0.18)	(0,0.04,0.1)	(0.3,0.36,0.4)
EC3.2	0.2	(0.03,0.06,0.09)	(0.11,0.14,0.17)	(0,0.02,0.05)
EC3.3	0.17	(0,0.02,0.04)	(0.03,0.05,0.08)	(0,0.02,0.04)
EC3.4	0.13	(0.02,0.04,0.06)	(0.07,0.09,0.11)	(0.07,0.09,0.11)
EC3.5	0.1	(0.08,0.09,0.1)	(0.04,0.05,0.07)	(0,0.01,0.03)
EC4.1	0.31	(0.05,0.09,0.14)	(0.17,0.22,0.26)	(0,0.03,0.08)
EC4.2	0.16	(0.09,0.11,0.14)	(0.06,0.08,0.1)	(0.09,0.11,0.14)
EC4.3	0.26	(0,0.03,0.07)	(0,0.03,0.07)	(0,0.03,0.07)
EC4.4	0.27	(0.2,0.24,0.27)	(0.09,0.14,0.18)	(0.04,0.08,0.12)
SC1.1	0.52	(0.39,0.47,0.52)	(0.08,0.16,0.23)	(0,0.05,0.13)
SC1.2	0.48	(0.36,0.43,0.48)	(0.36,0.43,0.48)	(0.17,0.24,0.31)
SC2.1	0.15	(0.05,0.08,0.1)	(0,0.02,0.04)	(0,0.02,0.04)
SC2.2	0.06	(0.03,0.04,0.05)	(0.03,0.04,0.05)	(0.05,0.05,0.06)
SC2.3	0.17	(0.06,0.09,0.11)	(0.13,0.15,0.17)	(0.13,0.15,0.17)
SC2.4	0.51	(0.28,0.36,0.43)	(0,0.05,0.13)	(0.38,0.46,0.51)
SC2.5	0.11	(0.06,0.08,0.09)	(0.02,0.03,0.05)	(0.08,0.1,0.11)
SC3.1	0.28	(0.15,0.2,0.24)	(0.21,0.25,0.28)	(0.21,0.25,0.28)
SC3.2	0.16	(0.12,0.14,0.16)	(0.06,0.08,0.1)	(0.09,0.11,0.14)
SC3.3	0.34	(0.12,0.17,0.22)	(0.26,0.31,0.34)	(0.19,0.24,0.29)
SC3.4	0.22	(0,0.02,0.06)	(0.17,0.2,0.22)	(0.12,0.15,0.19)
SC4.1	0.53	(0.19,0.27,0.34)	(0.19,0.27,0.34)	(0,0.05,0.13)
SC4.2	0.12	(0.09,0.11,0.12)	(0.07,0.08,0.1)	(0,0.01,0.03)
SC4.3	0.35	(0.26,0.32,0.35)	(0.05,0.11,0.16)	(0,0.04,0.09)
SC5.1	0.43	(0.15,0.22,0.28)	(0.32,0.39,0.43)	(0.32,0.39,0.43)
SC5.2	0.57	(0.31,0.4,0.48)	(0,0.06,0.14)	(0.43,0.51,0.57)
ENV1.1	0.41	(0.23,0.29,0.35)	(0,0.04,0.1)	(0.31,0.37,0.41)
ENV1.2	0.59	(0.09,0.18,0.27)	(0.09,0.18,0.27)	(0.32,0.41,0.5)
ENV2.1	0.54	(0.41,0.49,0.54)	(0.3,0.38,0.46)	(0,0.05,0.14)
ENV2.2	0.46	(0.07,0.14,0.21)	(0,0.05,0.12)	(0.35,0.41,0.46)
ENV3.1	0.52	(0.08,0.16,0.23)	(0.08,0.16,0.23)	(0.39,0.47,0.52)
ENV3.2	0.48	(0.17,0.24,0.31)	(0.17,0.24,0.31)	(0.26,0.34,0.41)
ENV4.1	0.2	(0.15,0.18,0.2)	(0.07,0.1,0.13)	(0,0.02,0.05)
ENV4.2	0.25	(0.09,0.13,0.16)	(0.19,0.23,0.25)	(0.09,0.13,0.16)
ENV4.3	0.17	(0.03,0.05,0.08)	(0.06,0.09,0.11)	(0.13,0.15,0.17)
ENV4.4	0.18	(0.1,0.13,0.15)	(0.1,0.13,0.15)	(0.06,0.09,0.12)
ENV4.5	0.2	(0.15,0.18,0.2)	(0.03,0.06,0.09)	(0.11,0.14,0.17)
ENV5	0.1	(0.06,0.07,0.09)	(0,0.01,0.03)	(0.06,0.07,0.09)

To normalise the fuzzy decision matrix, the sub-criteria must be divided into positive and negative ideal solutions. The Fuzzy positive ideal solution and Fuzzy negative ideal solution is calculated from Eq. 4.11 and Eq. 4.12. The Fuzzy positive ideal solution (FPIS) and Fuzzy negative ideal solution (FNIS) for given criteria is shown in following Table 4-18.

Table 4- 18 Fuzzy negative ideal solution ($\tilde{A}^{-}$) and Fuzzy positive ideal solution ($\tilde{A}^{+}$)

Ideal solutions								
Sub-criteria (LV.2)	FNIS(-)	FPIS(+)	Sub-criteria (LV.2)	FNIS(-)	FPIS(+)	Sub-criteria (LV.2)	FNIS(-)	FPIS(+)
EC1.1	0.00	0.08	SC1.1	0.00	0.13	ENV1.1	0.00	0.10
EC1.2	0.00	0.04	SC1.2	0.00	0.12	ENV1.2	0.09	0.27
EC1.3	0.00	0.04	SC2.1	0.00	0.04	ENV2.1	0.00	0.14
EC1.4	0.00	0.05	SC2.2	0.00	0.02	ENV2.2	0.00	0.12
EC1.5	0.00	0.04	SC2.3	0.00	0.04	ENV3.1	0.00	0.13
EC2.1	0.00	0.04	SC2.4	0.00	0.13	ENV3.2	0.00	0.12
EC2.2	0.00	0.08	SC2.5	0.00	0.03	ENV4.1	0.00	0.05
EC2.3	0.00	0.06	SC3.1	0.04	0.13	ENV4.2	0.00	0.06
EC2.4	0.00	0.05	SC3.2	0.00	0.04	ENV4.3	0.00	0.04
EC2.5	0.00	0.03	SC3.3	0.05	0.15	ENV4.4	0.03	0.08
EC3.1	0.00	0.10	SC3.4	0.00	0.06	ENV4.5	0.03	0.09
EC3.2	0.00	0.05	SC4.1	0.00	0.13	ENV5	0.00	0.03
EC3.3	0.00	0.04	SC4.2	0.00	0.03			
EC3.4	0.00	0.03	SC4.3	0.00	0.09			
EC3.5	0.00	0.03	SC5.1	0.00	0.11			
EC4.1	0.00	0.08	SC5.2	0.00	0.14			
EC4.2	0.00	0.04						
EC4.3	0.00	0.07						
EC4.4	0.04	0.12						

Then the distance between each alternative from $\widetilde{D}_i^{+}$ and $\widetilde{D}_i^{-}$ is calculated from Eq. 4.13. $\widetilde{CC}_i$ is the closeness index which is calculated from Eq. 4.14. $\widetilde{CC}_i$ is given in following Table 4-19.

Table 4- 19 Fuzzy closeness index and ranking of supplier alternatives

Tyre rubber supplier	$\widetilde{D}_i^{+}$	$\widetilde{D}_i^{-}$	$\widetilde{CC}_i$	Tier 1 Ranking	Global Ranking	Tyre rubber supplier	$\widetilde{D}_i^{+}$	$\widetilde{D}_i^{-}$	$\widetilde{CC}_i$	Tier 2 Ranking	Global Ranking
T1.1	3.667	2.277	0.617	3	3	T2.1	3.583	2.326	0.606	3	13
T1.2	3.779	2.426	0.609	8	10	T2.2	3.864	2.611	0.597	8	18
T1.3	4.044	2.551	0.613	6	6	T2.3	4.239	2.977	0.587	10	20
T1.4	3.518	2.198	0.615	4	4	T2.4	3.783	2.481	0.604	5	15
T1.5	4.462	2.877	0.608	9	11	T2.5	3.961	2.584	0.605	4	14

T1.6	3.545	2.245	0.612	7	8	T2.6	4.155	2.848	0.593	9	19
T1.7	3.841	2.356	0.620	2	2	T2.7	4.064	2.576	0.612	2	9
T1.8	4.358	2.821	0.607	10	12	T2.8	3.944	2.606	0.602	7	17
T1.9	4.093	2.567	0.615	5	5	T2.9	4.250	2.807	0.602	6	16
T1.10	3.809	2.284	0.625	1	1	T2.10	3.995	2.529	0.612	1	7

Likewise, the closeness coefficients for twenty Tyre rubber suppliers including Tier 1 and Local Tier 2 are computed and shown in Table 4-19. The application of the combined multi-criteria decision making methods (Fuzzy AHP and Fuzzy TOPSIS) has demonstrated that the final result of sustainable supplier selection alternatives in the Tyre rubber industry in Thailand are shown in Table 4-20 which shows the final ranking for suppliers alternatives, which is based on the closeness index. The supplier T2.10 (Local Tier 2 Company 10) and T1.10 (Tier 1 Company 10) are selected as the better alternatives among twenty suppliers for the tyre rubber companies. These values show the average values of nineteen appropriate criteria for select suppliers based on sustainability criteria.

4.3.4 Types of Thai Tyre rubber suppliers ownership in Tier 1 suppliers

The result of ranking the tier 1 suppliers from consider 46 sub-criteria level 2 and types of Tyre rubber suppliers are presented in Table 4-20.

Table 4- 20 Type of ownership in Tier 1 supplier

Tyre rubber supplier	Tier 1 Ranking	Type of ownership
T1.1	3	Foreign majority
T1.2	9	Thai majority
T1.3	10	Pure Thai
T1.4	6	Thai majority
T1.5	7	Pure Thai
T1.6	8	Thai majority
T1.7	2	Foreign majority
T1.8	5	Pure Thai
T1.9	4	Thai majority
T1.10	1	Foreign majority

As shown in Table 4-20, Tier 1 Foreign majority suppliers are the top-three highest rank scores. The last three values consist of 1 supplier in Thai majority and 2 suppliers in Pure Thai ownership.

4.3.4.1 Foreign majority and Thai majority suppliers in Tier 1 Tyre rubber supplier

From the two types of ownership in Tier 1 supplier, interviewees identified many criteria and government policy for engaging in sustainability initiatives. These large companies state that there is a difference in the way business is conducted in large firms, compared to small and medium firms. This imply that large companies have different requirements or expectations when it comes to working with suppliers and promoting sustainable practices. For instance, large companies have more resources and capacity to implement sustainable supply chain initiatives and expect their suppliers to have similar capabilities. On the other hand, small and medium-sized firms face more significant challenges in implementing sustainable practices, and as a result, require more support and guidance from their customers. Furthermore, the statement also suggest that large companies have a greater responsibility to promote sustainability due to their size and influence in the market. This involve taking a more proactive approach to supplier selection and engaging with suppliers to promote sustainable practices and address any issues that arise. Overall, the statement suggests that large companies recognize that sustainable supplier selection require different approaches depending on the size and capacity of the supplier. It also highlights the importance of considering the unique challenges and opportunities faced by different types of suppliers and taking a collaborative approach to promote sustainability across the supply chain. Multinational companies, which is foreign majority shares, need to take a more active role in influencing supplier integrity via procurement processes enforced across their value chains. This is particularly important because only large companies have the financial resources to hire compliance consultants and the authority to influence decisions to access regulators as needed. Large multinationals start by applying the thinking they have used to drive sustainability into their supply chains. By referring to ranking results, it is concluded that by means of both external and internal stakeholders, the government and through customer demands, tyre rubber manufacturers have developed an awareness of sustainability. Our sub-critera level 2 weight show that stakeholders of a firm also have a positive opinions on its sustainable practices in the Thai Tyre rubber industry. From interviews, many tyre rubber manufacturers have enforced a stern environmental evaluation and regulatory system for suppliers, so the suppliers are forced to participate in the sustainable initiatives of the company. Therefore, supplier involvement in the focal company's environmental work moderates the focal company's sustainable practices.

4.3.4.2 Pure Thai suppliers in Tier 1 and Local suppliers in Tier 2 Tyre rubber supplier

Interviewing within 13 tyre rubber suppliers (Pure Thai and Tier 2 local), the perception of sustainablility related to 46 sub-criteria level 2 for choosing suppliers vary. In the case of the perception in these suppliers, the financial concerns are viewed as one of the issues arising for becoming the sustainability theme of this research. Most of them explain that they view technology to reduce pollution or design a new method for producing green products and employ green packaging when transporting tyre rubber to upper level tier companies. However, they also state that this hits their profits. In addition, providing a good welfare and rights, health and safety to employees and balance between the financial condition, social commitment and respect for the working condition indicate the awareness of the existing shortcomings in these areas. Perception of the level of stakeholder involvement has the highest values to concern in social aspects, which provokes some reflections. For instance, it may prompt an organization to consider the level of involvement of its suppliers in promoting social sustainability. This could include factors such as the suppliers' commitment to fair labour practices, human rights, environmental protection, and community development. The obtained result is clearly the effect of little commitment to social problems of the surveyed suppliers. This may be caused by a general low level of social capital in the case of the Thai society, which is also reflected in the actions and subsequently the subjective of the surveyed suppliers. On the other hand, it is relevant that suppliers are aware of their little commitment to “investing in the society”. Obviously, the obtained result is not overcome, however, it indicates the poorest involvement in this area, which, in turn, the stakeholder themselves are aware of. Inviting stakeholders to take part in the research relating to the perception of the discussed areas can be regarded as the signal for the surveyed suppliers emphasizing the significance of the discussed problems.

4.4 Sensitivity Analysis of a Combined Decision Making Model

Sensitivity analysis is a method for testing changes of the final order by a modification of the original input data or by a small deviation of the original weights of the criteria. This is a fundamental concept for the effective use and implementation of quantitative decision models (Dantzig, 1963). The objective of sensitivity analysis here is to find out when the input data (preference judgements and degrees of fuzziness) are changed into new values, how the ranking of the alternatives will change. This study will utilize sensitivity analysis to measure degrees of fuzziness and will explain it in this section. The sensitivity analysis of the proposed decision-making model was conducted by varying the fuzzification factor (α) and decision-making attitude (λ).

The fuzzification factor (α) is a parameter used in fuzzy logic systems to control the degree of membership of an element in a fuzzy set. It determines the degree of uncertainty or vagueness associated with the input data, where a higher α value represents a higher degree of fuzziness. In decision-making models that use fuzzy logic, α determines the degree of overlap between the different linguistic terms used to describe the input data. For instance, if α is set to 0.5, the degree of overlap between two adjacent linguistic terms will be higher than if α is set to 0.1, as the latter implies a higher degree of separation between the terms.

The decision-making attitude (λ) is a parameter used in multi-criteria decision-making models to reflect the decision maker's preferences towards risk and uncertainty. λ is a weighting factor that determines the relative importance of the criteria in the decision-making process, with higher values indicating a more optimistic attitude towards the criteria, and lower values indicating a more pessimistic attitude. λ values can range from 0 to 1, where a value of 0 indicates risk-averse behaviour, a value of 0.5 indicates a neutral attitude, and a value of 1 indicates risk-seeking behaviour. The choice of λ value depends on the decision maker's preferences, the nature of the decision problem, and the level of uncertainty associated with the input data.

By varying the values of α and λ in the sensitivity analysis of the proposed decision-making model, the researcher can assess how the model's results change when the degree of fuzziness and the decision maker's attitude towards risk and uncertainty are varied. This allows for a more comprehensive evaluation of the model's performance and can help identify the most appropriate values of α and λ for different decision-making contexts.

4.4.1 Sensitivity Analysis of Sustainable Criteria in FAHP Decision Making

The application of the FAHP model assumes that all managers' answers include an uncertainty level. The fuzzy triangle (2,3,4) is a triangular fuzzy set with a left vertex at 2, a peak at 3, and a right vertex at 4. It is defined by a membership function that assigns degrees of membership to each element in the universe of discourse based on their proximity to the triangular shape. The function of the fuzzy triangle (2,3,4) can be represented as follows:

$$\mu(x) = 0, if\ x \leq 2$$
$$\mu(x) = (x-2)/(3-2), if\ 2 \leq x \leq 3$$
$$\mu(x) = (4-x)/(4-3), if\ 3 \leq x \leq 4$$
$$\mu(x) = 0, if\ x \geq 4$$

Here, μ(x) represents the degree of membership of an element x in the fuzzy triangle.

This means that, if for example manager attributes the value 3 to the comparison of two factors, Fuzzy Saaty's scale assumes that this value could vary from 2 in the worst case (so having a lower valuation of pair-wise comparison factors) to 4 in the best case (so having a higher valuation of pair-wise comparison factors) as shown in Figure 4-15. The answer given is not so precise due to subjectivity and uncertainty typical of human judgments.

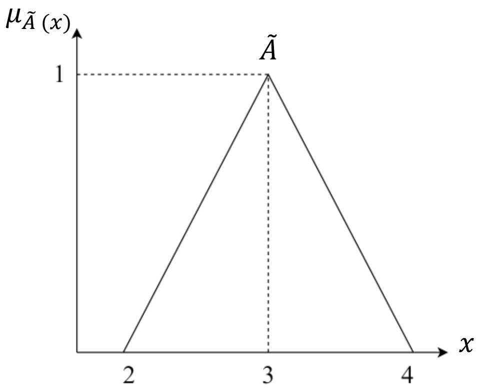


Figure 4- 15 Example of fuzzy triangle with values equal to (2, 3, 4)

Now, this assumption is no longer considered. If previously the width of the fuzzy triangle base varied of +1 or -1 unit with respect to the mean value, now the width of the base can change, as Balusa et al. (2019) proposes in their following formula Eq. 4.15

$$\bar{x}_\alpha = \quad [x - \alpha, x + \alpha]; \frac{1}{\bar{x}_\alpha} = \left[\frac{1}{x+\alpha}\right], \left[\frac{1}{x-\alpha}\right] \quad (4.15)$$

$\bar{x}_\alpha$ indicates the possible values range of Saaty's fundamental scale at the base of fuzzy triangle, while α describes the uncertainty level of the responses provided by the five selected companies. According to Balusa et al. (2019), the value of α can change and be equal to 0.2, 0.4, 0.6, 0.8, 1 (as the original model). The higher values of α (i.e., close to 1) represent more uncertainty and the lower values less uncertainty (Gorai et al., 2015).

More precisely:

$x - \alpha$ refers to ℓ value (the smallest possible value relates to fuzzy triangle).

$x + \alpha$ refers to u value (the largest possible value relates to fuzzy triangle).

Before α = 1, it meant that if the manager's answer was 3, it considered the possibility that this could also be 2 or 4. Now, if for example α = 0.2, it means that, when the manager assigns the value 3 to the pair-wise comparison of two factors, his response could also be 2.8 or 3.2 as shown in Figure 4-16. The manager's answers are characterized by a lower level of vagueness than in the α = 1 case. The same reasoning is also applied when α = 0.4, 0.6 and 0.8.

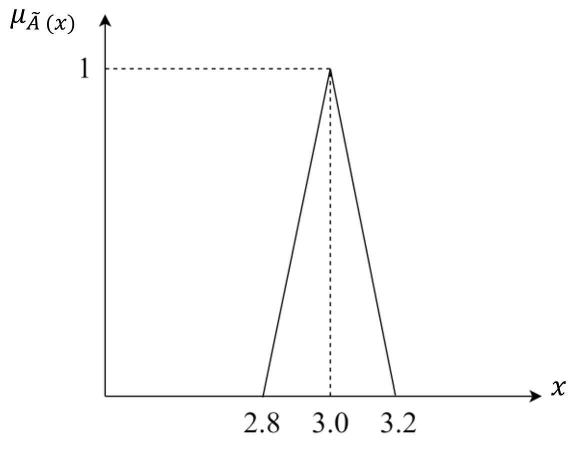


Figure 4- 16 Example of fuzzy triangle with values equal to (2.8, 3.0, 3.2)

The Fuzzy AHP method is applied again to the three main criteria, 14 sub-criteria level 1 and 51 sub-criteria level 2 evaluation, according to companies' preferences. Detailed values are not reported since they are identical to those explained above. The only different element is Fuzzy Saaty's scale: (ℓ, m, u). The value of "ℓ" is no more -1 unit and "u" is no more +1-unit with regard to "m" value, as Table 4-2 shows, but this value can change based on α level of uncertainty.

The decision-making attitude was considered for three conditions (the optimistic, pessimistic, and neutral). The λ values for optimistic, pessimistic, and neutral conditions were chosen as 1, 0, and 0.5, respectively. When the decision-maker is optimistic, they tend to be more willing to take risks and pursue opportunities, even in the face of uncertainty. This can be reflected in a decision-making attitude of λ = 1, which indicates a preference for optimistic decision-making. For example, a company that is optimistic about its ability to innovate and develop new sustainable products may be more likely to invest in a supplier that offers innovative sustainable solutions, even if the supplier's track record is relatively unproven. When the decision-maker is pessimistic, they tend to be more cautious and risk-averse, preferring to avoid losses rather than seeking gains. This can be reflected in a decision-making attitude of λ = 0, which indicates a preference for pessimistic decision-making. For example, a company that is pessimistic about the reliability of its suppliers may prioritize working with established suppliers with a proven track record of delivering sustainable products and services. When the decision-maker is neutral, they aim to balance risk and reward, seeking to achieve a level of stability and predictability in their decision-making. This can be reflected in a decision-making attitude of λ = 0.5, which indicates a preference for balanced decision-making. For example, a company that is neutral about its suppliers' performance may weigh a range of factors, such as cost, innovation, and sustainability, to make a decision that balances the risks and rewards of working with different suppliers. Overall, the selection of λ values for different decision-making attitudes reflects the importance of considering the decision-maker's attitude towards risk and uncertainty when making sustainable supplier selection decisions. By taking these attitudes into account, companies can make more informed and effective decisions that align with their overall sustainability goals and values.

In general, the α value ranges between 0 and 1, and it may be any fractional value in between 0 and 1. The higher values of α (i.e., close to 1) represent more uncertainty and the lower values less uncertainty. Using Eq. 4.15, the relative importance matrices of criteria sub-criteria and sustainable suppliers in Tyre rubber were converted into fuzzy matrices.

The sensitivity analysis used six sets (0, 0.2, 0.4, 0.6, 0.8 and 1) of the fuzzification factor (α) in the range of 0–1 to analyse decision making results. The fuzzy pair-wise comparison matrices were formulated using different fuzzification factors (α) for each set of criteria and sub-criteria. The crisp comparison matrices corresponding to each fuzzy pair-wise comparison matrix were derived for three decision-making attitudes. In other words, the crisp comparison matrices were derived for three λ values (λ = 0, 0.5, 1) using Eq. 4.16 The sensitivity output was analysed for each combination of α and λ.

$$a_{ij}^{\alpha} = \lambda a_{iju}^{\alpha} + (1-\lambda) a_{ijl}^{\alpha} \quad (4.16)$$

a_{iju}^{α} and a_{ijl}^{α}in the above eq. (4.16) are the upper and lower bounds, respectively, of relative importance value a_{ij} in the previously developed matrix. The defuzzified value a_{ij}^{α} returns the crisp value for the relative importance value a_{ij}. In Eq. 4.16, λ represents the decision-making attitude. The value of λ can be any value between 0 and 1. Crisp comparison matrices for the parameters at each level were constructed.

The validation of the proposed decision-making model was conducted with data of the tyres rubber companies in Thailand. In the proposed study, the FAHP model was developed by considering three main criteria, 14-criteria level 1, and 46 sub criteria level 2.

The results indicated that the ranking or priorities of sustainable criteria were not altered by either changing of the fuzzification factor from 0 to 1 or changing the decision-making attitude. Therefore, for any value of λ and α, the rank of each criteria remains the same. The rank of criteria is decided based on global weights. The higher the global weight of sustainable criteria, the higher is the rank or priority. To demonstrate the sensitivity of the ranking of various criteria under different degrees of uncertainty (α) and different decision-makers' attitudes (λ), The sensitivity of the decision-making results for all other parameters are shown in Figure 4-17 to Figure 4-22. The global weights of different criteria for a different level of uncertainty or fuzzification factors (α) and the decision-maker's attitude (λ) were determined using Eq. 4.15, 4.16 and 4.17. The global weights of sub-criteria correspond to under different fuzzification factors (α) and the decision-maker's attitude (λ), all of which are shown in Tables 4–20 to 4-21 respectively. The fuzzy global weights (G_k) can be computed from the local weight of the kth level and the global weights of the (k-1)th level using Eq. 4.17 and show an example in Table 4-21.

$$G_k = w_k \; G_{k-1} \text{ , } start\ with\ k = 2, G_2 = w_2 \; G_1$$

$$G_3 = w_3 \; G_2 \text{ , } G_3 = w_3 \; w_2 \; G_1 \qquad (4.17)$$

Table 4- 21 Example of Fuzzy global weights (G_k) with k = 2

Sub-criteria level 1	Local fuzzy weight G_1	Main criteria	Main fuzzy weight w_2	Fuzzy global weight G_2
Criteria 1.1	0.5	Criteria 1	0.3	0.15
Criteria 1.2	0.5			0.15
Criteria 2.1	0.3	Criteria 2	0.4	0.12
Criteria 2.2	0.7			0.28
Criteria 3.1	0.2	Criteria 3	0.3	0.06
Criteria 3.2	0.8			0.24

Table 4-22 shows the ranks of three main criteria for six fuzzification factors (α = 0, 0.2, 0.4, 0.6, 0.8 and 1) in three decision-making attitudes, these being pessimistic (λ = 0), unbiased (λ = 0.5), and optimistic (λ = 1).

Table 4- 22 Global weights of 3 main criteria for different decision-making attitudes (λ) and fuzzification factors (α)

λ = 0 (pessimistic)					
Main criteria	α = 0	α = 0.2	α = 0.6	α = 0.8	α = 1
Economic (EC)	0.4022	0.4112	0.4001	0.4102	0.4111
Social (SC)	0.2677	0.2561	0.2712	0.2714	0.2700
Environment (ENV)	0.3110	0.3202	0.3208	0.3102	0.3211
λ = 0.5 (unbiased)					
Main criteria	α = 0	α = 0.2	α = 0.6	α = 0.8	α = 1
Economic (EC)	0.4101	0.4111	0.4124	0.4105	0.4001
Social (SC)	0.2710	0.2669	0.2701	0.2702	0.2711
Environment (ENV)	0.3201	0.3210	0.3205	0.3208	0.3209
λ = 1 (optimistic)					
Main criteria	α = 0	α = 0.2	α = 0.6	α = 0.8	α = 1
Economic (EC)	0.4105	0.4100	0.4103	0.4211	0.4099
Social (SC)	0.2689	0.2696	0.2702	0.2701	0.2711
Environment (ENV)	0.3215	0.3112	0.3105	0.3228	0.3223

The trend of global weights for different fuzzification factors indicates that economic criteria is most appropriate for choosing tyre rubbers suppliers in sustainability, irrespective of the fuzzification factors and decision-making attitudes.

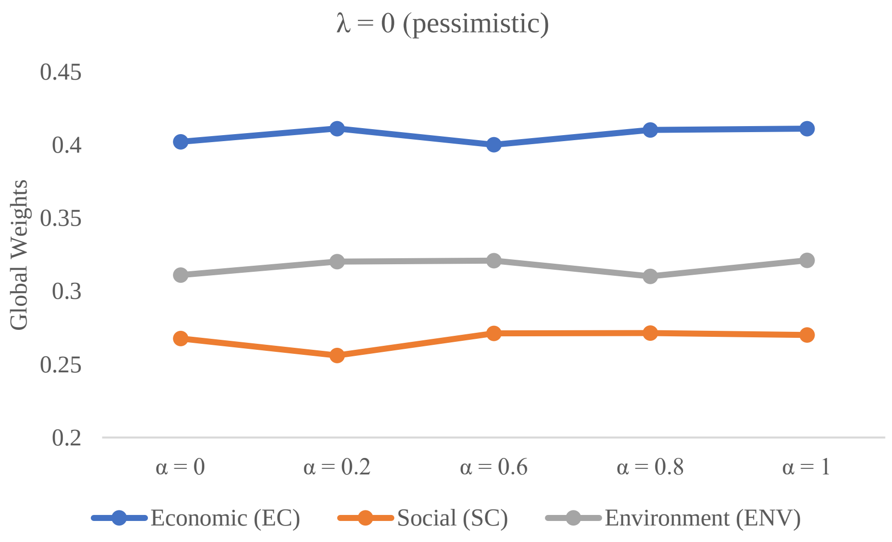


Figure 4- 17 Sensitivity of main criteria in a pessimistic attitude for different level of uncertainty

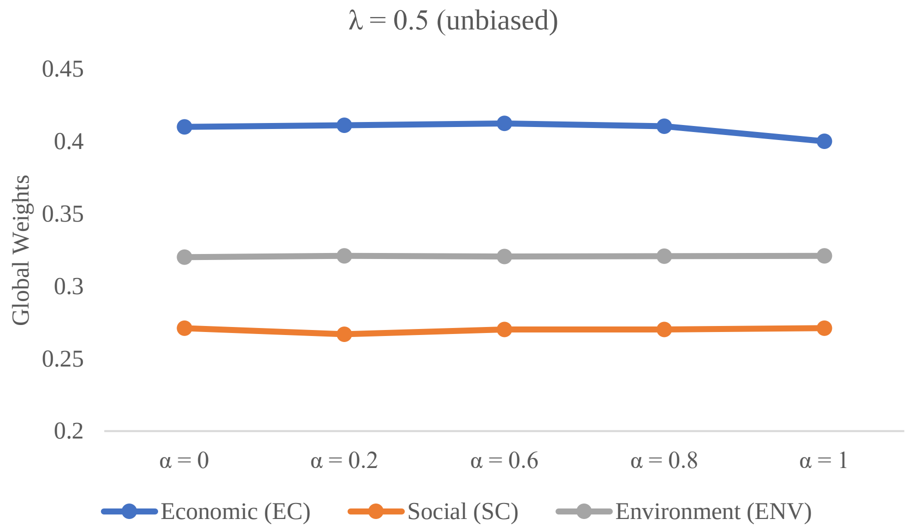


Figure 4- 18 Sensitivity of main criteria in an unbiased attitude for different level of uncertainty

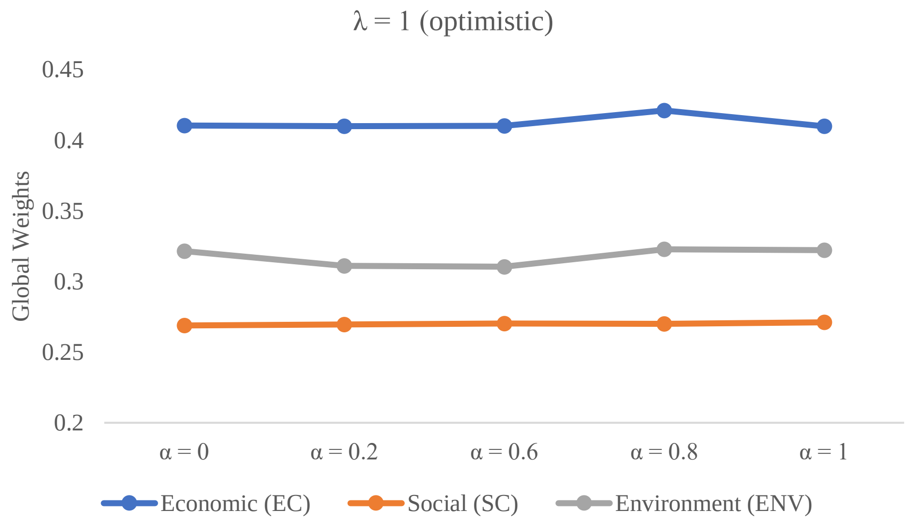


Figure 4- 19 Sensitivity of main criteria in an optimistic attitude for different level of uncertainty

From Figure 4-17 to Figure 4-19, the sensitivity results are implied that ranking of economic, environment and social criteria is never varying when changing the values of α and λ. It was also observed that though the global weights of each criterion were altered due to changes in the value of α and λ, the rank of the main criteria never changed.

Similarly, Table 4-23 shows the ranks of 14 sub-criteria level 1 for six fuzzification factors (α = 0, 0.2, 0.4, 0.6, 0.8 and 1) in three decision-making attitudes, these being pessimistic (λ = 0), unbiased (λ = 0.5), and optimistic (λ = 1) with sub-criteria level 1.

Table 4- 23 Global weights of 14 sub-criteria level 1 for different decision-making attitudes (λ) and fuzzification factors (α)

Economic criteria					
λ = 0 (pessimistic)/ λ = 0.5 (unbiased)/ λ = 1 (optimistic)					
Sub criteria level 1	α = 0	α = 0.2	α = 0.6	α = 0.8	α = 1
Cost and price (EC1)	0.3611	0.3601	0.3615	0.3620	0.3559
Financial stability (EC2	0.2712	0.2669	0.2699	0.2701	0.2713
Service (EC3)	0.1697	0.1705	0.1711	0.1689	0.1701
Quality (EC4)	0.1998	0.2010	0.2001	0.1999	0.2002

Social criteria					
λ = 0 (pessimistic)/ λ = 0.5 (unbiased)/ λ = 1 (optimistic)					
Sub criteria level 1	α = 0	α = 0.2	α = 0.6	α = 0.8	α = 1
Employee’s health and safety (SC1)	0.1599	0.1601	0.161	0.1589	0.1610
Employee’s welfare and right (SC2)	0.2005	0.1998	0.2001	0.2010	0.2012
Working condition (SC3)	0.1901	0.1909	0.1895	0.1899	0.1903
Ethics (SC4)	0.3105	0.3112	0.3101	0.3099	0.3089
Social commitment (SC5)	0.1412	0.1402	0.1399	0.1401	0.1389

Environment criteria					
λ = 0 (pessimistic)/ λ = 0.5 (unbiased)/ λ = 1 (optimistic)					
Sub criteria level 1	α = 0	α = 0.2	α = 0.6	α = 0.8	α = 1
Green product (ENV1)	0.1901	0.1950	0.1901	0.1911	0.1899
Green competencies (ENV2)	0.1209	0.1199	0.1206	0.1210	0.1186
Environmental management (ENV3)	0.4099	0.4105	0.4201	0.4101	0.4087
Pollution control (ENV4)	0.1810	0.1797	0.1787	0.1811	0.1801
Green Image (ENV5)	0.0900	0.1100	0.1020	0.1090	0.0999

The trend of global weights for different fuzzification factors indicates that cost and price (EC1), ethics (SC4), and the environmental management system (ENV3) are most suitable for selecting sustainable suppliers in the three bottom line dimensions irrespective of the fuzzification factors and decision-making attitudes. Here, also, the rank of cost and price (EC1) is always at the top and never alters when changing the values of α and λ. It was also observed that although the global weights of each sub-criterion level 1 were altered with changes in the value of α and λ, the rank of the sub-criteria level 1 never changed as shown in Figure 4-20 to Figure 4-22.

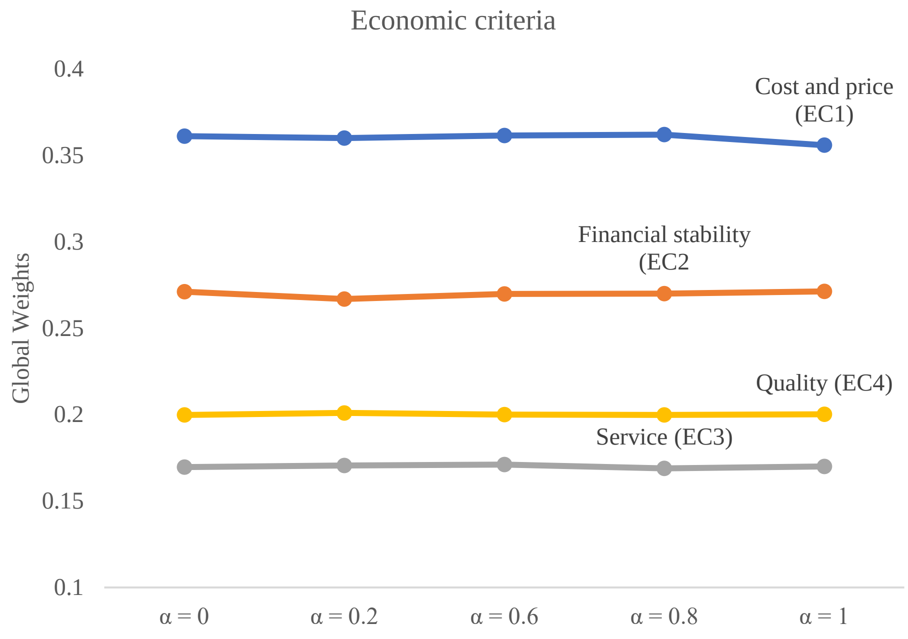


Figure 4- 20 Sensitivity of economic sub-criteria for different level of uncertainty

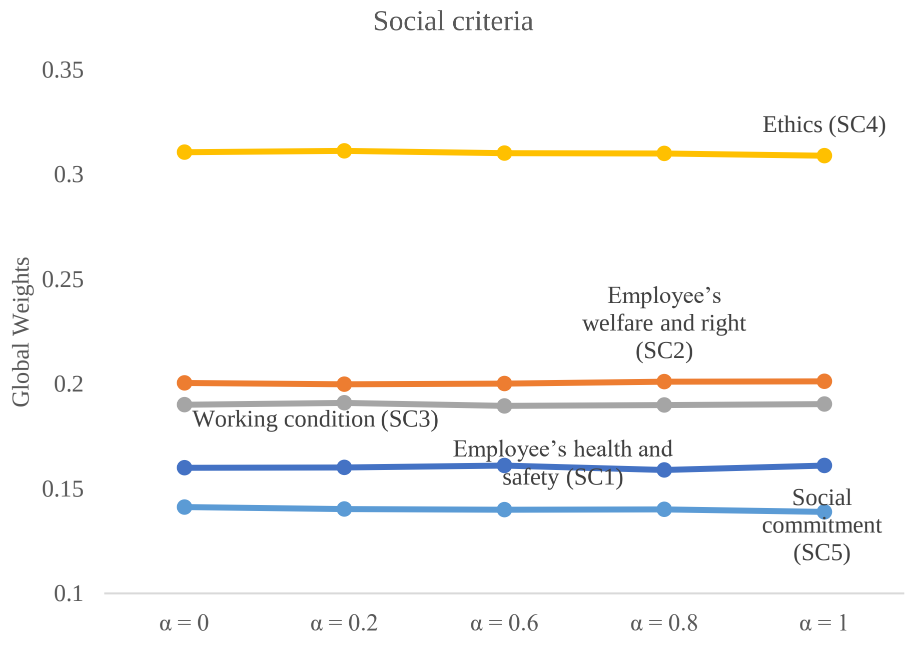


Figure 4- 21 Sensitivity of social sub-criteria for different level of uncertainty

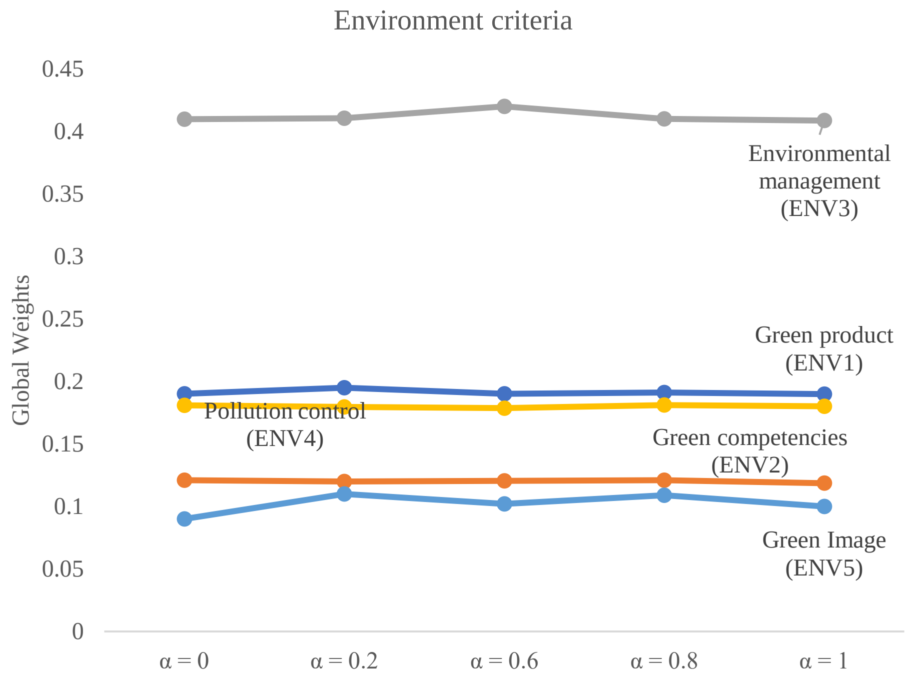


Figure 4- 22 Sensitivity of environmental sub-criteria for different level of uncertainty

In the same way, overall global weights of 46 sub-criteria level 2 for different decision-making attitudes (λ) and, fuzzification factors (α) for selectin sustainable criteria. In this case, bid price (EC1.1), cashflow issues (EC1.2), reliability (EC3.1), and quality management (EC4.4) exhibit the highest global weight in economic criteria. Health care (SC1.1), job security (SC2.4), contract labour (SC3.3), supplier ethics (SC4.1), and stakeholder involvement (SC5.2) show the highest global weight in social criteria. Here, also, the global weights of each sub criteria level 2 were altered due to changes in the value of α and λ, but the rank of the sub-criteria level 2 never changed. Therefore, the sub-criteria level 2 above was always at the top and did not alter when changing the values of α and λ.

In conclusion, the sensitivity in decision-making for the criteria of selection of a Tyre rubbers suppliers in sustainability using the FAHP model. The results indicate that the proposed FAHP decision-making model could be robustly used for the sustainable supplier selection, as the factor's uncertainty levels do not influence the final decision.

4.4.2 Sensitivity analysis of sustainable suppliers in FTOPSIS decision-making

This original approach is very slow and computationally demanding in the case of a change of the value of any attribute. Many methods have been developed for determining the weights of the criteria. FTOPSIS does not test the effect of the weight settings. However, sensitivity analysis is one of the ways to test the impact of weight adjustments.

To investigate the sensitivity of FTOPSIS for selecting sustainable supplier to the weights of 3 main criteria, 14 sub-criteria level 1 and 46 sub-criteria level 2, 20 suppliers were selected from the Tyres rubber industry of Thailand. The process of the investigation of SA on FTOPSIS is given as in Figure 4-23 below.

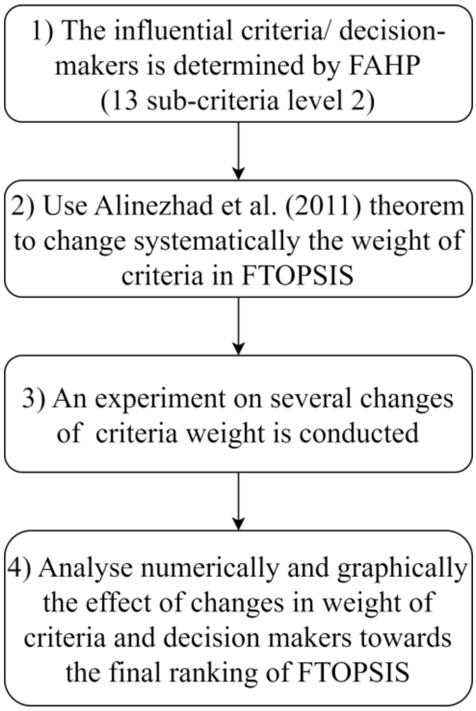


Figure 4- 23 the procedure to investigate sensitivity analysis on FTOPSIS

Step1: Determine a decision matrix of evaluation of the 20 suppliers with respect to the 13 sustainable sub-criteria level 1 under consideration of decision makers.

Step 2: The vector of attributes weights is $W = (w_1, w_2, \ldots, w_n)$ wherein weights are normalised ($\sum_{j=1}^{n} w_j = 1$). Assuming that W changes, the weight of the other attributes (sustainable factors based on Thesis case) change accordingly. So, the new transformed weight vector is $W' = (w_1' \; w_2', \ldots, w_n')$.

Assuming a pth attribute w_p, the new weight of pth attribute changes as:

$$w_p' = w_p + \Delta_p \tag{4.18}$$

So, according to the Alinezhad et al. (2011) theorem, it is possible to state that if the weight of the pth attribute changes by Δ_p, then the weight of other attributes changes by Δ_j, where:

$$\Delta_j = \frac{\Delta_p w_j}{w_p - 1}\ ; j = 1, 2, \ldots, n, j \neq p \tag{4.19}$$

So, the weight of the other attributes would change as follows:

$$w_j' = w_j + \Delta_j \text{ ; j = 1, 2, …, n, j} \neq \text{p} \quad (4.20)$$

In particular,

$$w_j' = w_j + \Delta_j = w_j + \frac{\Delta_p w_j}{w_p - 1} = \frac{1 - w_p'}{1 - w_p} * w_j \text{ ; j = 1, 2, …, n, j} \neq \text{p}$$

The new vector of attributes weights will be W' = (w_1' w_2', … , w_n'), that is:

$$w_j' = \begin{cases} w_j + \Delta_p & j = p \\ \frac{1 - w_p'}{1 - w_p} * w_j & j \neq p, \quad j = 1, 2, \ldots, n \end{cases} \quad (4.21)$$

with, $\sum_{j=1}^{n} w'_j = 1$ with j = 1, …, n, as for w_j

Step 3: Once understood as the weights of attributes change, it is possible to apply the FTOPSIS method to data changing weights values, calculate the relative closeness to the ideal solution, and sort the results in decreasing order.

In Figure 4-4, there are three primary criteria and forty-six level 2 sub-criteria. To perform a sensitivity analysis, the weights assigned to each criterion in Table 4-6 are adjusted incrementally by 20%, 40%, 60%, 80%, and 100%. For example, the cost factor bid price (EC1.1) can change its value five different times, increasing its weight by 20%, then by 40% and so on. If the EC1.1 weight calculated by Fuzzy AHP model is 0.320, increasing its weight of 20% means that EC1.1 (1 + 20%) = 0.384, increasing its weight by 40% means that EC1.1 (1 + 40%) = 0.448 and so on.
The same reasoning was applied to all the other sub-factors level 2. Changing factor value each time shows how this variation influences the values of the other remaining factors.

Step4: Once one gets the new normalised weights vector, it is possible to apply the FTOPSIS method steps and notice whether the final ranking of the countries is equal to the initial one (Table 4-19) or not. As before, it is assumed that the bid price factor (EC1.1) increases its value by 20%. This change influences the final ranking and the FTOPSIS method select a sustainable supplier different from tyre rubber. In the example, this means that the bid price factor (EC1.1) changes its weight and the other factors, influenced by this variation, change their weights too. The FTOPSIS method is applied to all possible scenario, starting from “Bid price” (EC1.1) from “Cost factor” (EC1) + 0% to “Pollution control" factor (ENV4.2) + 100%. The results in a sustainable supplier ranking (as done for Table 4-19).

The researcher applies the FTOPSIS method to all possible scenario, starting from case EC1.1 + 0% till ENV4.2 + 100% and observe the suppliers ranking (as done for Table 4-19).

For example, consider "Bid price" factor (EC1.1). Increasing its normalised weighted value of EC1.1 (1 + 0%) = 0.320, EC1.1 (1 + 20%) = 0.384, EC1.1 (1 + 40%) = 0.448 and so on. This influences also weights of other factors change, according to Eq. 4.21.

To clarify, in EC1.1 (1 + 20%) case, it is considered EC1.1 value = 0.320 and this value is increases by 20% (EC1.1' = 0.384). The new values of other factors vary as follows:

$$w_j' = \frac{1 - w_p'}{1 - w_p} * w_j; \text{ p = 1 and j = 2, …, 13}$$

$$w_2' = EC_{2.2}'$$

So, for instance,

$$EC_{2.2}' = \frac{1 - EC_{1.1}'}{1 - EC_{1.1}} * w_{2.2} = \frac{1 - 0.384}{1 - 0.320} * 0.310 = 0.281$$

Doing the same for EC1.3′, EC1.4′ to ENV4.2′. So, there will be five different normalised weight vectors (from an increment of 20% to 100%) for each of the thirteen different factors as shown in Appendix 5.

Table 4- 24 Bid price (EC1.1) sample values variation of normalized weights in Sensitivity analysis

				w_j					
		w_j'		EC	EC	EC	EC	EC	EC
w_p'	$\frac{1 - w_p'}{1 - w_p}$	$= \frac{1 - w_p'}{1 - w_p} * w_j$		1.1+0%	1.1+20%	1.1+40%	1.1+60%	1.1+80%	1.1+100%
0.320	1.000	EC'	1.1	0.320	0.384	0.448	0.512	0.576	0.640
0.384	0.906	EC'	2.2	0.310	0.281	0.252	0.222	0.193	0.164
0.448	0.812	EC'	3.1	0.400	0.362	0.325	0.287	0.249	0.212
0.512	0.718	EC'	4.1	0.310	0.281	0.252	0.222	0.193	0.164
0.576	0.624	SC'	1.1	0.520	0.471	0.422	0.373	0.324	0.275
0.640	0.529	SC'	2.4	0.510	0.462	0.414	0.366	0.318	0.270
		SC'	3.3	0.340	0.308	0.276	0.244	0.212	0.180
		SC'	4.1	0.530	0.480	0.430	0.380	0.330	0.281
		SC'	5.2	0.570	0.516	0.463	0.409	0.355	0.302
		ENV'	1.2	0.590	0.534	0.479	0.423	0.368	0.312
		ENV'	2.1	0.150	0.136	0.122	0.108	0.094	0.079
		ENV'	3.1	0.280	0.254	0.227	0.201	0.175	0.148
		ENV'	4.2	0.120	0.109	0.097	0.086	0.075	0.064

Finally, FTOPSIS method is applied, considering every different situation. The final score of tyre rubber sustainable suppliers might change or remain unvaried.

This procedure is intuitive to apply and it conveniently highlights the changes that could occur in the ranking obtained. The comments and considerations on the results obtained from this sensitivity analysis are presented below.

4.4.3 Final considerations with sensitivity analysis results

In the proposed study, the FTOPSIS model was developed by considering 46 sub-criteria level 2. However, sensitivity analysis was conducted based on 13 sub-criteria level 2 due to the decision makers high priority scores ranking in Table 4-6, these being: bid price, cashflow issues, reliability of delivery service, control of products defect, health care delivery, job security, contract labour, supplier ethics, stakeholder involvement, green packaging, green design of products, environment standard certifications, and pollution reduction capability.

4.4.3.1 Bid price (EC1.1)

The first factor analyses bid price factor. This criterion appears to be the most influential among the economic sub-criteria level 2. The bid price factor has a weight not so distant from the average, showing no differences with most tier 1 suppliers. Concerning the authorised capital and type of ownership in tier 1 supplier, the weight of bid price appears to be one of the lowest in a high capital and foreign majority ownership in tier 1 supplier, unlike a lower authorised capital and Thai majority ownership supplier, are particular a high importance weight.

In tier 1 supplier ranking, Figure 4-24, if the weight of EC1.1 increases by 100%, both foreign majority supplier's ownership from Rayong province (T1.1 and T1.10) move from 3rd to 5th and 5th to 8th respectively. This shows that bid prices is not an element of their strategy to win jobs in competitive tenders. Differently, tier 1 supplier T1.4 in Samutprakarn moves from 6th to 3rd place. T1.4 gains three positions due to concerns about low bid prices and high profits.

In tier 2 suppliers, the bid price attribute appears to be an important criterion for among the SMEs tyre rubber suppliers because they required to achieve a maximum profit from low bid prices.

By analysing EC1.1 through sensitivity analysis in Figure 4-25, 40% of tier 2 suppliers show that tier 2 suppliers obtain benefit from increase weight 100% by gaining about 2 to 4 positions, while, two tyre rubber suppliers lose positions. This happens because T2.7 and T2.8 have long-term partners with tier 1 supplier T.5 and T.6. Therefore, they do not consider the bid price at first priority.

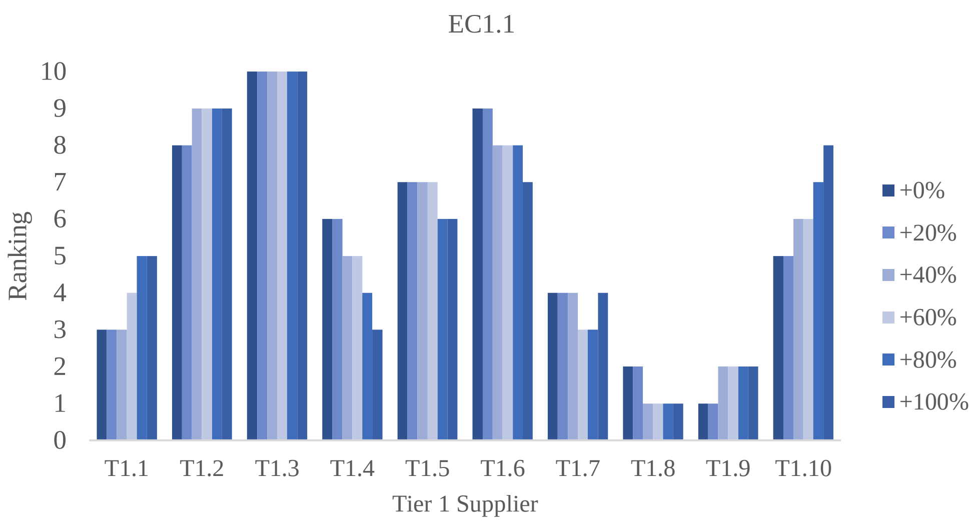


Figure 4- 24 Sensitivity analysis of tier 1 suppliers ranking in “Bid price”

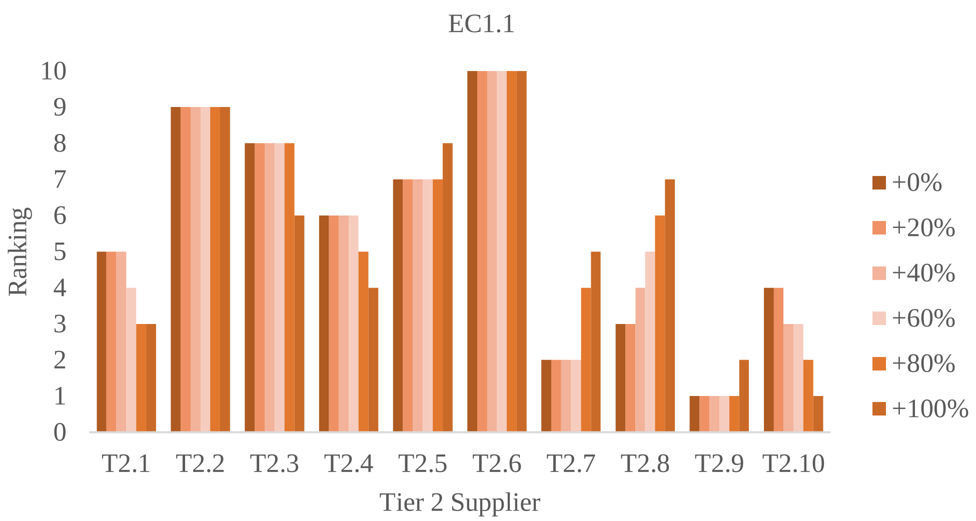


Figure 4- 25 Sensitivity analysis of tier 2 suppliers ranking in “Bid price”

4.4.3.2 Cashflow issues (EC2.2)

In the financial criteria, there was need to include the cash flow issues criterion since it affects the selected tyre rubber suppliers. Based on interviewed decision makers and FAHP model results, the cash flows criterion is the dominant criterion and accounts for one-third of the financial stability attribute.

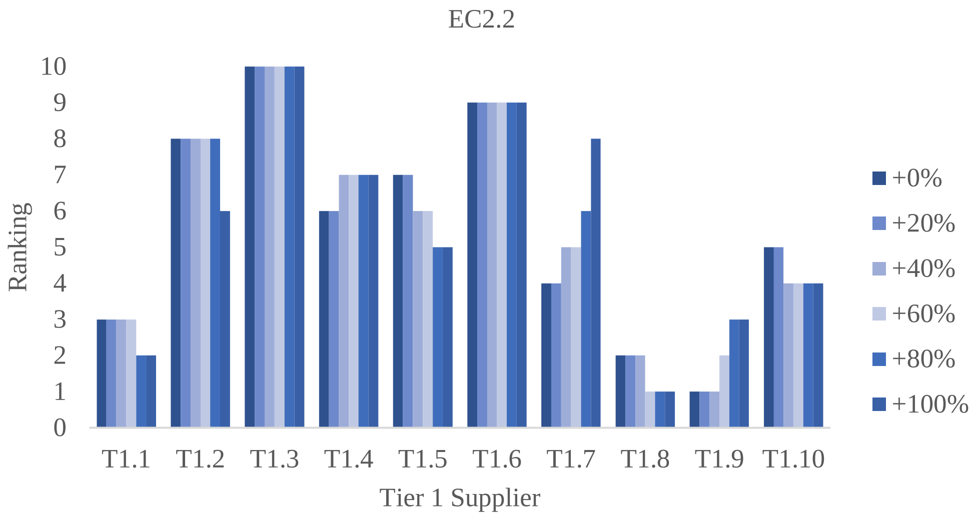


Figure 4- 26 Sensitivity analysis of tier 1 suppliers ranking in “Cashflow issues”

Between Figure 4-26 and Figure 4-27, the cashflow issues (EC2.2) of tier 1 and tier 2 suppliers ranking showing no differences with most suppliers ranking except for T1.7. When cash flows criterion increases in importance, T1.7 drops to 8th position, due to a company does have a problem with extended payment terms.

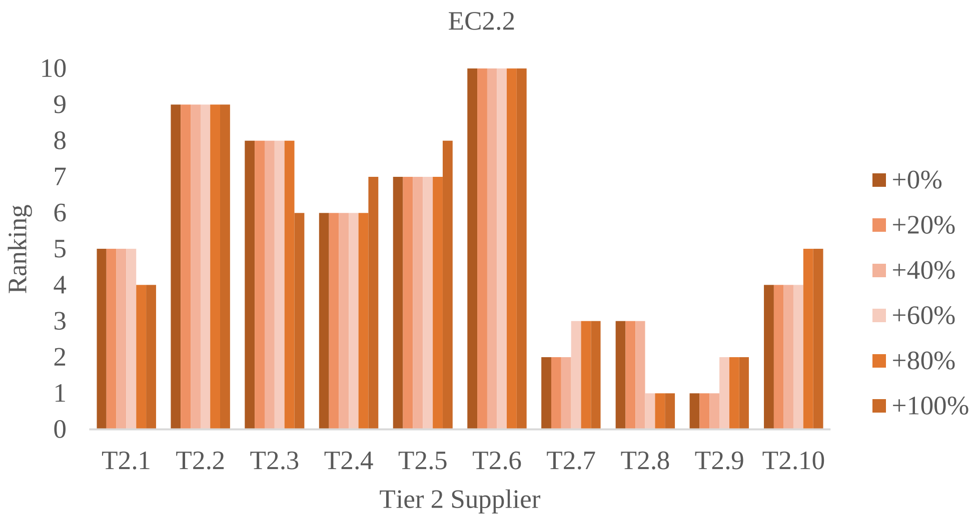


Figure 4- 27 Sensitivity analysis of tier 2 suppliers ranking in “Cashflow issues”

4.4.3.3 Reliability of delivery service (EC3.1)

The third criterion considers the reliability of delivery service between tyre rubber suppliers and car manufacturers through truck travel. In the case in which problems arise in tier 1 and tier 2 companies, more easily accessible and on-time delivery suppliers will be preferred. Nearly 50% of tyre rubber suppliers are located in the eastern province such as Rayong, Chonburi, Prachinburi. This advantage supports each supplier reached more easily and have more reliability in on-time delivery since most of automotive manufactures are also located in eastern part in Thailand, unlike more distant tyre rubber suppliers (for example, the central provinces, and the western provinces).

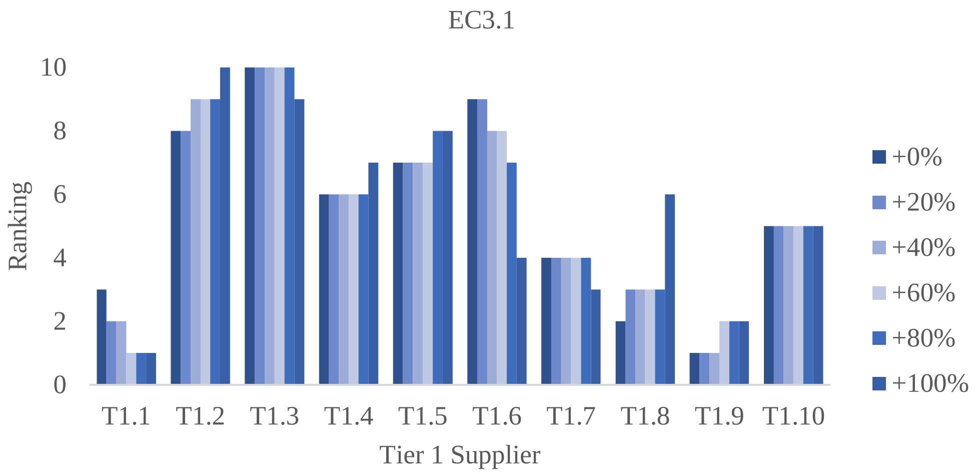


Figure 4- 28 Sensitivity analysis of tier 1 suppliers ranking in “Reliability of delivery service”

When the weight of EC3.1 changing in the sensitivity analysis between Figure 4-28 and Figure 4-29, T1.1, T1.6 and, T2.5 which located in eastern part in Thailand gain three and five positions respectively because of the geographical proximity to car manufacturers. Differently, T2.9 and T2.10, which suffer from difficult truck travel with the western part in Thailand due to their extreme proximity, moves from 1st and 4th to 6th and 8th, respectively.

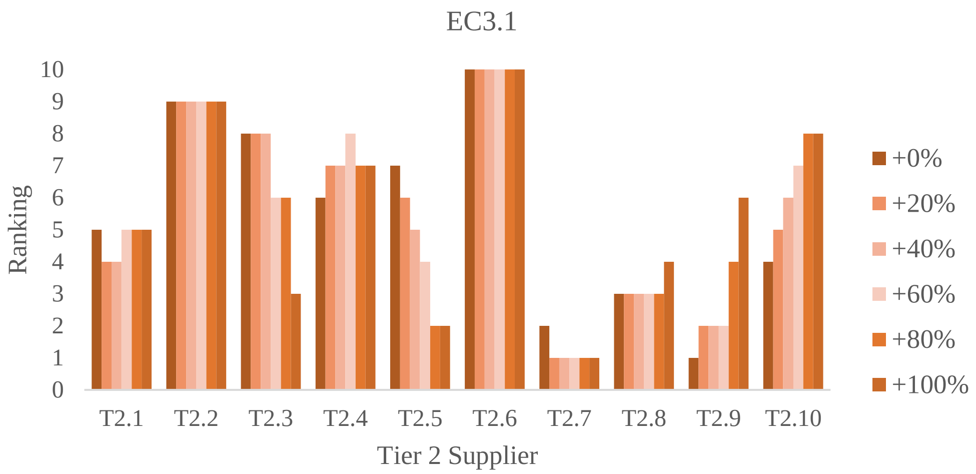


Figure 4- 29 Sensitivity analysis of tier 2 suppliers ranking in “Reliability of delivery service”

4.4.3.4 Control of products defect (EC4.1)

The next analysis is control of product defect factor. The control of defects represented the best single indicator of analytical quality, as perceived by car manufacturers. Small and medium-sized suppliers in tier 2 find it difficulty with effectively measuring products defect because of small budget investment.

While, larger organizations with foreign firms such as tier 1 suppliers have invested higher amounts of capital in building out these competencies compare with tier 2 suppliers, which are instrumental to controlling a defect data to all levels of the organization.

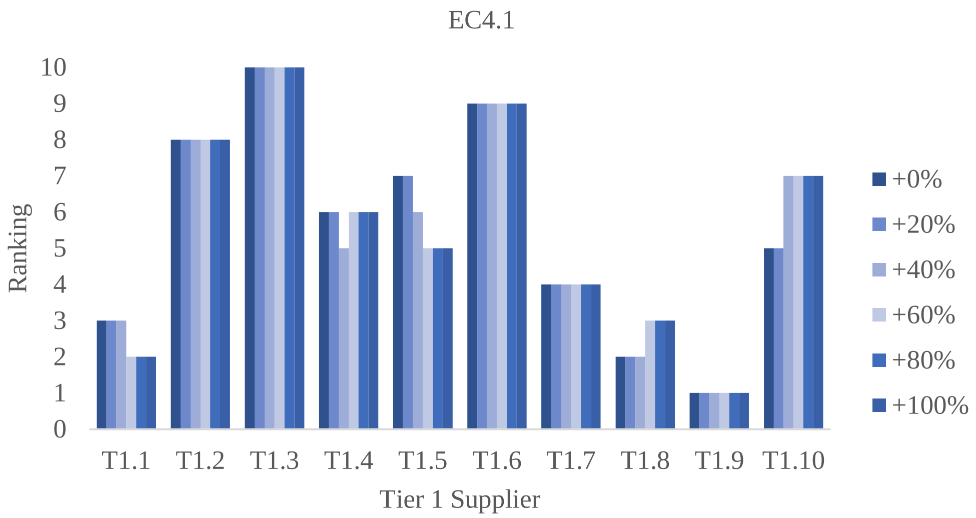


Figure 4- 30 Sensitivity analysis of tier 1 suppliers ranking in “Control of products defect”

During sensitivity analysis, the final tier 1 suppliers ranking highlights no many positions changes once EC4.1 weight changing from +20% to +100% as shown in Figure 4-30. On the contrary, T2.10 in tier 2 supplier loses four positions as shown in Figure 4-31 owing to small investment in quality control management.

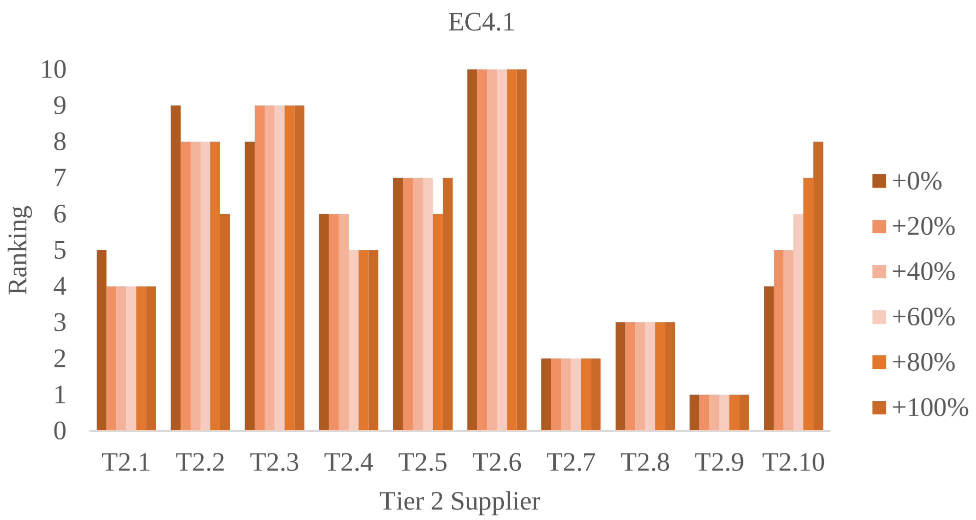


Figure 4- 31 Sensitivity analysis of tier 2 suppliers ranking in “Control of products defect”

4.4.3.5 Health care delivery (SC1.1)

The health care delivery criterion analyses the consistency of service delivery in the form of health care service, an employee’s insurance, and preventive care on the basis of social factors of the suppliers.

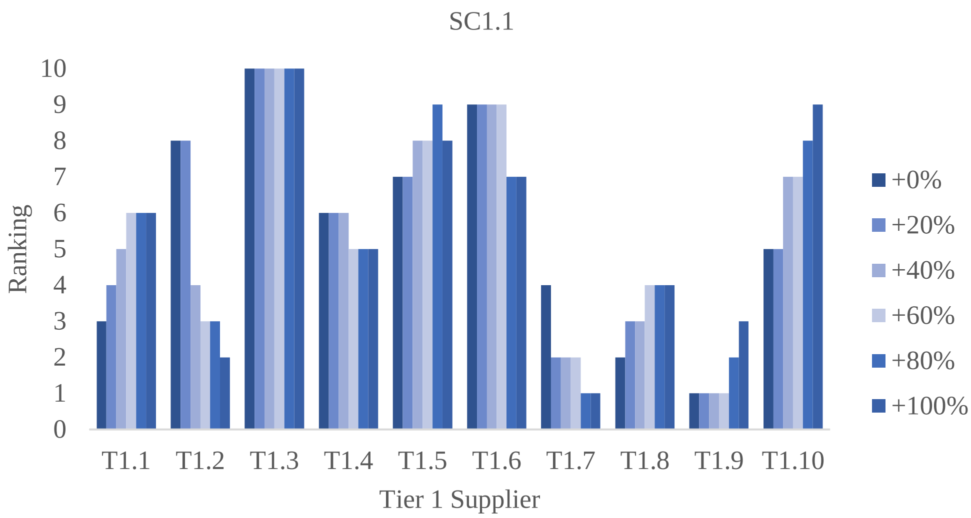


Figure 4- 32 Sensitivity analysis of tier 1 suppliers ranking in "Health care delivery"

In sensitivity analysis results as shown in Figure 4-32 and 4-33, when the weight increases from +20% to +100%, T1.2 and T2.2 gain many positions thanks to policy direction of Provincial Governor of Samutsakorn. While T1.10 and T2.10 loses five position due to less concern in social responsibility.

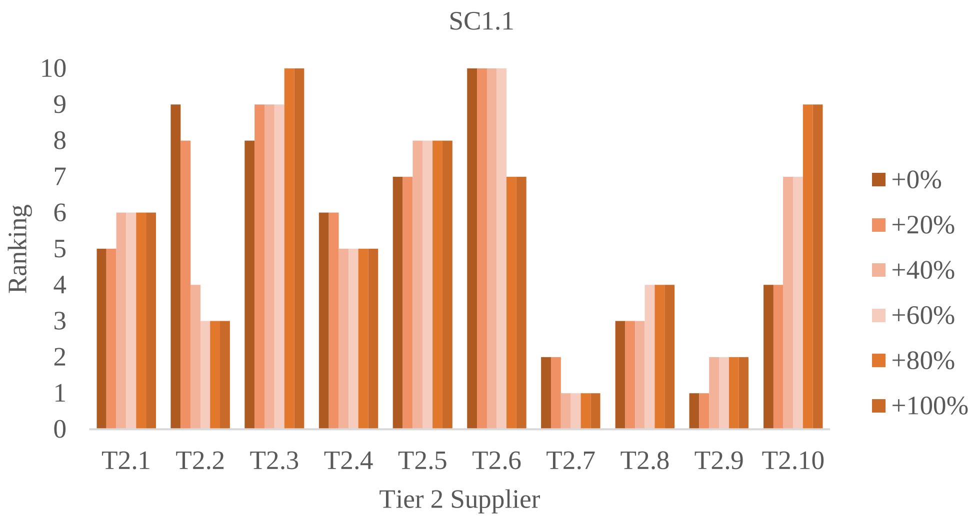


Figure 4- 33 Sensitivity analysis of tier 2 suppliers ranking in "Health care delivery"

4.4.3.6 Job security (SC2.4)

According to the decision makers interviewed, job security is the top priority sub-factor level 2 of employee's welfare and rights (SC2). This attribute affects the most selected tyre rubber suppliers relating to social aspects.

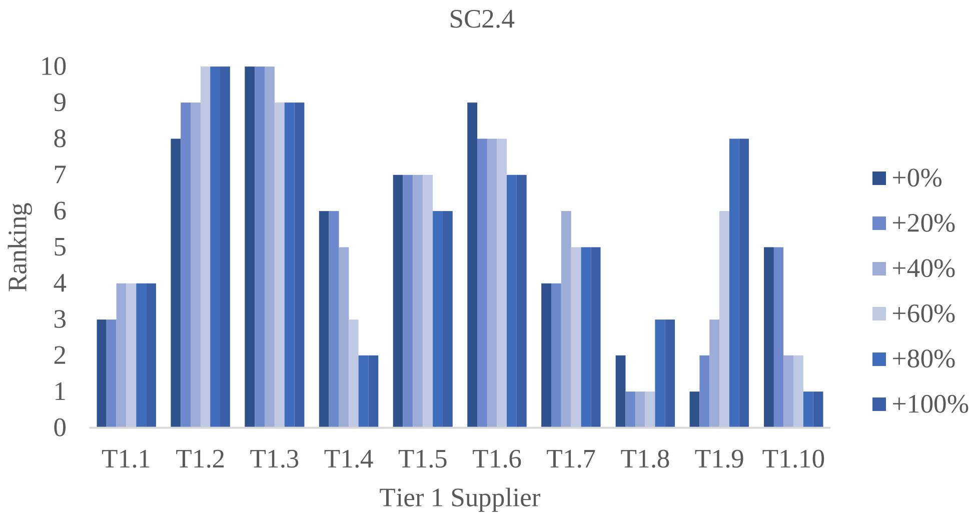


Figure 4- 34 Sensitivity analysis of tier 1 suppliers ranking in “Job security”

In the sensitivity analysis, the suppliers ranking of job security shows that there are no differences with most tier 1 suppliers as shown in Figure 4-34 once the weight is increased to significance +100%. As opposed to other tyre rubber suppliers, T1.9 pure Thai ownership moves from 1st to 8th due to high turnover rates. In addition, the results of sensitivity analysis in tier 2 supplier show that there are low incentives but also high pressures.

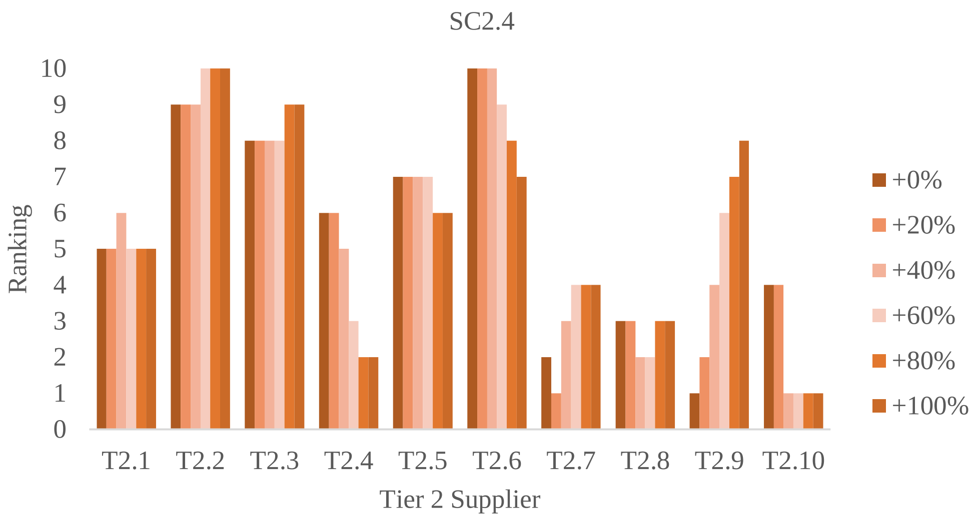


Figure 4- 35 Sensitivity analysis of tier 2 suppliers ranking in “Job security”

4.4.3.7 Contract labour (SC3.3)

The factor describing contract labour characteristics is now analysed. Eastern province in Thailand has one of the lowest salary rates of employees compared with the central province of Thailand. However, despite the low rate of salary, the level of unemployment is not so high as shown in Figure 4-35.

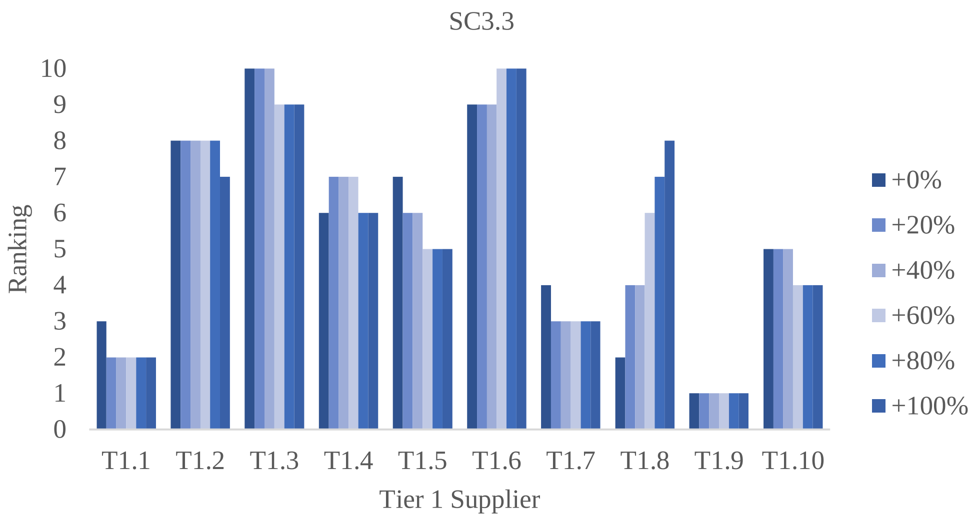


Figure 4- 36 Sensitivity analysis of tier 1 suppliers ranking in "Contract labour"

During sensitivity analysis results in Figure 4-36, when this social factor increases its weight to 100%, T1.8 loses six positions. It soars from 3rd to 9th. This shows a significance shift due to the central province Bangkok which is supplier located as a higher rate of unemployment, higher salary rate, and higher cost of daily lives. This is similar with tier 2 supplier T2.8 because of high level of salary rate located in the central province compare with other tier 2 suppliers which mostly located in the eastern of Thailand and have mostly maintain a ranking as shown in Figure 4-37.

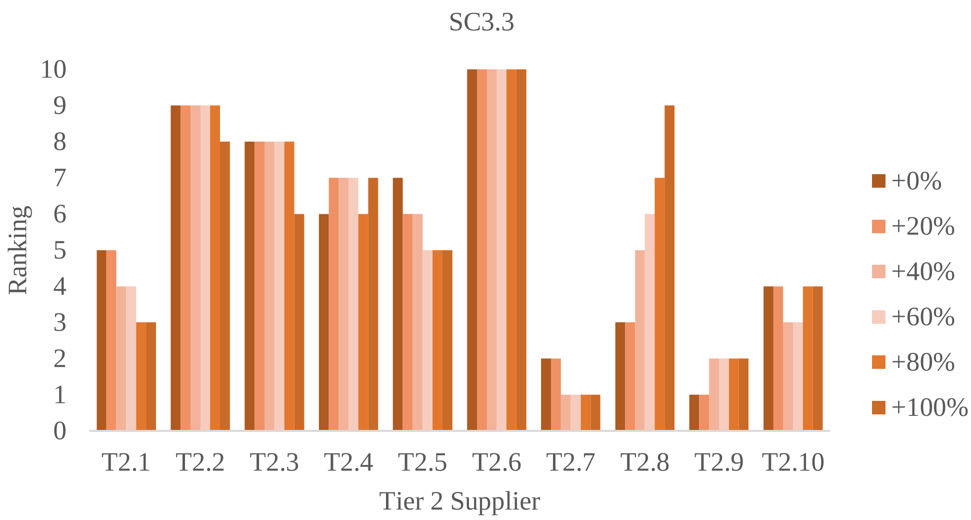


Figure 4- 37 Sensitivity analysis of tier 2 suppliers ranking in "Contract labour"

4.4.3.8 Supplier ethics (SC4.1)

The next step analyses supplier ethics. Tyre rubber suppliers in Thailand have less concern in ethics standard mostly in SMEs. This can be seen as the low percentages of social aspects from FAHP results, except for tier 1 large enterprises having foreign majority ownership. These suppliers have a plan to introduce with ethical training programs and manage the risk of suppliers rather than meeting acceptable workplace standards.

Through sensitivity analysis results in Figure 4-38, The tier 1 supplier ranking points out little positional changes, when adjusting a weight of SC4.1 from +20% to +100%, except for T1.9. When ethical principles for suppliers increase in importance, suppliers with more sustainable organisational structures such as T1.10 gains more positions, caused by a companies' commitment to promote ethical standards and more investment in ethical policy than other suppliers. For example, a small authorised capital T2.7 in tier 2 suppliers loses six positions when an increment the weight is increased to +100% as shown in Figure 4-39.

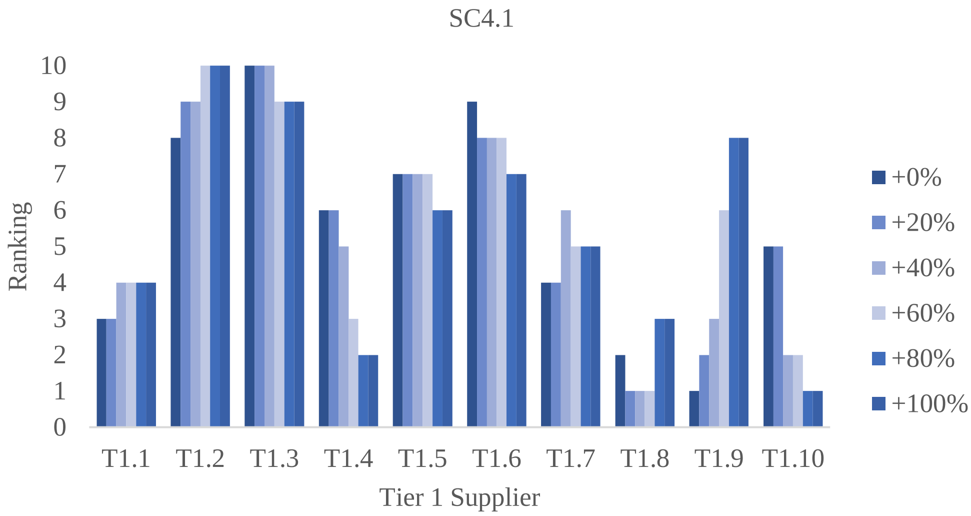


Figure 4- 38 Sensitivity analysis of tier 1 suppliers ranking in “Supplier ethics”

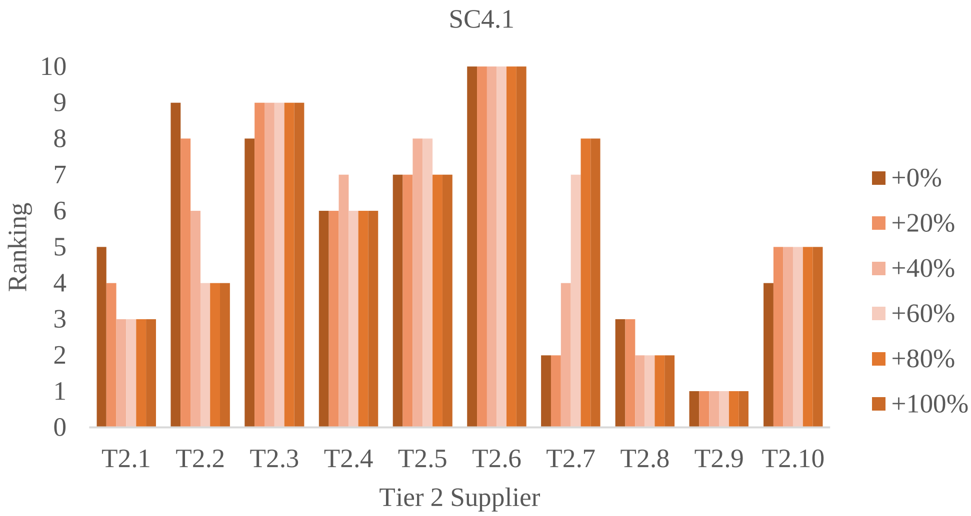


Figure 4- 39 Sensitivity analysis of tier 2 suppliers ranking in “Supplier ethics”

4.4.3.9 Stakeholder involvement (SC5.2)

The last social attribute to analyse is stakeholder involvement. This factor seems to have the most impact on social commitment, according to the results from the Fuzzy AHP model and interviews with decision makers.

The sensitivity analysis results (see Figure 4-40 and 4-41) shows that, if this criterion increases in weight from +20% to +100%, T1.7 and T1.8 lose many positions due to lower social responsibility from internal stakeholders and external stakeholders. This is also less concern in tier 2 T2.7 and T2.8 due to no funding organization to sustain the engagement initiatives in social community. The supplier's ranking is also related to the interview from decision makers.

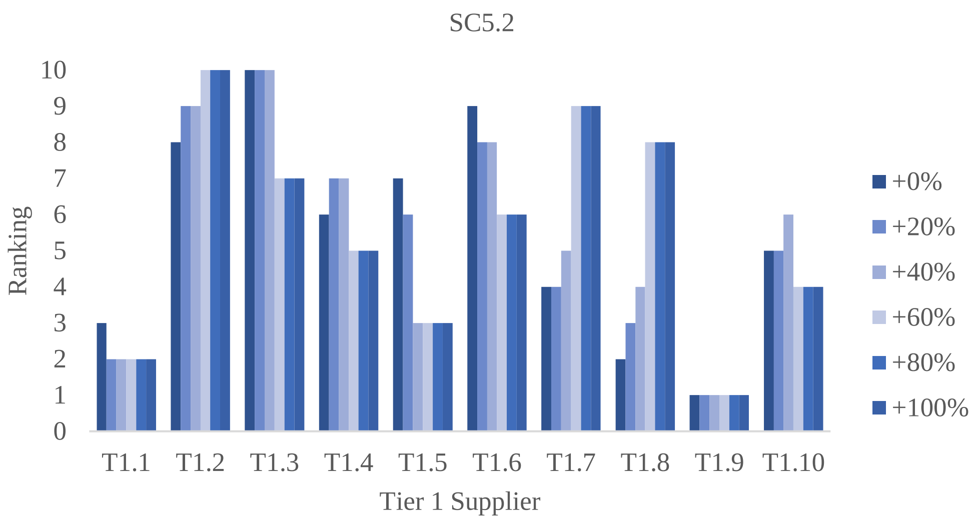


Figure 4- 40 Sensitivity analysis of tier 1 suppliers ranking in "Stakeholder involvement"

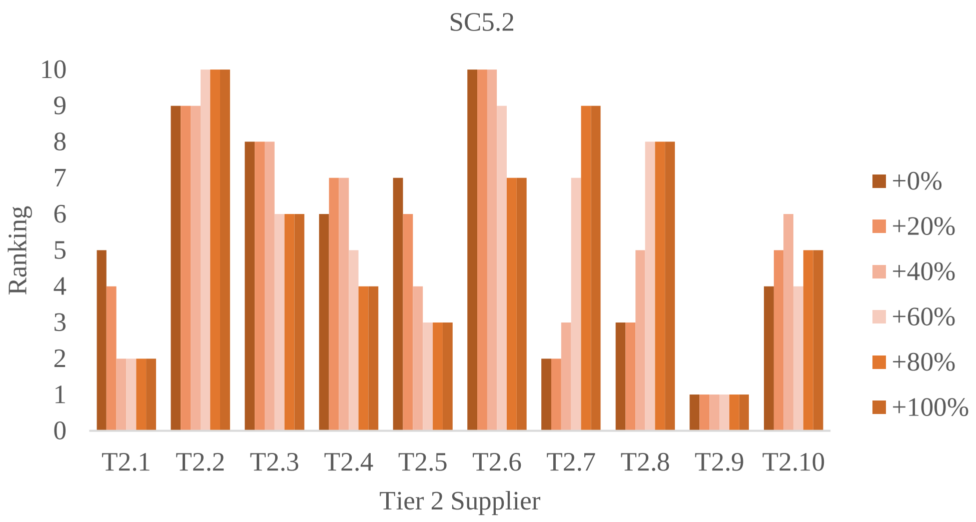


Figure 4- 41 Sensitivity analysis of tier 2 suppliers ranking in "Stakeholder involvement"

4.4.3.10 Green packaging (ENV1.2)

Green packaging turns out to be the most important criterion of the first sub-criteria level 2 of a green product according to the decision makers interviewed (result of the application of Fuzzy AHP method). In Thailand, there are government incentives and laws on recycling package materials to enhance tyre rubber suppliers to participated with environmental awareness.

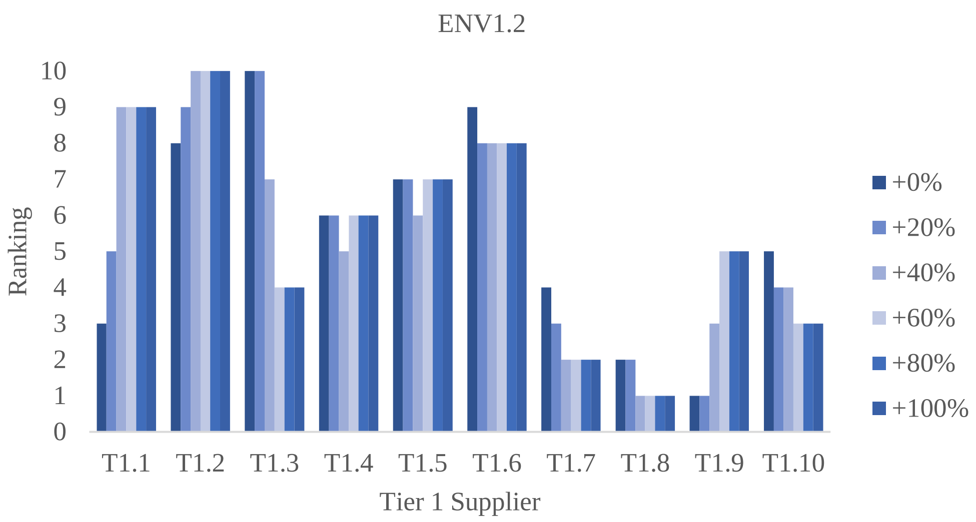


Figure 4- 42 Sensitivity analysis of tier 1 suppliers ranking in “Green packaging”

The result from sensitivity analysis in Figure 4-42 and Figure 4-43 shows that when the green packaging factor increases from +20% to +100%, there is no significant difference in each supplier. However, T1.1 loses six positions from 3rd to 9th due to the high investment for outsourcing the packaging manufacturers that adapted to new green technology. While, T1.3 gain six positions from 10th to 4th and T2.3 gains four positions when changing weight to +100%. This happens since Prachinburi province has a latest support policy incentive from government to implement package recycling.

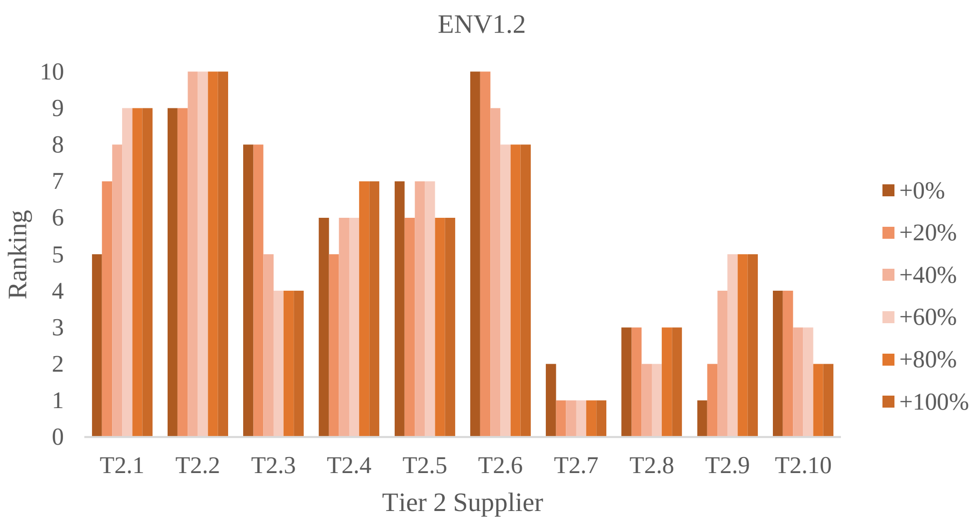


Figure 4- 43 Sensitivity analysis of tier 2 suppliers ranking in “Green packaging”

4.4.3.11 Green design of products (ENV2.1)

The percentage of tyre rubber suppliers that have established a green product design in order to incorporate ecological care is low in tier 2 suppliers. Nevertheless, there are tier 1 suppliers and medium size suppliers in tier 2 that have a big concern for environmental issues and have actually established a plan to respond to regulations and environmental compliance. From the results of FAHP model, the larger the company, the greater the interest in integrating a green product design.

Between Figure 4-44 and 4-45 in sensitivity analysis results, when the changing weight of ENV2.1 attribute soars from +20% to +100%, there is no difference significantly in each supplier.

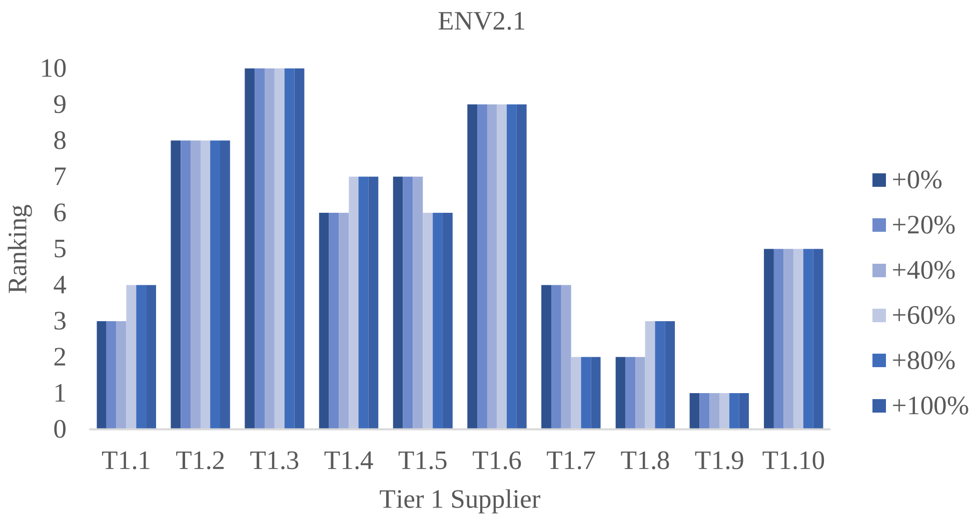


Figure 4- 44 Sensitivity analysis of tier 1 suppliers ranking in “Green design of products”

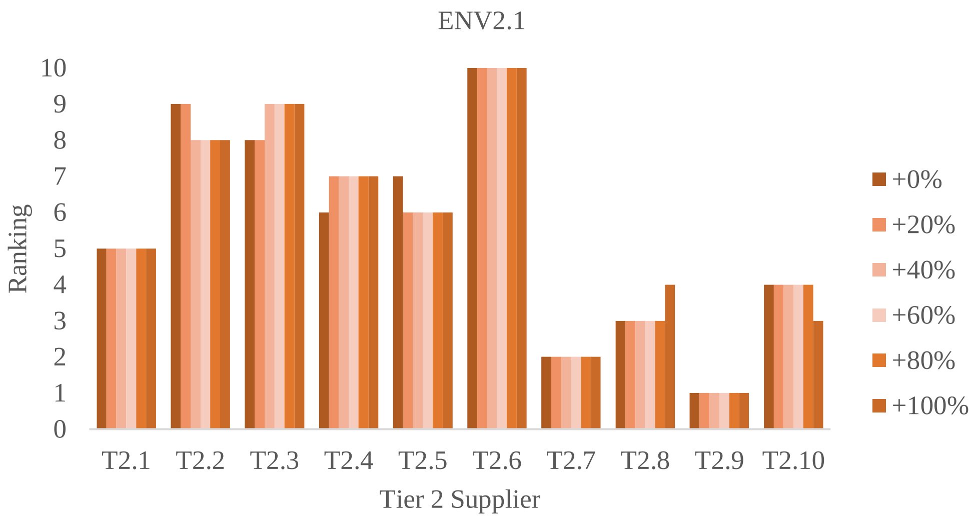


Figure 4- 45 Sensitivity analysis of tier 2 suppliers ranking in “Green design of products”

4.4.3.12 Environmental standard certifications (ENV3.1)

This factor appears to be the majority relevant in the case of environmental management system, according to decision makers who were interviewed and the findings of the Fuzzy AHP model.

From Figure 4-46 to 4-47, it shows the ranking comparison of tier 1 suppliers and tier 2 suppliers from different decision makers' point of view. The sensitivity analysis showed that the changing in weight of ENV 3.1 did not have a significant effect on the ranking. This implies that all suppliers consider environmental standard certifications is the importance of standard compliance in spite of the weight changing from +20% to +100% in ENV3.1.

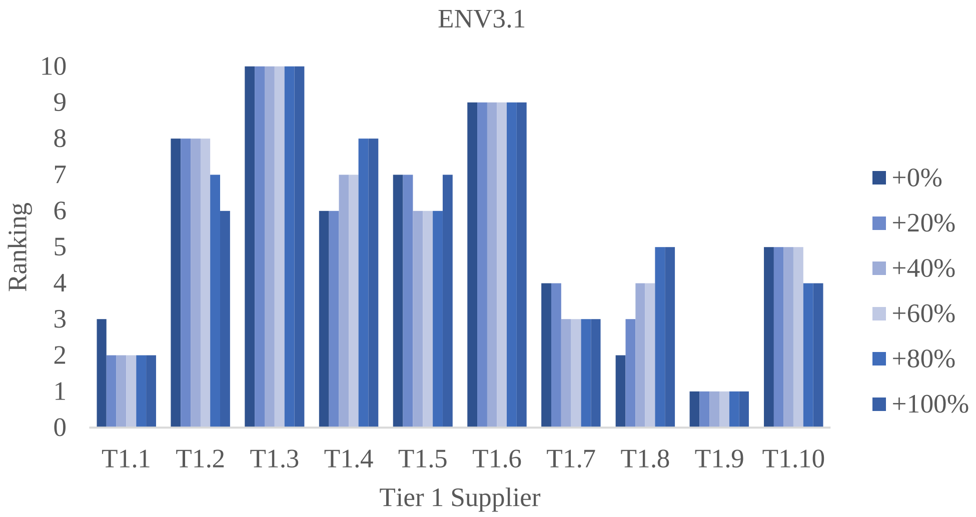


Figure 4- 46 Sensitivity analysis of tier 1 suppliers ranking in "Environmental standard certifications"

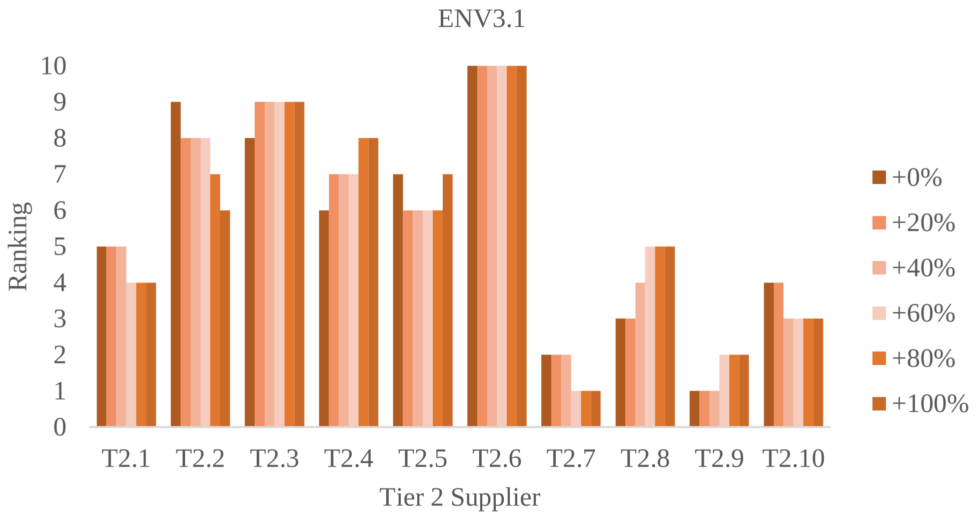


Figure 4- 47 Sensitivity analysis of tier 2 suppliers ranking in "Environmental standard certifications"

4.4.3.13 Pollution reduction capability (ENV4.2)

Pollution reduction capability is an important parameter which should be accomplished to get priority selected as sustainable supplier. From interviewers, tier 1 and tier 2 suppliers are obligatory that the wastes should be controlled and regulated by particular programs and directives. The use of harmful material has also to be limited.

From Figure 4-48 and 4-49, if the weight of ENV 4.2 changing from +20% to +100%, the sensitivity analysis results show that the final ranking does not significantly.

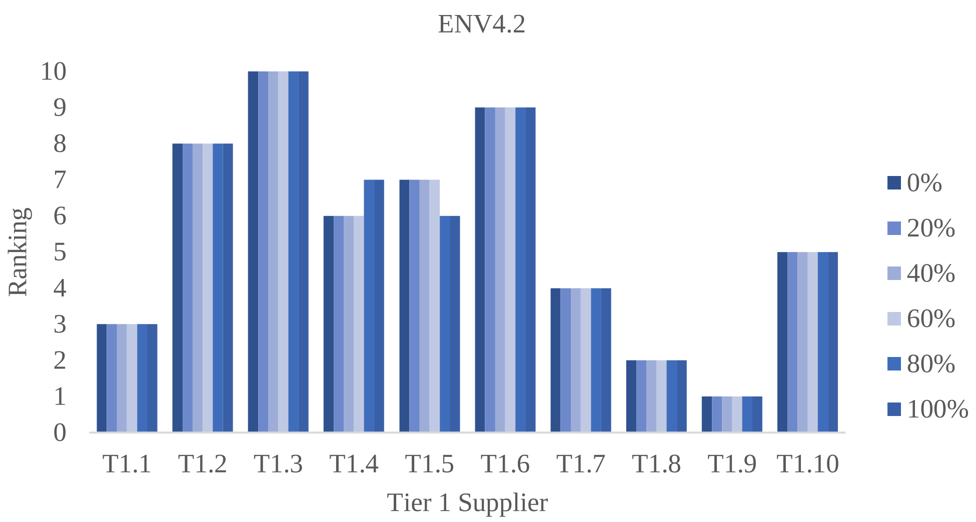


Figure 4- 48 Sensitivity analysis of tier 1 suppliers ranking in “Pollution reduction capability”

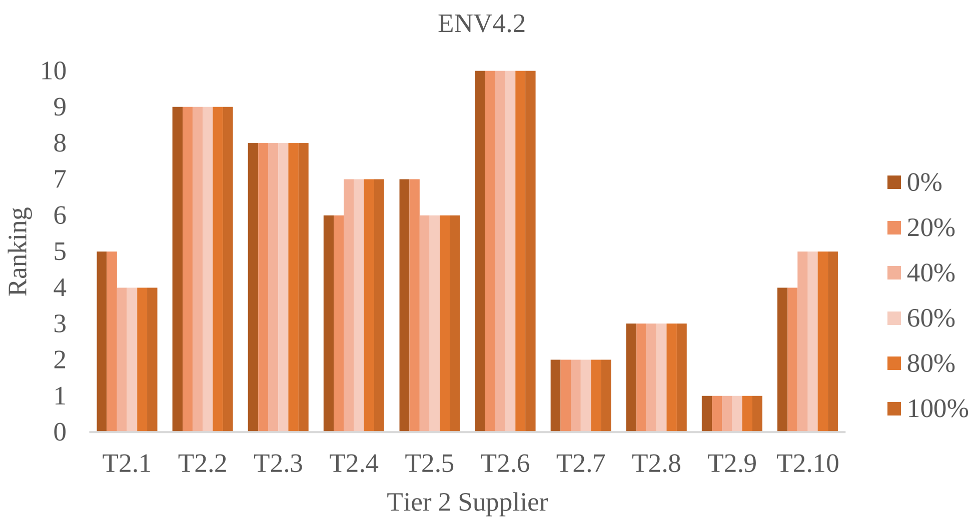


Figure 4- 49 Sensitivity analysis of tier 2 suppliers ranking in “Pollution reduction capability”

4.4.4 Summary of sensitivity analysis results in tyre rubber suppliers ranking

In this section, a sensitivity analysis was conducted to analyse the impact of different criteria on supplier's ranking. The researcher investigated to different thirteen criteria in both tier 1 and tier 2. Table 4-25 shows the details of considered decision criteria.

Table 4- 25 Results of sensitivity analysis for supplier's ranking

Changing a decision criterion	Top three tier 1 supplier ranking	The ranking of tier 1 suppliers has completely changed	Top three tier 2 supplier ranking	The ranking of tier 2 suppliers has completely changed
No change (Original ranking)	T1.9 > T1.8 > T1.1	-	T2.9 > T2.7 > T2.8	-
Bid price (EC1.1)	T1.8 > T1.9 > T1.4	O	T2.10 > T2.9 > T2.1	O
Cashflow issues (EC2.2)	T1.8 > T1.1 > T1.9	O	T2.8 > T2.9 > T2.7	O
Reliability of delivery services (EC3.1)	T1.1 > T1.9 > T1.7	O	T2.7 > T2.5 > T2.3	O
Control of products defect (EC 4.1)	T1.9 > T1.1 > T1.8	O	T2.9 > T2.7 > T2.8	O
Health care delivery (SC1.1)	T1.7 > T1.2 > T1.9	O	T2.7 > T2.9 > T2.2	O
Job security (SC2.4)	T1.10 > T1.4 > T1.8	O	T2.10 > T2.4 > T2.8	O
Contract labour (SC3.3)	T1.9 > T1.1 >T1.7	O	T2.7 > T2.9 > T2.1	O
Supplier ethics (SC4.1)	T1.10 > T1.4 > T1.8	O	T2.9 > T2.8 > T2.1	O
Stakeholder involvement (SC5.2)	T1.9 > T1.1 > T1.5	O	T2.9 > T2.1 > T2.5	O
Green packaging (ENV1.2)	T1.8 > T1.7 > T1.10	O	T2.7 > T2.10 > T2.8	O
Green design of products (ENV2.1)	T1.9 > T1.7 T1.8	O	T2.9 > T2.7 >T2.10	O
Environment standard certifications (ENV3.1)	T1.9 > T1.1 > T1.7	O	T2.7 > T2.9 > T2.10	O
Pollution reduction capability (ENV4.2)	T1.9 > T1.8 > T1.1	O	T2.9 > T2.7 > T2.8	O

Remarks: O = not having tier 1 and 2 completely change, ✓ = having tier 1 and 2 completely change

It can be seen from sensitive for the changes appeared in different criteria. If the ranking of suppliers in tier 1 and tier 2 has completely changed after applying sensitivity analysis, it means that the weights assigned to the criteria and sub-criteria were adjusted, and as a result, the order of the suppliers in the ranking has undergone significant changes. This also implies that the sensitivity analysis has had a significant impact on the selection and evaluation process, potentially leading to a different set of suppliers. However, from Table 4-25, the result shows that the rankings of both tier 1 and tier 2 suppliers have changed to some extent after applying sensitivity analysis in sustainable supplier selection, but not completely. Despite some changes in the order of supplier ranking, the overall rankings have not undergone a significant transformation. Therefore, this capability of the Fuzzy TOPSIS method can assist decision makers when the nature of criteria is very subjective, and judgement is not straightforward.

5. Discussion

Based on the quantitative survey, the interview, and the case study introduced in Chapter 4, the supplier selection in sustainability aspects have been explored among the Tyre rubber industry in Thailand and discussed under the theoretical framework of sustainability which was introduced in Chapter 2. The discussion on the interconnections between the criteria and sub-criteria, and a combined mathematical model is provided in this chapter.

5.1 Sustainable main criteria and sub-criteria

The decision criteria were derived from the Tyre rubber industry interviews and the review of the literature. The commonly accepted attributes of supplier selection were included in the current research framework alongside sustainable supplier criteria in the Thesis as shown in Table 5-1 and Table 5-2 below.

Table 5- 1 Summary of the Tier 1 Tyre suppliers' Main Criteria and Sub-criteria

Tier 1 suppliers	Main criteria	Economic	Social	Environment
	Ranking	2	1	3
Sub-criteria level 1	1st criteria	Cost and price	Social commitment	Environmental management
	2nd criteria	Financial stability	Employee's welfare and right	Green product
	3rd criteria	Service	Employee's health and safety	Green competencies
Sub-criteria level 2	1st criteria	Bid price	Support for the local community	Environmental standard certifications
	2nd criteria	Profits	Supplier ethics	Regulatory compliance
	3rd criteria	Cashflow issues	Job security	Waste disposal schemes

Table 5- 2 Summary of the Tier 2 Tyre suppliers' (Local suppliers) Main Criteria and Sub-criteria

Tier 1 suppliers	Main criteria	Economic	Social	Environment
	Ranking	1	3	2
Sub-criteria level 1	1st criteria	Cost and price	Ethics	Environmental management
	2nd criteria	Financial stability	Employee's welfare and right	Green product
	3rd criteria	Quality	Working condition	Pollution control

Sub-criteria level 2	1st criteria	Bid price	Supplier ethics	Environmental standard certifications
	2nd criteria	Cashflow issues	Job security	Green packaging
	3rd criteria	Reliability of delivery service	Health care delivery	Green design of products

Although some of these factors have been considered before in different supplier selection models, there were limited supplier selection models that addressed all the identified criteria collectively. There was an assumption in this research that there were other attributes of suppliers that could influence purchasing decisions that had not been previously considered as supplier selection criteria. This was based on the idea that not only economic criteria, environmental criteria, but also, currently social criteria could influence the decisions that are made regarding suppliers. Importantly, the current research included two different tier suppliers from diverse company size – the Tier 1 and the Tier 2 (local suppliers). Overall, the results show that there were both similarities and significant differences among various suppliers in terms of the importance of selection criteria.

5.2 The important selection criteria

From the results of the current research, it become evident that there is a difference in the decisions made by Tier 1 and Tier 2 suppliers about social dimension and economic dimension in main criteria. The social dimension was the most important criterion for the Tier 1 decision makers, followed by economic dimension in the second place. Conversely, economics was most important for the Tier 2 decision makers, followed by environment dimension in second place respectively.

These results agreed with much of the literature about supplier criteria, where economics is the most important criterion followed by environment criteria (Zimmer et al., 2016). However, the high level of importance attributed to social criteria by the Tier 1 managers in this research contradicts some research that revealed the existence of negative attitudes in the economic criteria towards choosing a sustainable criteria (Mansour & Jakka, 2013). This can be attributed to the fact that decision makers in the Tier 1 are more concerned about their suppliers applying economic criteria and environmental criteria in sustainability. The social dimension is a necessary consideration because it directly affects the choice of tyre rubber suppliers in sustainability aspects.

For the Tier 2 decision makers, the economic dimension was the most important criterion when choosing their suppliers. This includes cost and price in acquiring supplier products, which are considered in the literature to be the most important concerns for the purchase decision makers (Cengiz et al., 2017; Pal et al., 2013) because they are closely associated with savings (Chang et al., 2011) and competitiveness (Dargi et al., 2014). The present research involves the tyre rubber industry, which purchases involve sustainablilty. Furthermore, tyre rubber suppliers are mostly restrained by cost and price considerations (Olawale & Sun, 2010).

5.3 Decision similarities

For a number of the sub-criteria level 1, there was agreement between the two tiers about their importance. Specifically, there was agreement about the importance of cost and price, ranked at 1st out of the four criteria in the economics dimension. Although there was a difference in the decisions made by the tier 1 and tier 2 suppliers over the sustainable sub-criteria level 1, both tiers ranked the main criterion economic as first. Similarly, for the environmental management criterion, both ranked this criteria 2nd out of the fourteen criteria. Financial stability was ranked by both as 3rd, Employee's welfare and right came in 10th position and the green product criteria were ranked in 7th position. These findings contradict some of the literature that has reported differences in supplier selection. For example, Carter et al. (2010) highlighted that decision makers from different tiers in tyre rubber firms do not make similar business decisions. Carter et al. (2010) also noted that, based on this argument, each organisation needs to consider the specific internal and external sustainble factors which transcend the linearity of culture in the identification of efficient business models to realise continuity. Such reality is important as it augments the efficiency of the steps that have been undertaken to ensure that the supply chain indeed meets the needs of the organisation at different stages of production.

This research has revealed definite trends in the sustainable supply chain criteria concept. For example, the agreement between the two groups of various suppliers on several criteria. The little importance given to social commitment attributes in the tiers 2 shows that the stakeholder involvement, that comes from a social dimension founded on support local community actions, recieves less attention in local companies in Thailand. Therefore, this could be an acknowledgment of the fact that the social responsibility in the Thai tyre rubber industry in the Tier 2 are not concerned as explained by Wu and Jia (2018), El-Said (2013) and Srinual et al. (2020). Meanwhile, it is important that in general, tier 2 suppliers reflect local supplier selection values in Thailand. It would be reasonable to expect that there is merit in this idea because the tier 2 depends heavily on an outsourced workforce and low daily wages, for both the management and unskilled labour levels. The following paragraphs show sub-criteria level 1 and sub-criteria level 2 that were agreed upon by the decision makers from both the Tier 1 and Tier 2 regarding their sustainable supplier selection.

5.3.1 Sub-criteria

5.3.1.1 Cost and price

Cost and price was found to be equally important for both Tier 1 and Tier 2 decision makers when choosing sustainable suppliers. In the literature, the bid price is an attribute of suppliers considered in supplier selection in the rubber industry (Patil et al., 2016). Also, a total cost including logistics, product and ordering cost has been one of the most important selection criteria for many decades and has become more important in recent time (Aguezzoul, 2011).

5.3.1.2 Financial stability

Historically, financial stability has been claimed to be one of the most important attributes of a supplier (Chen, 2011), and for the Tier 1 decision makers this was shown to be the case, as it was ranked 5th out of the fourteen criteria. However, it was a slightly less important attribute for the Tier 2 decision makers when choosing suppliers, as they ranked financial stability 3rd out of the fourteen criteria. The difference was only small, so it can still be said that the two different groups (Tier 1 and Tier 2) decision makers were close in their opinions of the importance of financial stability when making decisions regarding sustainable supplier selection. However, considering the sub-criteria level 1 within financial stability, expertise was found profits in financial stability to be the most important subcriterion for Tier 2 decision makers but less important for the Tier 1 decision makers. This is because high loan capital are the first criteria that the Tier 1 decision makers considered when defining the financial stability. Also, Tier 2 suppliers are Thai local firms with a small business. Therefore, this was a first priority criteria to make the company survive. It absolutely are cashflow issues and profits. The difference shows that decision makers from the Tier 1 and Tier 2 define financial stability differently.

5.3.1.3 Employee's welfare and right

To select sustainable suppliers from Tier 1 and Tier 2 procurement managers (buyers), this study shows that employee's welfare and right is one of the important social criteria. Although, Tier 2 decision makers found this sub-criterion the least important, equity, gender, equality job security and child labour are of high concern in the Thai labour market as claimed by Srinual et al. (2019). In addition, Livanis et al. (2016) mention that suppliers in a small business (in this case Tier 2) are less concerned in social responsibility aspects. Tier 1 suppliers, which have a bigger company size, are currently focusing on more social responsibility. This is in agreement with Darrat (2011).

5.3.1.4 Environmental management

Environmental management is an important part of selecting sustainable tyre rubber supplier in Thailand and this sub-factor was found to be prioritised by both Tier 1 and Tier 2 decision makers. This is reflected, in the fact that both of the decision-making groups ranked environmental management in 2nd place in order of importance out of the fourteen criteria. This suggests that Tier 1 and Tier 2 decision makers have a similar agreement to increase environmental standard about ISO certificates in Thailand and also, comply with Thai regulatory plans to concern about sustainability, which has an impact on how management considers environmental criteria, as noted by Srinual et al. (2019). A similar inference is made by Gurel et al. (2015), who argue that environmental management system goals influence supplier selection processes globally.

5.3.1.5 Green product

The results of this study show that both Tier 1 and Tier 2 procurement managers (buyers) expressed that green product possesses moderate importance when choosing sustainable suppliers – it was ranked as 7th out of the fourteen criteria. This conclusion agrees with the research presented by Wang and Zhong (2009), which highlighted the importance of the recycle/reuse and green packaging of the supply chain in supplier selection.

5.4 Decision discrepancies

The current research noticed that there were two criteria that had contradictions between the two groups of decision makers (Tier 1 and Tier 2) about sustainable supplier selection. These are Ethics and Pollution control.

5.4.1 Sub-criteria

5.4.1.1 Ethics

There was a huge discrepency in the importance of ethics criteria to the Tier 1 and Tier 2 decision makers. For the Tier 2 decision makers, it had very little importance, even though ethics is seen as an important attribute because it is important for the reputation of the organisation (Moghaddam, 2015), and generally is a major concern for most organisations. It is not just a matter of reputation, but neglecting supplier ethics, ethical environment, and disclosure of information can lead to loss of revenue (Chen & Baddam, 2015) through a perception of unethical behaviour (Goebel et al., 2012). Therefore, the results of this study for the Tier 2 decision makers deviates from the prevailing business dynamics which suggest that the ethics criterion is a compelling concern. The Tier 2 decision makers valued the presence and application of ethics, but they did not think that having more ethics behaviour would increase suppliers' chance of being chosen. Also, ranking ethics at the end of the list of importance does not mean that it is not important to the Tier 2 decision makers. They viewed it simply as less important than other criteria. In reflecting on the criticality of ethics in influencing the supply chain selection process. Chiouy, Chou & Yeh (2011) suggested that it does play a crucial role in higher tier suppliers settings. Nonetheless, this may not be replicated in the Tier 2 because of the differences in the company size, revenue, and production capacity that are reflected in the two tiers.

The Tier 1 decision makers considered ethics to be much more important – they ranked it in 4th place out of fourteen criteria. These results could reflect Thai regulatory and legal standards (Gillogly, 2014) in sustainability aspects. This legal and regulatory framework is reflected in the Tier 1 decision makers' consideration of the importance of ethics. Therefore, it might be reasonable to deduce that the lack of importance attributed by the Tier 2 decision makers to ethics is reflected of a less established legal and regulatory sustainability framework in Thailand. Furthermore, although there is now greater awareness of ethics in the Thailand, the emphasis on complying with mandatory legislation, both social and environmental, is limited. Similarly, there is less concern about legislation that is not mandatory and there is a need to promote contribution to community activities (Al Tamimi & Hussein, 2014). These explanations might have been reflected in the results of the present research concerning three sub-criteria in ethics (supplier ethics, ethical environment, disclosure of information). The results show that for Tier 2 decision makers, environmental and economic sustainability was more important than social responsibility. In reference to social responsibility, the results of the current research disagreed with the literature, because some small businesses now are following the Thai sustainability plan especially in ethics criteria as explained by de Waal & Frijns (2016). However, this is the case for the tyre rubber industry but not all industry sectors in Thailand.

5.4.1.2 Pollution control

One of the major differences in the findings between the two tiers was the importance of the pollution prevention solutions of the supplier during the sustainable supplier selection process. Although it pointed out that air pollution from Tyre rubber industries are the main source for the hostile environment in the nearby area of production, it was of very little importance to the Tier 2 decision makers, ranked 12^{th} in terms of importance, but was considered important by the Tier 1 decision makers, ranked 6^{th} out of the fourteen criteria. The Tier 1 decision makers placed considerable importance on this criteria. This study found that the development of joint efforts between the buying firm and its Tier 1 suppliers motivates changes in pollution control to meet environmental requirements. Similary, Gualandris et al. (2014) found that the implemenation of pollution prevention systems helped to improve the sustainability performance of the buying firm when colloborating with suppliers tend to have large company size and strong financial stability.

5.5 Mathematical model

In terms of the methodology of the approach, the contribution of this study stems from the use of multi-criteria decision making model (MCDM) using combined method. In this study, the MCDM model represents a collection of two fuzzy techniques with the overall goal to determine a preference ordering in sustainable criteria among tyre rubber suppliers decision in Thailand. A combined multi-criteria decision making model is a model for analysis that has not been previously utilised in any study of sustainable supplier selection in Tyre rubber industry. In fact, only a few supplier selection studies adopted the single multi-criteria technique but none of the previous studies used a hybrid multi-criteria decision making techniques with Fuzzy set theory in their data analysis. Fuzzy logic has the advantage of being able to formulate very complex models with a combination of all constructs and variables. Furthermore, combining more than single multi-criteria decision making model can handle the entire measurement model and reduce the level of ambiguity from a decision-maker’s opinion. Thus, in the present research, a considerable methodological approach contribution has been made by using a combined AHP-TOPSIS multi-criteria decision making model and Fuzzy set theory to deal with a tyre rubber respondents from a different types of companies.

There are many mathematical models propounded by some scholars such as Thanki et al. (2016), Beikkhakhian et al. (2015) and Saaty (1980). These models did not focus on the tyre rubber industry. Thus, the current research examined different models and found that the Fuzzy AHP and Fuzzy TOPSIS model could be useful for the Tyre rubber industry. The Fuzzy AHP and Fuzzy TOPSIS were applied to the current research framework. Then, a model from Bello (2003) and Saaty (1980, 1990) was used to develop a mathematical formula based on the current research framework criteria, sub-criteria, the weights, and ranking of Tier 1 and Tier 2 suppliers derived from the Fuzzy AHP and Fuzzy TOPSIS outputs. This formula can be used to find the overall score of a sustainable supplier in any tyre rubber company located in Thailand or other countries. When applying this formula, the decision maker has the right to exclude any criteria or sub-criteria or alternatives (suppliers) based on their requirements and needs. It will offer not only quick decision-making and reduce the time and effort but also reduce individual bias during the sustainble supplier selection process.

In addition to this, the current study combines the qualitative and quantitative techniques of data collection. Semi-structured key informant interviews enabled the exploration of the concept of sustainable supplier selection in Thai Tyre rubber industry, which had not been previously examined, and to refine the research framework. This was later followed by a quantitative phase, with the survey results analysed via a hybrid decision making modelling using Fuzzy AHP anfd Fuzzy TOPSIS. This particular combination had not been previously adopted in this area of research. With this in mind, such an attempt has set a new benchmark for future researchers in this field.

The present study also provides reliable and valid measurement scales for all constructs which can be used for future research by employing sensitivity analysis to measure degrees of fuzziness to find out when the input data (preference judgements and degrees of fuzziness) are changed into new values, how the sustainable criteria and ranking of the alternatives will change. Also, the results of the sensitivity testing revealed that all the factors and the proposed FAHP and FTOPSIS decision-making decision making model are robustly used for the sustainable supplier selection, as the factor's uncertainty levels do not influence the final decision on different areas of supplier selection in the tyre rubber industry. Therefore, this study contributes predictive factors which influence supplier selection in sustainability dimensions as well as the desired outcomes from implementing these in a particular context, namely sustainble supplier selection in the tyre rubber industry. In conclusion, the combined Fuzzy AHP and Fuzzy TOPSIS has brought about significant contributions in terms of a combined multi-criteria decision making model in this area.

6. Conclusion and future work

In this chapter, the main arguments of this Thesis are combined and the significant conclusions that have been reached are presented. The contributions of this research are also presented, as well as the research limitations, and recommendations for possible future research.

6.1 Conclusion

The availability of several scholarly articles on the current research topic shows that scholars have been discussing it for decades. The work of Dickson (1966) also shows that the choice of supplier selection criteria has been an important issue for decades. Similarly, recent works, such as Salam and Khan (2018), Rojniruttikul (2017), Trapp and Sarkis (2016), Polat and Eray (2015) and Waris et al. (2014), show that multiple selection criteria have sparked scholarly debates recently. Likewise, the works of Saaty (2001) and more recent works from Carter et al. (2010), and Roshandel et al. (2013) show that proposing a combining model for sustainable supplier selection is among interesting research areas for scholars. Meanwhile, these previous works did not focus on the 'most important' selection criteria in sustainability. The previous works also did not focus on the large sizes and small-medium sizes of the sustainable supplier selection decision maker. Finally, the previous works have not yet considered the tyre rubber industry in Thailand.

The aforementioned gaps propelled the current research. As shown in previous works, several criteria are needed. However, not all the criteria would be significant for every position or every decision-makers, as shown in the results of the current research. The current research revealed that some key criteria are relevant only to some supplier selection decision makers in a specific department and company size, even they operate in the same industry. Similarly, the current research revealed that projects or products combining some key economics, environmental and social trends determine the most significant criteria to be used for selecting suppliers in developing country. Thus, it can be concluded that identifying and focusing on the most important criteria is essential for sustainable supplier selection decision-making.

Although the previous works, which include Livanis et al. (2016), Carter et al. (2010) and Liu et al. (2010), considered economic and environmental factors in their studies and models, the current research found that there is a social influence in decision-making. The current research revealed that social criteria influenced Tier 1 supplier decision makers in the Tyre rubber industry. Additionally, the current research pinpointed that combining environment with social influence is beyond economics dimension for some decision makers. It is shown that decision makers currently not only focus on cost and price or profits but also, they focused on employees and environmental issues. The current research noticed that employee's welfare and right aspects are still hidden because decision makers do not want to discuss them openly. Meanwhile, the current research emphasised that Employee's health and safety and social commitment of social dimension might influence decision makers in the tyre rubber industry in selecting their suppliers. Hence, it can be concluded that the current research throws more light on the social influences on selection of sustainable suppliers.

Previous works have examined many industrial sectors, as shown in the work of Amorim et al. (2016) and Banaeian et al. (2016) for the food industry, Dweiri et al. (2016), Hirakubo and Kublin (1998) for the electronics industry, Gupta et al. (2015), and Shahroudi and Tonekaboni (2012) for the automotive industry, Feurtey et al. (2016) for the packaging industry, Rojniruttikul (2017) for motorcycle spare parts, and Lee (2010) for the Production of TFT-LCD sector. Meanwhile, very few previous works considered the tyre rubber industry in sustainable ways. Chanchaichujit (2014) considered only green criteria for Thai natural rubber industry, and Sembiring et al. (2019) considered only economics criteria for selecting suppliers in rubber industry cases in Indonesia. The current research investigated all three dimensions in sustainability in the Tyre rubber industry from large sizes and small-medium sizes in different regions in Thailand. Therefore, it can be concluded that the current research contextualises the scholarly discussion on sustainable supplier selection.

In respect to the above, it can be concluded that the current research has to be decided by the reviewers identified and prioritised the most important sustainable supplier selection criteria and all sub-criteria related to Tyre rubber organisations in Thailand. It can be concluded that the current research attained its aim by identifying the similarities and differences in how the Tier 1 (Large size companies) and Tier 2 (Thai local small-medium size companies) decision makers evaluated suppliers. Similarly, it can be concluded that the current research was able to outline the effects of combining economics, environmental, and social dimension on the decision-making process of sustainable supplier selection. This research not only considered the economics attributes of the decision makers, but also the role of the social and environment attributes of the suppliers.

The current research developed a combined multi-criteria decision-making model for evaluating and selecting sustainable suppliers in the tyre rubber industry in Thailand. The model is based on a comprehensive literature review to find a suitable list of sustainable supplier selection criteria and sub-criteria relevant to the tyre rubber industry. The model also includes the traditionally accepted criteria, as well as new criteria such as social factors and factors intersected with economics and environmental. The model can be customised to reflect on specific criteria that are under analysis and an effective mathematical model can be generated to test the pre-established criteria structure. Therefore, it can be concluded that the current research achieved its goal in providing and proposing a mathematical model for sustainable supplier selection in the tyre rubber industry.

The goals of the current research were achieved through a mixed research method. It collected its data from decision makers who have more than three years of working experience. These decision makers are working with large companies which have more than 1,000 employees and Thai local small-medium companies in tyre rubber industry less than 1,000 employees are presently engaging in Automotive industry in Thailand. The collected data were analysed quantitively and quantitatively. Therefore, it can be stated that the current research achieved its research objective.

6.2 Contribution of this research

This study is structured in novelty by the proposing of a combined multi-criteria decision-making model that studies the significant criteria influencing the sustainable supplier selection for Tyre rubber companies in Thailand. In prior studies, it appears that research has not been conducted with focus on economic, environment, and social criteria when studying at supplier selection criteria in sustainability, but rather on supply chain management in the more commonly recognised areas that are deemed influencing factors. Therefore, it can be claimed that this research is the first study which empirically proposed and examined these multi-criteria decision-making model framework in tyre rubber industry. As far as the researcher is aware, this research study is the first work that focuses at the combination of economic criteria (cost and price, financial stability, services, and etc.), social criteria (social commitment, employee's welfare and right, employee's health and safe, and etc.), and environmental criteria (environmental management system, green product, pollution reduction capability, and etc.) together with other influencing factors in the supplier selection criteria.

This section summarises the contributions and implications of this study to research and highlights implications for practice in several ways below.

1. The current research provides the most important criteria for selection of sustainable suppliers in Tier 1 and Tier 2 Thai local suppliers. This information has not yet been provided by previous scholars and practitioners. Thus, this research contributes to a further understanding of the factors of sustainability that influence the decision-making process in supplier selection in the Tyre rubber industry. More specifically, the current research contributes the finding that the Cost and price, Bid-price, Ethics, Employee's welfare and right, Environmental management, and Pollution control, are the key criteria in the Tyre rubber industry in Thailand.
2. There is a gap in the supplier selection literature in research based specially in sustainability in Thailand. Most existing literature is based on countries, for instance, United States of America, United Kingdom, and European countries. Thailand is identified by the literature as a developing country in the South East Asian region and highlights a strong presence in the manufacturing industry (Boonsiritomachai et al., 2016).
3. Current studies in the area of sustainable supplier selection, mostly use secondary data to conduct their studies (Hajidimitriou and Georgiou, 2002). This research project builds on existing literature to make an empirical contribution, by adding rich data derived from in-depth interviews with Thai companies.
4. Sustainable supplier selection methods are defined and classified in the research and are defined to be process driven. Furthermore, pricing, quality, product and service is defined as the criteria used by these methods (Hadi and Mastor, 2005). The research provides empirical evidence that the supplier selection method varies in these cases, along with the supplier selection criteria.

5. The study introduces the influence of the Thai culture on the supplier selection decision-making process for the first time, by identifying the importance of social issues. Relevant literature in supplier selection criterion excludes social aspects as an influential factor in the decision-making process (Srinual et al., 2020). This research builds on the supplier selection decision-making literature by considering the social responsibility in Thai tyre rubber manufacturing literature.

6. Sustainability is perceived by the literature to be incorporated in the supplier selection decision-making process (Efthymiou et al., 2016). The decision-making technique is also viewed as one that solves the supplier selection decision-making problem (Hadi and Mastor, 2005). The relevant literature highlights many studies dedicated to the sustainable supplier selection decision-making process (Sarkar and Mohapatra, 2006) However, this study provides empirical evidence that there is no presence of a combined FAHP-FTOPSIS multi-criteria decision-making model supporting the sustainable supplier selection decision-making process in Tyre rubber manufacturing.

7. To the best of the author's knowledge, the current research is the first comparative studies in Tyre rubber industry. It examined two scale economies with diverse company size. It also applied a mixed method with several participants from the large and SMEs companies. Its findings revealed the areas of similarities and discrepancies when making sustainable supplier selection decisions. All these make the current research contribute to a better understanding of supplier selection mechanism with respect to sustainability aspects of supplier selection literature.

8. The current research introduced a combined multi-criteria decision-making model that can enable scholars to understand the importance of different selection criteria. This model can also enable practitioners to rank their selection criteria. The model contains the main criteria and sub-criteria. The model can facilitate supplier selection decision-making. Thus, the current research contributes to the scholarly models of sustainability for choosing supplier.

9. The current research introduced a list of main and sub-criteria that can be used in selecting suppliers in the tyre rubber industry. The list was based on previous scholarly works. This effort reduces fragmentation in the literature and contributes to the state-of-the-art knowledge in sustainable supplier selection and evaluation.

10. The current research employed Fuzzy AHP and Fuzzy TOPSIS to the decision making of three main dimensions for sustainable supplier selection and evaluation. The combination of these is not commonly used in scholarly works for selecting tyre rubber suppliers. The application of these models enriched the current research. Therefore, the current research contributes to the theory and practices of sustainability.

11. Sustainability in global supply chain mentioned in the established literature is identified as needing to be developed in developed countries (Hadi and Mastor, 2005). This research adds to the limited area of sustainability in supplier selection by establishing that there is a decision-making model for choosing sustainable supplier selection being developed in Thailand for Thai tyre rubber manufacturers.

12. Srinual et al., (2020), points out that green and social aspects have become an important aspect of a firm's decision-making tools, and is most beneficial for manufacturing firms. Relevant literature in both environment and social responsibility criteria seldom mentions the adoption of these tools in Thailand (Srinual et al., 2020). Countries such as France, Australia and the United States of America are the most mentioned countries in other aspects not only economic point of view. This research adds empirical evidence to social dimensions literature by identifying the criteria used in Tyre rubber industry.

13. The implementation and use of a multi-criteria decision-making model are an integral part of supporting the sustainable supplier selection decision-making process. Within the established literature relative to Thailand manufacturing, a single-model approach in multi-criteria decision making in literature is mostly presented as a decision model used to support supplier selection (Mahmut, 2006). This research proposed and validated a combined multi-criteria decision-making model by identifying the application of Fuzzy AHP and Fuzzy TOPSIS to support the supplier selection decision-making process.

6.3 Limitation of the research

6.3.1 Limitations of this study

One of the limitations of this research is that the sub-criteria were bound to the main criteria. This research used just three main criteria and 14 sub-criteria level 1 and 46 sub-criteria level 2 related to sustainable supplier selection. Thus, the list of criteria could be expanded to achieve a more comprehensive framework by reviewing more literature.

Another limitation was the research participants. Even within the same company, the decision makers surveyed had different technical backgrounds, and this was not taken into consideration when making priority calculations. Similarly, the participants had different previous working experience. This might influence their responses or interview answers. There were difficulties in arranging the personal interviews, as they were conducted with managerial-level employees and the nature of the questionnaire questions (pairwise comparison) were not straightforward to understand and had to be explained to the interviewees before they answered the questions. This meant that data collection took a very long time to complete. These challenges influenced the outcome of the current research, though they did not reduce the quality of the findings.

The current research was also limited by its context – the Thai tyre rubber industry in the Tier 1 suppliers and Tier 2 local suppliers. This limit resulted in generalisation of the framework and model of the research. The application of the model might lose precision or accuracy, especially when integrated into a company with significantly different size. Essentially, since only twenty Tyre rubber suppliers were considered for the research, it may not be feasible to generalise the findings without approximation errors to the whole of Thailand.

Meanwhile, the above limitations do not affect the quality of the current research. The limitations provide opportunities for future studies that are presented in the following subsection.

6.3.2 Limitations of the Research Approach

The initial data collection method for this study was to use a large-scale questionnaire method, to gather information from 22 Thai tyre rubber companies on their supplier selection decision-making process, Economic dimension, social dimension, and environmental dimensions, this would have allowed a more generalised overview of Thai Tyre rubber manufacturing. However, due to a low response rate from decision makers, and limited time, the data collection method was changed to semi-structured interviews.

For each interview the interviewees were singular candidates. The research would have benefited from more than one interviewee, as the responses given from each interviewee could be bias. However, the interviewees were very knowledgeable.

6.4 Future research

Although the research confirms that economic, environmental, and social aspects have been appropriately covered in the field, a misalignment between these three aspects still exists. This analysis shows that economic criteria are considered more in the evaluation and selection process compared with environmental criteria. However, this difference is negligible. Oppositely, the difference between economic and social aspects is more tangible, where the analysis shows that considering economic criteria is far more than social variables in evaluating suppliers' sustainability performance. One of the main reasons behind this, in the researcher opinion, is the existence of a well-defined justification for considering environmental variables based on their undeniable effects on economic efficiency, particularly cost and price and quality defect. Thus, it is advantageous to conduct more research and investigate how tyre rubber companies can benefit from social sustainability performance.

Future research could consider below:

- Future research may include more participants within Tyre rubber suppliers in Southern Thailand or North, North-Eastern and Eastern areas. Given the difficulties related to collecting data from SMEs in the Thai context, a larger sample would make for a more comprehensive study, as long as more time can be allocated for data collection.
- It can be noticed from the study by Winter et al. (2016) that the nature of organisational culture affects decision-making, a future study can consider both organisational and national cultural factors in sustainable supplier selection decision-making.
- Future studies could consider a comparative study between decision makers from tyre rubber industry and other industries in Thailand and/or other countries that have less of a relationship with the sustainability.

- A future study could examine the effect of the decision maker's technical background on sustainable supplier selection decisions. The managers in this study had different backgrounds and expertise, and this needs to be considered in future research.
- A comparison of developed countries and developing countries, in the context of the sustainable supplier selection decision-making process, to highlight differences in the supplier selection decision-making process.
- The influence of the Thai culture on the supplier selection decision-making process should be further explored. As highlighted in the findings of this study, the Thai cultural influence plays an impacting role on decision-making, due to trust. Future research should explore the trust factor in supplier selection decision-making.
- Future research can employ a different data collection instrument, for instance a large-scale questionnaire to investigate the supplier selection decision-making process in other manufacturing industries, for complete representation of the sector.
- It would be beneficial to duplicate this study in different developing countries to compare the findings.
- For practitioners in the respective fields, this decision-making model can be developed to reflect the specific needs of different industries. Data collection can be conducted to understand managerial needs to be integrated into sustainability assessment tools.
- A study into the area of sustainability criteria in other developing countries to compare if the usage and presence of this combined decision-making model are the same or different.
- The findings of the research show there are no government interviewees present involved in this study. Using a different data collection instrument and a larger sample, would be beneficial to practitioners to understand the usage and presence, and to ascertain what the issues or problems are, in order to provide solutions.

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Appendix 1 Interview decision makers

Sustainable supplier evaluation and selection for selecting Tyres rubber suppliers in Thailand

Interviews for Academician.

Interview Protocol for Sustainable supplier evaluation and selection problem.

1. Your contact details:

Name:

Company:

Department/Position:

Email:

2. In your opinion, does the Tyres company need to have the formal sustainable criteria for selecting suppliers?)? If yes, how? If no, why? and please suggest any sustainable criteria for choosing suppliers. (Please rate the degree of importance from 1, with 1 being the most important.)

Main criteria in Sustainable Supplier selection	Economic dimension	Environmental dimension	Social dimension
Ranking (1 to 3)			

Do you have any suggestions in your traditional criteria or sustainable criteria to choosing suppliers?

3. In your opinion, does the company need to associate the sustainability in supplier selection with the company competitive strategy? If yes, how? If no, why?
4. In your opinion, do the Tyres rubber industry need to differentiate the sustainability in their suppliers with other industry (Manufacture and other service industry)? If yes, how? If no, why?
5. In your opinion, is the sustainable criteria in choosing suppliers important to increase the company competitiveness? If yes, how? If no, why?
6. In your opinion, how Tyres rubber firm concern about or awareness of sustainability?

Appendix 2 Survey questionnaire

Part one: General information

Please indicate your current department

President/CEO		Procurement/Purchasing	
General Manager		Production/Quality	
Finance		Logistics/Engineer	

For how long you have been in this position?

Less than 3 years		3-6 years		7-10 years		More than 10 years	

How many employees do you have in your company?

Less than 1,000		1,001-1,500		More than 1,500	

Please indicate the age of your company

Less than 3 years		3-6 years		7-10 years		More than 10 years	

Part two: Sustainable supplier selection criteria

This part is further divided into three sections, A, B and C.

- In section A, you are kindly asked to compare the main criteria.
- In section B, you are kindly asked to compare the sub-criteria level 1.
- In section C, you are kindly asked to compare the sub-criteria level 2.

Weights of criteria indicate which criterion is more important and then indicate the relative importance of the selected criterion on a scale from 1—9 (please see the table provided below).

Section A: Main criteria pairwise comparison

Main criteria	Importance scale 1 to 9	Importance scale 1 to 9	Main criteria
Economic (EC)			Environmental (ENV)
Economic (EC)			Social (SC)
Environmental (ENV)			Social (SC)

Section B: Sub criteria level 1 pairwise comparison

- Economic dimension (EC)

Sub criteria level 1	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 1
Cost and price (EC1)			Financial stability (EC2)
Cost and price (EC1)			Service (EC3)
Cost and price (EC1)			Quality (EC4)
Financial stability (EC2)			Service (EC3)
Financial stability (EC2)			Quality (EC4)
Service (EC3)			Quality (EC4)

- Environmental dimension (ENV)

Sub criteria level 1	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 1
Green product (ENV1)			Green competencies (ENV2)
Green product (ENV1)			Environmental management (ENV3)
Green product (ENV1)			Pollution control (ENV4)
Green product (ENV1)			Green image (ENV5)
Green competencies (ENV2)			Environmental management (ENV3)
Green competencies (ENV2)			Pollution control (ENV4)
Green competencies (ENV2)			Green image (ENV5)
Environmental management (ENV3)			Pollution control (ENV4)
Environmental management (ENV3)			Green image (ENV5)
Pollution control (ENV4)			Green image (ENV5)

- Social dimension (SC)

Sub criteria level 1	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 1
Employee’s health and safety (SC1)			Employee’s welfare and right (SC2)
Employee’s health and safety (SC1)			Working condition (SC3)
Employee’s health and safety (SC1)			Ethics (SC4)
Employee’s health and safety (SC1)			Social commitment (SC5)
Employee’s welfare and right (SC2)			Working condition (SC3)
Employee’s welfare and right (SC2)			Ethics (SC4)
Employee’s welfare and right (SC2)			Social commitment (SC5)

Working condition (SC3)			Ethics (SC4)
Working condition (SC3)			Social commitment (SC5)
Ethics (SC4)			Social commitment (SC5)

Section C: Sub criteria level 2 pairwise comparison

- Economic dimension (EC)
    - Cost and price (EC1)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Bid price (EC1.1)			Discounts (EC1.2)
Bid price (EC1.1)			Logistics cost (EC1.3)
Bid price (EC1.1)			Product cost (EC1.4)
Bid price (EC1.1)			Ordering cost (EC1.5)
Discounts (EC1.2)			Logistics cost (EC1.3)
Discounts (EC1.2)			Product cost (EC1.4)
Discounts (EC1.2)			Ordering cost (EC1.5)
Logistics cost (EC1.3)			Product cost (EC1.4)
Logistics cost (EC1.3)			Ordering cost (EC1.5)
Product cost (EC1.4)			Ordering cost (EC1.5)

- Financial stability (EC2)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Profits (EC2.1)			Cashflow issues (EC2.2)
Profits (EC2.1)			High loan capital (EC2.3)
Profits (EC2.1)			Takeover potential (EC2.4)
Profits (EC2.1)			Clients’ dependency (EC2.5)
Cashflow issues (EC2.2)			High loan capital (EC2.3)
Cashflow issues (EC2.2)			Takeover potential (EC2.4)
Cashflow issues (EC2.2)			Clients’ dependency (EC2.5)
High loan capital (EC2.3)			Takeover potential (EC2.4)

High loan capital (EC2.3)			Clients' dependency (EC2.5)
Takeover potential (EC2.4)			Clients' dependency (EC2.5)

- Service (EC3)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Reliability of delivery service (EC3.1)			Lead time (EC3.2)
Reliability of delivery service (EC3.1)			Accuracy of product and quantity delivered (EC3.3)
Reliability of delivery service (EC3.1)			Warranty/Returns (EC3.4)
Reliability of delivery service (EC3.1)			Responsiveness communication (EC3.5)
Lead time (EC3.2)			Accuracy of product and quantity delivered (EC3.3)
Lead time (EC3.2)			Warranty/Returns (EC3.4)
Lead time (EC3.2)			Responsiveness communication (EC3.5)
Accuracy of product and quantity delivered (EC3.3)			Warranty/Returns (EC3.4)
Accuracy of product and quantity delivered (EC3.3)			Responsiveness communication (EC3.5)
Warranty/Returns (EC3.4)			Responsiveness communication (EC3.5)

- Quality (EC4)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Control of products defect (EC4.1)			Return rate (EC4.2)
Control of products defect (EC4.1)			Certificate of quality (EC4.3)
Control of products defect (EC4.1)			Quality management capability (EC4.4)

Return rate (EC4.2)			Certificate of quality (EC4.3)
Return rate (EC4.2)			Quality management capability (EC4.4)
Certificate of quality (EC4.3)			Quality management capability (EC4.4)

- Environmental dimension (ENV)
    - Green product (ENV1)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Recycle/reuse (ENV1.1)			Recycle/reuse (ENV1.1) Green packaging (ENV1.2)

- Green competencies (ENV2)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Green design of products (ENV2.1)			Green technology capability (ENV2.2)

- Environmental management (ENV3)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Environmental standard certifications (ENV3.1)			Regulatory compliance (ENV3.2)

- Pollution control (ENV4)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Waste disposal schemes (ENV4.1)			Pollution reduction capability (ENV4.2)
Waste disposal schemes (ENV4.1)			Energy consumption (ENV4.3)
Waste disposal schemes (ENV4.1)			Hazardous substances (ENV4.4)
Waste disposal schemes (ENV4.1)			Air emissions (ENV4.5)
Pollution reduction capability (ENV4.2)			Energy consumption (ENV4.3)
Pollution reduction capability (ENV4.2)			Hazardous substances (ENV4.4)

Pollution reduction capability (ENV4.2)			Air emissions (ENV4.5)
Energy consumption (ENV4.3)			Hazardous substances (ENV4.4)
Energy consumption (ENV4.3)			Air emissions (ENV4.5)
Hazardous substances (ENV4.4)			Air emissions (ENV4.5)

- Social dimension (SC)
  - Employee's health and safety (SC1)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Health care delivery (SC1.1)			Safety measures (SC1.2)

  - Employee's welfare and right (SC2)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Equity (SC2.1)			Gender discrimination (SC2.2)
Equity (SC2.1)			Equality (female vs male wages) (SC2.3)
Equity (SC2.1)			Job security (SC2.4)
Equity (SC2.1)			Child labour (SC2.5)
Pollution reduction capability (ENV4.2)			Equality (female vs male wages) (SC2.3)
Pollution reduction capability (ENV4.2)			Job security (SC2.4)
Pollution reduction capability (ENV4.2)			Child labour (SC2.5)
Energy consumption (ENV4.3)			Job security (SC2.4)
Energy consumption (ENV4.3)			Child labour (SC2.5)
Hazardous substances (ENV4.4)			Child labour (SC2.5)

  - Working condition (SC3)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Wages (SC3.1)			Working hours (SC3.2)

Wages (SC3.1)			Contract labour (SC3.3)
Wages (SC3.1)			Training programs (SC3.4)
Working hours (SC3.2)			Contract labour (SC3.3)
Working hours (SC3.2)			Training programs (SC3.4)
Contract labour (SC3.3)			Training programs (SC3.4)

- Ethics (SC4)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Supplier ethics (SC4.1)			Ethical environment (SC4.2)
Supplier ethics (SC4.1)			Disclosure of information (SC4.3)
Ethical environment (SC4.2)			Disclosure of information (SC4.3)

- Social commitment (SC5)

Sub criteria level 2	Importance scale 1 to 9	Importance scale 1 to 9	Sub criteria level 2
Support for the local community (SC5.1)			Stakeholder involvement (SC5.2)

Appendix 3 Fuzzy AHP results

Main criteria

- Table Appendix 3-1 Fuzzy AHP output weights of the main criteria

Decision maker from each company	Economic (EC)	Social (SC)	Environmental (ENV)
1	0.44	0.13	0.43
2	0.11	0.36	0.53
3	0.57	0.29	0.14
4	0.41	0.11	0.48
5	0.44	0.29	0.27
6	0.43	0.32	0.25
7	0.49	0.09	0.42
8	0.45	0.16	0.39
9	0.41	0.20	0.39
10	0.10	0.18	0.72
11	0.57	0.13	0.30
12	0.60	0.15	0.25
13	0.13	0.70	0.17
14	0.75	0.05	0.20
15	0.36	0.50	0.14
16	0.34	0.49	0.17
17	0.27	0.6	0.13
18	0.43	0.14	0.43
19	0.55	0.15	0.30
20	0.31	0.44	0.25
Average Weight	0.41	0.27	0.32

Sub-criteria level 1

- Table Appendix 3-2 Fuzzy AHP output weights of the sub-criteria level 1 in Economic dimension

Decision maker from each company	Cost and price (EC1)	Financial stability (EC2)	Service (EC3)	Quality (EC4)
1	0.43	0.10	0.24	0.23
2	0.37	0.24	0.13	0.26
3	0.39	0.35	0.06	0.20
4	0.42	0.33	0.12	0.13
5	0.33	0.32	0.17	0.18
6	0.39	0.35	0.13	0.13

7	0.34	0.22	0.16	0.28
8	0.37	0.22	0.20	0.21
9	0.37	0.40	0.14	0.09
10	0.36	0.11	0.13	0.40
11	0.35	0.21	0.15	0.29
12	0.46	0.33	0.16	0.05
13	0.29	0.12	0.17	0.42
14	0.31	0.28	0.16	0.25
15	0.27	0.26	0.28	0.19
16	0.38	0.22	0.28	0.12
17	0.34	0.40	0.13	0.13
18	0.29	0.33	0.18	0.20
19	0.30	0.15	0.28	0.27
20	0.35	0.11	0.24	0.30
Average Weight	0.36	0.27	0.17	0.20

- Table Appendix 3-3 Fuzzy AHP output weights of the sub-criteria level 1 in Social dimension

Decision maker from each company	Employee's health and safety (SC1)	Employee's welfare and right (SC2)	Working condition (SC3)	Ethics (SC4)	Social commitment (SC5)
1	0.19	0.13	0.18	0.27	0.23
2	0.15	0.18	0.25	0.25	0.17
3	0.16	0.13	0.11	0.42	0.18
4	0.17	0.29	0.09	0.39	0.06
5	0.16	0.21	0.19	0.39	0.06
6	0.28	0.10	0.18	0.25	0.19
7	0.13	0.28	0.23	0.20	0.17
8	0.13	0.19	0.28	0.34	0.06
9	0.19	0.19	0.17	0.27	0.18
10	0.12	0.26	0.20	0.25	0.17
11	0.17	0.10	0.17	0.43	0.13
12	0.13	0.38	0.18	0.25	0.06
13	0.15	0.26	0.07	0.24	0.28
14	0.16	0.25	0.11	0.20	0.28
15	0.17	0.19	0.12	0.39	0.13
16	0.17	0.13	0.21	0.39	0.11
17	0.13	0.18	0.12	0.40	0.17
18	0.17	0.13	0.18	0.30	0.22
19	0.13	0.23	0.33	0.25	0.06

20	0.16	0.21	0.33	0.25	0.06
Average Weight	0.16	0.20	0.19	0.31	0.14

- Table Appendix 3-4 Fuzzy AHP output weights of the sub-criteria level 1 in Environmental dimension

Decision maker from each company	Green product (ENV1)	Green competencies (ENV2)	Environmental management (ENV3)	Pollution control (ENV4)	Green image (ENV5)
1	0.17	0.13	0.44	0.14	0.13
2	0.18	0.18	0.35	0.19	0.10
3	0.23	0.08	0.41	0.15	0.13
4	0.28	0.09	0.38	0.16	0.09
5	0.18	0.13	0.41	0.17	0.11
6	0.21	0.13	0.43	0.13	0.10
7	0.12	0.08	0.54	0.16	0.10
8	0.18	0.19	0.36	0.18	0.09
9	0.07	0.13	0.41	0.28	0.11
10	0.11	0.20	0.39	0.24	0.06
11	0.11	0.13	0.51	0.15	0.10
12	0.09	0.12	0.55	0.16	0.08
13	0.28	0.12	0.31	0.17	0.12
14	0.17	0.10	0.55	0.13	0.05
15	0.18	0.16	0.41	0.16	0.09
16	0.07	0.14	0.46	0.20	0.13
17	0.11	0.12	0.44	0.14	0.18
18	0.33	0.10	0.26	0.18	0.13
19	0.33	0.04	0.29	0.28	0.06
20	0.33	0.11	0.2	0.24	0.12
Average Weight	0.19	0.12	0.41	0.18	0.10

Appendix 4 Fuzzy TOPSIS results

Criteria	Weight	sub-criteria 1	Weight level 1	sub-criteria 2	Weight level 2	T1.1	l	m	u	T1.2	l	m	u	T1.3	l	m	u	T1.4	l	m	u	T1.5	l	m	u	T1.6	l	m	u	T1.7	l	m	u	T1.8	l	m	u	T1.9	l	m	u	T1.10	l	m	u
EC	0.41	EC1	0.36	EC1.1	0.32	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00
				EC1.2	0.17	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	L	0.15	0.30	0.45	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85
				EC1.3	0.15	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	M	0.35	0.50	0.65
				EC1.4	0.2	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25
				EC1.5	0.16	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25
		EC2	0.27	EC2.1	0.15	M	0.35	0.50	0.65	L	0.15	0.30	0.45	L	0.15	0.30	0.45	L	0.15	0.30	0.45	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00
				EC2.2	0.31	L	0.15	0.30	0.45	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45
				EC2.3	0.24	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VH	0.75	0.90	1.00
				EC2.4	0.18	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45
				EC2.5	0.12	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00
		EC3	0.17	EC3.1	0.4	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00
				EC3.2	0.2	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85
				EC3.3	0.17	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	H	0.55	0.70	0.85
				EC3.4	0.13	L	0.15	0.30	0.45	H	0.55	0.70	0.85	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VH	0.75	0.90	1.00
				EC3.5	0.1	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VH	0.75	0.90	1.00
		EC4	0.2	EC4.1	0.31	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85	M	0.35	0.50	0.65	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VL	0.00	0.10	0.25
				EC4.2	0.16	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	M	0.35	0.50	0.65
				EC4.3	0.26	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	M	0.35	0.50	0.65	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65
				EC4.4	0.27	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	M	0.35	0.50	0.65
SC	0.27	SC1	0.16	SC1.1	0.52	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VL	0.00	0.10	0.25
				SC1.2	0.48	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00
		SC2	0.2	SC2.1	0.15	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00
				SC2.2	0.06	H	0.55	0.70	0.85	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	H	0.55	0.70	0.85	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00
				SC2.3	0.17	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	M	0.35	0.50	0.65
				SC2.4	0.51	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45
				SC2.5	0.11	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	M	0.35	0.50	0.65
		SC3	0.19	SC3.1	0.28	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	M	0.35	0.50	0.65
				SC3.2	0.16	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85
				SC3.3	0.34	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65	H	0.55	0.70	0.85
				SC3.4	0.22	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VL	0.00	0.10	0.25
		SC4	0.31	SC4.1	0.53	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85
				SC4.2	0.12	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	M	0.35	0.50	0.65	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65
				SC4.3	0.35	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65
		SC5	0.14	SC5.1	0.43	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	H	0.55	0.70	0.85
				SC5.2	0.57	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00
ENV	0.32	ENV1	0.19	ENV1.1	0.41	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45	M	0.35	0.50	0.65
				ENV1.2	0.59	L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	H	0.55	0.70	0.85
		ENV2	0.12	ENV2.1	0.54	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	M	0.35	0.50	0.65
				ENV2.2	0.46	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25
		ENV3	0.41	ENV3.1	0.52	L	0.15	0.30	0.45	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	L	0.15	0.30	0.45
				ENV3.2	0.48	M	0.35	0.50	0.65	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65
		ENV4	0.18	ENV4.1	0.2	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25
				ENV4.2	0.25	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25
				ENV4.3	0.17	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00
				ENV4.4	0.18	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	L	0.15	0.30	0.45	M	0.35	0.50	0.65
				ENV4.5	0.2	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	M	0.35	0.50	0.65	M	0.35	0.50	0.65
		ENV5	0.1		0.1	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45

Figure Appendix 4-1 The summary of fuzzy numbers evaluation matrix for the ranking Tier 1 suppliers

T2.1	l	m	u	T2.2	l	m	u	T2.3	l	m	u	T2.4	l	m	u	T2.5	l	m	u	T2.6	l	m	u	T2.7	l	m	u	T2.8	l	m	u	T2.9	l	m	u	T2.10	l	m	u
M	0.35	0.50	0.65	H	0.55	0.70	0.85	L	0.15	0.30	0.45	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	L	0.15	0.30	0.45
VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85
VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	H	0.55	0.70	0.85
L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25
L	0.15	0.30	0.45	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45	L	0.15	0.30	0.45	L	0.15	0.30	0.45	L	0.15	0.30	0.45
M	0.35	0.50	0.65	H	0.55	0.70	0.85	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VL	0.00	0.10	0.25
VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00
VL	0.00	0.10	0.25	H	0.55	0.70	0.85	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VL	0.00	0.10	0.25
M	0.35	0.50	0.65	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	M	0.35	0.50	0.65
VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	M	0.35	0.50	0.65	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	L	0.15	0.30	0.45
H	0.55	0.70	0.85	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25
VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25
VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	M	0.35	0.50	0.65	L	0.15	0.30	0.45	L	0.15	0.30	0.45
VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	M	0.35	0.50	0.65	H	0.55	0.70	0.85	H	0.55	0.70	0.85	VL	0.00	0.10	0.25
VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VL	0.00	0.10	0.25
L	0.15	0.30	0.45	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	L	0.15	0.30	0.45	VL	0.00	0.10	0.25
VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	H	0.55	0.70	0.85	M	0.35	0.50	0.65	M	0.35	0.50	0.65	M	0.35	0.50	0.65	H	0.55	0.70	0.85
VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00
VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	M	0.35	0.50	0.65
VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VL	0.00	0.10	0.25
VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00
M	0.35	0.50	0.65	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00
H	0.55	0.70	0.85	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	H	0.55	0.70	0.85	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00
M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	M	0.35	0.50	0.65
H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45
H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	M	0.35	0.50	0.65
H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	M	0.35	0.50	0.65
VH	0.75	0.90	1.00	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85
M	0.35	0.50	0.65	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65	L	0.15	0.30	0.45	M	0.35	0.50	0.65	H	0.55	0.70	0.85
VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VL	0.00	0.10	0.25
M	0.35	0.50	0.65	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	L	0.15	0.30	0.45	H	0.55	0.70	0.85
VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	M	0.35	0.50	0.65	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65
VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65
M	0.35	0.50	0.65	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	H	0.55	0.70	0.85
H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00
H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45	M	0.35	0.50	0.65
L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	H	0.55	0.70	0.85
VH	0.75	0.90	1.00	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	M	0.35	0.50	0.65
L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25
L	0.15	0.30	0.45	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	L	0.15	0.30	0.45
M	0.35	0.50	0.65	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VL	0.00	0.10	0.25	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	L	0.15	0.30	0.45	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65
VH	0.75	0.90	1.00	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	M	0.35	0.50	0.65	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25
M	0.35	0.50	0.65	VH	0.75	0.90	1.00	M	0.35	0.50	0.65	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	VL	0.00	0.10	0.25
L	0.15	0.30	0.45	M	0.35	0.50	0.65	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	M	0.35	0.50	0.65	VL	0.00	0.10	0.25	L	0.15	0.30	0.45	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	VH	0.75	0.90	1.00
H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	VH	0.75	0.90	1.00	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	L	0.15	0.30	0.45	M	0.35	0.50	0.65
VH	0.75	0.90	1.00	L	0.15	0.30	0.45	H	0.55	0.70	0.85	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	M	0.35	0.50	0.65	H	0.55	0.70	0.85	M	0.35	0.50	0.65	M	0.35	0.50	0.65
H	0.55	0.70	0.85	VL	0.00	0.10	0.25	H	0.55	0.70	0.85	H	0.55	0.70	0.85	M	0.35	0.50	0.65	L	0.15	0.30	0.45	VH	0.75	0.90	1.00	H	0.55	0.70	0.85	H	0.55	0.70	0.85	L	0.15	0.30	0.45

Figure Appendix 4-2 The summary of fuzzy numbers evaluation matrix for the ranking Tier 2 suppliers

					neg -	pos +	Dneg -										Dpos+									
Criteria	Weight	sub-criteri	Weight	sub-criteri	Min	Max	T1.1	T1.2	T1.3	T1.4	T1.5	T1.6	T1.7	T1.8	T1.9	T1.10	T1.1	T1.2	T1.3	T1.4	T1.5	T1.6	T1.7	T1.8	T1.9	T1.10
EC	0.41	EC1	0.36	EC1.1	0	0.08	0.131291	0.095107	0.028721	0.095107	0.095107	0.059867	0.131291	0.164298	0.164298	0.164298	0.086163	0.051433	0.031098	0.051433	0.051433	0.02444	0.086163	0.118539	0.118539	0.118539
				EC1.2	0	0.0425	0.031804	0.015258	0.015258	0.031804	0.015258	0.069748	0.031804	0.087283	0.015258	0.069748	0.012984	0.016521	0.016521	0.012984	0.016521	0.045774	0.012984	0.062974	0.016521	0.045774
				EC1.3	0	0.0375	0.077015	0.077015	0.061543	0.044581	0.077015	0.061543	0.077015	0.061543	0.077015	0.044581	0.055565	0.055565	0.040389	0.024109	0.055565	0.040389	0.055565	0.040389	0.055565	0.024109
				EC1.4	0	0.05	0.017951	0.017951	0.082057	0.059442	0.037417	0.017951	0.037417	0.102686	0.102686	0.082057	0.019437	0.019437	0.053852	0.032146	0.015275	0.019437	0.015275	0.074087	0.074087	0.053852
				EC1.5	0	0.04	0.082149	0.082149	0.065646	0.029933	0.029933	0.029933	0.029933	0.029933	0.082149	0.029933	0.05927	0.05927	0.043081	0.01222	0.01222	0.01222	0.01222	0.01222	0.05927	0.01222
		EC2	0.27	EC2.1	0	0.0375	0.028062	0.061543	0.044581	0.028062	0.044581	0.013463	0.061543	0.013463	0.013463	0.044581	0.011456	0.040389	0.024109	0.011456	0.024109	0.014577	0.040389	0.014577	0.014577	0.024109
				EC2.2	0	0.0775	0.027823	0.027823	0.057996	0.127188	0.159164	0.159164	0.159164	0.057996	0.127188	0.159164	0.030127	0.030127	0.023677	0.08347	0.114835	0.114835	0.114835	0.023677	0.08347	0.114835
				EC2.3	0	0.06	0.098468	0.098468	0.021541	0.021541	0.021541	0.021541	0.0449	0.098468	0.07133	0.098468	0.064622	0.064622	0.023324	0.023324	0.023324	0.023324	0.01833	0.064622	0.038575	0.064622
				EC2.4	0	0.045	0.053498	0.092418	0.033675	0.092418	0.053498	0.053498	0.016155	0.016155	0.016155	0.053498	0.028931	0.066678	0.013748	0.066678	0.028931	0.028931	0.017493	0.017493	0.017493	0.028931
				EC2.5	0	0.03	0.061612	0.035665	0.02245	0.049234	0.061612	0.02245	0.035665	0.01077	0.061612	0.02245	0.044452	0.019287	0.009165	0.032311	0.044452	0.009165	0.019287	0.011662	0.044452	0.009165
		EC3	0.17	EC3.1	0	0.1	0.205372	0.205372	0.074833	0.035901	0.164114	0.035901	0.035901	0.164114	0.164114	0.074833	0.148174	0.148174	0.030551	0.038873	0.107703	0.038873	0.038873	0.107703	0.107703	0.030551
				EC3.2	0	0.05	0.017951	0.102686	0.037417	0.102686	0.102686	0.017951	0.037417	0.102686	0.037417	0.082057	0.019437	0.074087	0.015275	0.074087	0.074087	0.019437	0.015275	0.074087	0.015275	0.053852
				EC3.3	0	0.0425	0.015258	0.031804	0.015258	0.031804	0.015258	0.031804	0.031804	0.050526	0.069748	0.031804	0.016521	0.012984	0.016521	0.012984	0.016521	0.012984	0.012984	0.027324	0.045774	0.012984
				EC3.4	0	0.0325	0.038637	0.038637	0.024321	0.011668	0.066746	0.011668	0.053337	0.053337	0.038637	0.038637	0.020895	0.020895	0.009929	0.012634	0.048157	0.012634	0.035004	0.035004	0.020895	0.020895
				EC3.5	0	0.025	0.008975	0.029721	0.051343	0.018708	0.051343	0.008975	0.029721	0.041028	0.029721	0.008975	0.009718	0.016073	0.037044	0.007638	0.037044	0.009718	0.016073	0.026926	0.016073	0.009718
		EC4	0.2	EC4.1	0	0.0775	0.092135	0.057996	0.057996	0.092135	0.057996	0.027823	0.057996	0.057996	0.092135	0.092135	0.049826	0.023677	0.023677	0.049826	0.023677	0.030127	0.023677	0.023677	0.049826	0.049826
				EC4.2	0	0.04	0.01436	0.082149	0.065646	0.047553	0.01436	0.065646	0.047553	0.047553	0.065646	0.047553	0.015549	0.05927	0.043081	0.025716	0.015549	0.043081	0.025716	0.025716	0.043081	0.025716
				EC4.3	0	0.065	0.077274	0.077274	0.023336	0.048642	0.133492	0.133492	0.106674	0.048642	0.048642	0.077274	0.041789	0.041789	0.025267	0.019858	0.096313	0.096313	0.070007	0.019858	0.019858	0.041789
				EC4.4	0.0405	0.1215	0.057804	0.057804	0.115432	0.057804	0.115432	0.057804	0.057804	0.115432	0.057804	0.057804	0.020622	0.020622	0.069423	0.020622	0.069423	0.020622	0.020622	0.069423	0.020622	0.020622
SC	0.27	SC1	0.16	SC1.1	0	0.13	0.097283	0.213348	0.266984	0.213348	0.266984	0.046671	0.097283	0.213348	0.097283	0.097283	0.039716	0.140014	0.192626	0.140014	0.192626	0.050535	0.039716	0.140014	0.039716	0.039716
				SC1.2	0	0.12	0.196937	0.0898	0.246447	0.0898	0.246447	0.246447	0.043081	0.246447	0.043081	0.196937	0.129244	0.036661	0.177809	0.036661	0.177809	0.177809	0.046648	0.177809	0.046648	0.129244
		SC2	0.2	SC2.1	0	0.0375	0.028062	0.077015	0.044581	0.077015	0.044581	0.077015	0.044581	0.061543	0.044581	0.028062	0.011456	0.055565	0.024109	0.055565	0.024109	0.055565	0.024109	0.040389	0.024109	0.011456
				SC2.2	0	0.015	0.011225	0.005385	0.024617	0.005385	0.024617	0.030806	0.005385	0.017833	0.005385	0.011225	0.004583	0.005831	0.016155	0.005831	0.016155	0.022226	0.005831	0.009644	0.005831	0.004583
				SC2.3	0	0.0425	0.050526	0.069748	0.050526	0.069748	0.050526	0.050526	0.050526	0.015258	0.050526	0.050526	0.027324	0.045774	0.027324	0.045774	0.027324	0.027324	0.027324	0.016521	0.027324	0.027324
				SC2.4	0	0.1275	0.209245	0.095412	0.209245	0.095412	0.209245	0.095412	0.26185	0.151577	0.26185	0.209245	0.137322	0.038952	0.137322	0.038952	0.137322	0.038952	0.188922	0.081971	0.188922	0.137322
				SC2.5	0	0.0275	0.056477	0.045131	0.045131	0.045131	0.045131	0.032693	0.032693	0.009873	0.032693	0.056477	0.040748	0.029618	0.029618	0.029618	0.029618	0.01768	0.01768	0.01069	0.01768	0.040748
		SC3	0.19	SC3.1	0.042	0.126	0.09109	0.09109	0.09109	0.09109	0.09109	0.059944	0.119707	0.031305	0.119707	0.09109	0.045004	0.045004	0.045004	0.045004	0.045004	0.021385	0.071994	0.031305	0.071994	0.045004
				SC3.2	0	0.04	0.029933	0.01436	0.082149	0.01436	0.082149	0.065646	0.029933	0.029933	0.029933	0.029933	0.01222	0.015549	0.05927	0.015549	0.05927	0.043081	0.01222	0.01222	0.01222	0.01222
				SC3.3	0.051	0.153	0.07279	0.145359	0.07279	0.145359	0.07279	0.110609	0.07279	0.038013	0.07279	0.07279	0.025968	0.087421	0.025968	0.087421	0.025968	0.054647	0.025968	0.038013	0.025968	0.025968
				SC3.4	0	0.055	0.090263	0.090263	0.019746	0.090263	0.019746	0.019746	0.065386	0.090263	0.065386	0.090263	0.059237	0.059237	0.02138	0.059237	0.02138	0.02138	0.03536	0.059237	0.03536	0.059237
		SC4	0.31	SC4.1	0	0.1325	0.047569	0.217451	0.157521	0.217451	0.157521	0.217451	0.099154	0.157521	0.099154	0.047569	0.051507	0.142707	0.085186	0.142707	0.085186	0.142707	0.040479	0.085186	0.040479	0.051507
				SC4.2	0	0.03	0.035665	0.02245	0.061612	0.02245	0.061612	0.035665	0.049234	0.061612	0.049234	0.035665	0.019287	0.009165	0.044452	0.009165	0.044452	0.019287	0.032311	0.044452	0.032311	0.019287
				SC4.3	0	0.0875	0.031413	0.065479	0.179701	0.065479	0.179701	0.104023	0.1436	0.179701	0.1436	0.031413	0.034014	0.026732	0.129652	0.026732	0.129652	0.056255	0.09424	0.129652	0.09424	0.034014
		SC5	0.14	SC5.1	0	0.1075	0.176422	0.1278	0.1278	0.1278	0.1278	0.176422	0.220775	0.1278	0.220775	0.176422	0.115781	0.069113	0.069113	0.069113	0.069113	0.115781	0.159287	0.069113	0.159287	0.115781
				SC5.2	0	0.1425	0.051159	0.292656	0.233862	0.292656	0.233862	0.292656	0.233862	0.051159	0.233862	0.051159	0.055394	0.211148	0.153477	0.211148	0.153477	0.211148	0.153477	0.055394	0.153477	0.055394
ENV	0.32	ENV1	0.19	ENV1.1	0	0.1025	0.168217	0.036799	0.168217	0.036799	0.168217	0.121856	0.076704	0.168217	0.076704	0.168217	0.110396	0.039845	0.110396	0.039845	0.110396	0.065898	0.031314	0.110396	0.031314	0.110396
				ENV1.2	0.0885	0.2655	0.191939	0.25224	0.065964	0.25224	0.065964	0.191939	0.25224	0.191939	0.25224	0.191939	0.094829	0.151701	0.065964	0.151701	0.065964	0.094829	0.151701	0.094829	0.151701	0.094829
		ENV2	0.12	ENV2.1	0	0.135	0.101025	0.048466	0.277253	0.048466	0.277253	0.160493	0.101025	0.277253	0.101025	0.101025	0.041243	0.052479	0.200035	0.052479	0.200035	0.086793	0.041243	0.200035	0.041243	0.041243
				ENV2.2	0	0.115	0.236178	0.086058	0.086058	0.086058	0.086058	0.041286	0.041286	0.086058	0.041286	0.236178	0.1704	0.035133	0.035133	0.035133	0.035133	0.044704	0.044704	0.035133	0.044704	0.1704
		ENV3	0.41	ENV3.1	0	0.13	0.097283	0.046671	0.097283	0.046671	0.097283	0.097283	0.097283	0.266984	0.097283	0.097283	0.039716	0.050535	0.039716	0.050535	0.039716	0.039716	0.039716	0.192626	0.039716	0.039716
				ENV3.2	0	0.12	0.0898	0.043081	0.14266	0.043081	0.14266	0.14266	0.196937	0.196937	0.196937	0.0898	0.036661	0.046648	0.077149	0.046648	0.077149	0.077149	0.129244	0.129244	0.129244	0.036661
		ENV4	0.18	ENV4.1	0	0.05	0.037417	0.059442	0.102686	0.059442	0.102686	0.017951	0.102686	0.082057	0.102686	0.037417	0.015275	0.032146	0.074087	0.032146	0.074087	0.019437	0.074087	0.053852	0.074087	0.015275
				ENV4.2	0	0.0625	0.128358	0.102571	0.074302	0.102571	0.074302	0.022438	0.128358	0.046771	0.128358	0.128358	0.092609	0.067315	0.040182	0.067315	0.040182	0.024296	0.092609	0.019094	0.092609	0.092609
				ENV4.3	0	0.0425	0.031804	0.031804	0.031804	0.031804	0.031804	0.087283	0.087283	0.069748	0.087283	0.031804	0.012984	0.012984	0.012984	0.012984	0.012984	0.062974	0.062974	0.045774	0.062974	0.012984
				ENV4.4	0.027	0.081	0.076955	0.058558	0.058558	0.058558	0.058558	0.038536	0.020125	0.058558	0.020125	0.076955	0.046282	0.028931	0.028931	0.028931	0.028931	0.013748	0.020125	0.028931	0.020125	0.046282
				ENV4.5	0.03	0.09	0.042817	0.022361	0.085505	0.022361	0.085505	0.042817	0.042817	0.065064	0.042817	0.042817	0.015275	0.022361	0.051424	0.022361	0.051424	0.015275	0.015275	0.032146	0.015275	0.015275
		ENV5	0.1	ENV5	0	0.025	0.051343	0.041028	0.041028	0.041028	0.041028	0.018708	0.041028	0.041028	0.041028	0.051343	0.037044	0.026926	0.026926	0.026926	0.026926	0.007638	0.026926	0.026926	0.026926	0.037044
							3.666633	3.778665	4.044166	3.518037	4.46167	3.545201	3.840705	4.357706	4.092628	3.809045	2.277053	2.42639	2.551123	2.19786	2.87653	2.245099	2.356256	2.820552	2.567139	2.283625

Figure Appendix 4-3 The Euclidian distances between each of Tier 1 and the FPIS and FNIS solution

					neg -	pos +	Dneg -										Dpos+									
Criteria	Weight	sub-criteri	Weight	sub-criteri	Min	Max	T2.1	T2.2	T2.3	T2.4	T2.5	T2.6	T2.7	T2.8	T2.9	T2.10	T2.1	T2.2	T2.3	T2.4	T2.5	T2.6	T2.7	T2.8	T2.9	T2.10
EC	0.41	EC1	0.36	EC1.1	0	0.08	0.164298	0.028721	0.131291	0.131291	0.131291	0.059867	0.059867	0.131291	0.059867	0.164298	0.118539	0.031098	0.086163	0.086163	0.086163	0.02444	0.02444	0.086163	0.02444	0.118539
				EC1.2	0	0.0425	0.069748	0.031804	0.031804	0.087283	0.031804	0.087283	0.015258	0.087283	0.050526	0.069748	0.045774	0.012984	0.012984	0.062974	0.012984	0.062974	0.016521	0.062974	0.027324	0.045774
				EC1.3	0	0.0375	0.044581	0.013463	0.061543	0.028062	0.061543	0.013463	0.044581	0.077015	0.077015	0.044581	0.024109	0.014577	0.040389	0.011456	0.040389	0.014577	0.024109	0.055565	0.055565	0.024109
				EC1.4	0	0.05	0.059442	0.017951	0.017951	0.102686	0.017951	0.102686	0.059442	0.059442	0.102686	0.017951	0.032146	0.019437	0.019437	0.074087	0.019437	0.074087	0.032146	0.032146	0.074087	0.019437
				EC1.5	0	0.04	0.029933	0.065646	0.082149	0.029933	0.065646	0.047553	0.029933	0.047553	0.047553	0.01436	0.01222	0.043081	0.05927	0.01222	0.043081	0.025716	0.01222	0.025716	0.025716	0.015549
		EC2	0.27	EC2.1	0	0.0375	0.028062	0.028062	0.028062	0.061543	0.028062	0.028062	0.061543	0.028062	0.077015	0.077015	0.011456	0.011456	0.011456	0.040389	0.011456	0.011456	0.040389	0.011456	0.055565	0.055565
				EC2.2	0	0.0775	0.057996	0.027823	0.159164	0.027823	0.027823	0.127188	0.057996	0.092135	0.057996	0.057996	0.023677	0.030127	0.114835	0.030127	0.030127	0.08347	0.023677	0.049826	0.023677	0.023677
				EC2.3	0	0.06	0.098468	0.0449	0.021541	0.098468	0.0449	0.0449	0.07133	0.098468	0.098468	0.123223	0.064622	0.01833	0.023324	0.064622	0.01833	0.01833	0.038575	0.064622	0.064622	0.088904
				EC2.4	0	0.045	0.053498	0.053498	0.092418	0.073851	0.092418	0.016155	0.053498	0.016155	0.033675	0.033675	0.028931	0.028931	0.066678	0.048466	0.066678	0.017493	0.028931	0.017493	0.013748	0.013748
				EC2.5	0	0.03	0.049234	0.061612	0.061612	0.01077	0.02245	0.035665	0.049234	0.061612	0.035665	0.061612	0.032311	0.044452	0.044452	0.011662	0.009165	0.019287	0.032311	0.044452	0.019287	0.044452
		EC3	0.17	EC3.1	0	0.1	0.035901	0.035901	0.205372	0.205372	0.074833	0.118884	0.035901	0.035901	0.164114	0.205372	0.038873	0.038873	0.148174	0.148174	0.030551	0.064291	0.038873	0.038873	0.107703	0.148174
				EC3.2	0	0.05	0.082057	0.037417	0.017951	0.059442	0.102686	0.102686	0.037417	0.082057	0.082057	0.082057	0.053852	0.015275	0.019437	0.032146	0.074087	0.074087	0.015275	0.053852	0.053852	0.053852
				EC3.3	0	0.0425	0.031804	0.015258	0.015258	0.069748	0.031804	0.015258	0.069748	0.015258	0.015258	0.069748	0.012984	0.016521	0.016521	0.045774	0.012984	0.016521	0.045774	0.016521	0.016521	0.045774
				EC3.4	0	0.0325	0.053337	0.024321	0.053337	0.024321	0.066746	0.053337	0.066746	0.053337	0.053337	0.066746	0.035004	0.009929	0.035004	0.009929	0.048157	0.035004	0.048157	0.035004	0.035004	0.048157
				EC3.5	0	0.025	0.029721	0.041028	0.008975	0.041028	0.018708	0.051343	0.018708	0.018708	0.008975	0.051343	0.016073	0.026926	0.009718	0.026926	0.007638	0.037044	0.007638	0.007638	0.009718	0.037044
		EC4	0.2	EC4.1	0	0.0775	0.127188	0.159164	0.027823	0.092135	0.127188	0.027823	0.092135	0.057996	0.127188	0.027823	0.08347	0.114835	0.030127	0.049826	0.08347	0.030127	0.049826	0.023677	0.08347	0.030127
				EC4.2	0	0.04	0.047553	0.065646	0.065646	0.065646	0.047553	0.065646	0.01436	0.01436	0.047553	0.047553	0.025716	0.043081	0.043081	0.043081	0.025716	0.043081	0.015549	0.015549	0.025716	0.025716
				EC4.3	0	0.065	0.023336	0.048642	0.023336	0.077274	0.133492	0.023336	0.077274	0.133492	0.048642	0.077274	0.025267	0.019858	0.025267	0.041789	0.096313	0.025267	0.041789	0.096313	0.019858	0.041789
				EC4.4	0.0405	0.1215	0.057804	0.057804	0.030187	0.057804	0.030187	0.030187	0.115432	0.030187	0.057804	0.057804	0.020622	0.020622	0.030187	0.020622	0.030187	0.030187	0.069423	0.030187	0.020622	0.020622
SC	0.27	SC1	0.16	SC1.1	0	0.13	0.097283	0.266984	0.046671	0.097283	0.046671	0.046671	0.213348	0.046671	0.266984	0.046671	0.039716	0.192626	0.050535	0.039716	0.050535	0.050535	0.140014	0.050535	0.192626	0.050535
				SC1.2	0	0.12	0.246447	0.043081	0.14266	0.246447	0.196937	0.14266	0.246447	0.196937	0.043081	0.246447	0.177809	0.046648	0.077149	0.177809	0.129244	0.077149	0.177809	0.129244	0.046648	0.177809
		SC2	0.2	SC2.1	0	0.0375	0.013463	0.061543	0.013463	0.013463	0.028062	0.013463	0.061543	0.028062	0.061543	0.077015	0.014577	0.040389	0.014577	0.014577	0.011456	0.014577	0.040389	0.011456	0.040389	0.055565
				SC2.2	0	0.015	0.024617	0.024617	0.030806	0.024617	0.017833	0.030806	0.017833	0.017833	0.024617	0.030806	0.016155	0.016155	0.022226	0.016155	0.009644	0.022226	0.009644	0.009644	0.016155	0.022226
				SC2.3	0	0.0425	0.087283	0.087283	0.087283	0.087283	0.050526	0.087283	0.015258	0.050526	0.087283	0.050526	0.062974	0.062974	0.062974	0.062974	0.027324	0.062974	0.016521	0.027324	0.062974	0.027324
				SC2.4	0	0.1275	0.045774	0.209245	0.26185	0.045774	0.209245	0.26185	0.151577	0.209245	0.209245	0.095412	0.049563	0.137322	0.188922	0.049563	0.137322	0.188922	0.081971	0.137322	0.137322	0.038952
				SC2.5	0	0.0275	0.020579	0.056477	0.056477	0.020579	0.032693	0.056477	0.009873	0.032693	0.056477	0.032693	0.008401	0.040748	0.040748	0.008401	0.01768	0.040748	0.01069	0.01768	0.040748	0.01768
		SC3	0.19	SC3.1	0.042	0.126	0.119707	0.031305	0.119707	0.119707	0.09109	0.119707	0.031305	0.09109	0.031305	0.059944	0.071994	0.031305	0.071994	0.071994	0.045004	0.071994	0.031305	0.045004	0.031305	0.021385
				SC3.2	0	0.04	0.047553	0.082149	0.065646	0.047553	0.047553	0.065646	0.029933	0.047553	0.082149	0.065646	0.025716	0.05927	0.043081	0.025716	0.025716	0.043081	0.01222	0.025716	0.05927	0.043081
				SC3.3	0.051	0.153	0.145359	0.038013	0.110609	0.145359	0.07279	0.110609	0.038013	0.07279	0.038013	0.110609	0.087421	0.038013	0.054647	0.087421	0.025968	0.054647	0.038013	0.025968	0.038013	0.054647
				SC3.4	0	0.055	0.112955	0.041158	0.090263	0.112955	0.065386	0.090263	0.090263	0.065386	0.041158	0.019746	0.081496	0.016803	0.059237	0.081496	0.03536	0.059237	0.059237	0.03536	0.016803	0.02138
		SC4	0.31	SC4.1	0	0.1325	0.157521	0.047569	0.047569	0.157521	0.272118	0.047569	0.157521	0.272118	0.047569	0.217451	0.085186	0.051507	0.051507	0.085186	0.196331	0.051507	0.085186	0.196331	0.051507	0.142707
				SC4.2	0	0.03	0.049234	0.035665	0.01077	0.049234	0.035665	0.01077	0.061612	0.035665	0.035665	0.035665	0.032311	0.019287	0.011662	0.032311	0.019287	0.011662	0.044452	0.019287	0.019287	0.019287
				SC4.3	0	0.0875	0.065479	0.179701	0.031413	0.065479	0.179701	0.031413	0.179701	0.179701	0.179701	0.104023	0.026732	0.129652	0.034014	0.026732	0.129652	0.034014	0.129652	0.129652	0.129652	0.056255
		SC5	0.14	SC5.1	0	0.1075	0.220775	0.080446	0.220775	0.220775	0.038594	0.220775	0.1278	0.038594	0.080446	0.176422	0.159287	0.032842	0.159287	0.159287	0.041788	0.159287	0.069113	0.041788	0.032842	0.115781
				SC5.2	0	0.1425	0.051159	0.292656	0.292656	0.051159	0.233862	0.292656	0.051159	0.233862	0.292656	0.292656	0.055394	0.211148	0.211148	0.055394	0.153477	0.211148	0.055394	0.153477	0.211148	0.211148
ENV	0.32	ENV1	0.19	ENV1.1	0	0.1025	0.036799	0.168217	0.210507	0.036799	0.036799	0.210507	0.168217	0.036799	0.168217	0.121856	0.039845	0.110396	0.151878	0.039845	0.039845	0.151878	0.110396	0.039845	0.110396	0.065898
				ENV1.2	0.0885	0.2655	0.065964	0.25224	0.191939	0.065964	0.25224	0.191939	0.191939	0.25224	0.25224	0.191939	0.065964	0.151701	0.094829	0.065964	0.151701	0.094829	0.094829	0.151701	0.151701	0.094829
		ENV2	0.12	ENV2.1	0	0.135	0.221554	0.221554	0.048466	0.221554	0.221554	0.048466	0.277253	0.221554	0.221554	0.160493	0.145399	0.145399	0.052479	0.145399	0.145399	0.052479	0.200035	0.145399	0.145399	0.086793
				ENV2.2	0	0.115	0.041286	0.188731	0.236178	0.041286	0.041286	0.236178	0.086058	0.041286	0.188731	0.041286	0.044704	0.123859	0.1704	0.044704	0.044704	0.1704	0.035133	0.044704	0.123859	0.044704
		ENV3	0.41	ENV3.1	0	0.13	0.097283	0.266984	0.266984	0.097283	0.213348	0.266984	0.266984	0.213348	0.266984	0.097283	0.039716	0.192626	0.192626	0.039716	0.140014	0.192626	0.192626	0.140014	0.192626	0.039716
				ENV3.2	0	0.12	0.14266	0.0898	0.196937	0.14266	0.043081	0.196937	0.196937	0.043081	0.0898	0.14266	0.077149	0.036661	0.129244	0.077149	0.046648	0.129244	0.129244	0.046648	0.036661	0.077149
		ENV4	0.18	ENV4.1	0	0.05	0.059442	0.017951	0.017951	0.059442	0.059442	0.017951	0.082057	0.059442	0.017951	0.017951	0.032146	0.019437	0.019437	0.032146	0.032146	0.019437	0.053852	0.032146	0.019437	0.019437
				ENV4.2	0	0.0625	0.128358	0.102571	0.074302	0.128358	0.074302	0.074302	0.046771	0.074302	0.102571	0.022438	0.092609	0.067315	0.040182	0.092609	0.040182	0.040182	0.019094	0.040182	0.067315	0.024296
				ENV4.3	0	0.0425	0.050526	0.015258	0.087283	0.050526	0.050526	0.087283	0.069748	0.050526	0.015258	0.087283	0.027324	0.016521	0.062974	0.027324	0.027324	0.062974	0.045774	0.027324	0.016521	0.062974
				ENV4.4	0.027	0.081	0.058558	0.020125	0.038536	0.058558	0.076955	0.038536	0.058558	0.076955	0.020125	0.038536	0.028931	0.020125	0.013748	0.028931	0.046282	0.013748	0.028931	0.046282	0.020125	0.013748
				ENV4.5	0.03	0.09	0.022361	0.065064	0.065064	0.022361	0.085505	0.065064	0.065064	0.085505	0.065064	0.042817	0.022361	0.032146	0.032146	0.022361	0.051424	0.032146	0.032146	0.051424	0.032146	0.015275
		ENV5	0.1	ENV5	0	0.025	0.008975	0.018708	0.041028	0.008975	0.029721	0.041028	0.041028	0.029721	0.018708	0.018708	0.009718	0.007638	0.026926	0.009718	0.016073	0.026926	0.026926	0.016073	0.007638	0.007638
							3.582915	3.863751	4.239211	3.783435	3.960568	4.155116	4.0642	3.943796	4.250486	3.995162	2.326243	2.610904	2.977079	2.481029	2.584442	2.848017	2.576216	2.605555	2.807006	2.529227

Figure Appendix 4-4 The Euclidian distances between each of Tier 2 and the FPIS and FNIS solution

Appendix 5 Sensitivity analysis results

- Fuzzy TOPSIS

EC1.1	0.32			
	wp+deltap	w'p	1-w'p/1-wp	w'j = 1-w'p / 1-wp*wj
	0	0.320	1.000	
	20%	0.384	0.906	
	40%	0.448	0.812	
	60%	0.512	0.718	
	80%	0.576	0.624	
	100%	0.640	0.529	

wj		1	0.905882353	0.811764706	0.717647059	0.623529412	0.529411765
		EC 1.1+0%	EC 1.1+20%	EC 1.1+40%	EC 1.1+60%	EC 1.1+80%	EC 1.1+100%
EC'	1.1	0.320	0.384	0.448	0.512	0.576	0.640
EC'	2.2	0.310	0.281	0.252	0.222	0.193	0.164
EC'	3.1	0.400	0.362	0.325	0.287	0.249	0.212
EC'	4.1	0.310	0.281	0.252	0.222	0.193	0.164
SC'	1.1	0.520	0.471	0.422	0.373	0.324	0.275
SC'	2.4	0.510	0.462	0.414	0.366	0.318	0.270
SC'	3.3	0.340	0.308	0.276	0.244	0.212	0.180
SC'	4.1	0.530	0.480	0.430	0.380	0.330	0.281
SC'	5.2	0.570	0.516	0.463	0.409	0.355	0.302
ENV'	1.2	0.590	0.534	0.479	0.423	0.368	0.312
ENV'	2.1	0.150	0.136	0.122	0.108	0.094	0.079
ENV'	3.1	0.280	0.254	0.227	0.201	0.175	0.148
ENV'	4.2	0.120	0.109	0.097	0.086	0.075	0.064

EC2.2	0.310			
	wp+deltap	w'p	1-w'p/1-wp	w'j = 1-w'p / 1-wp*wj
	0	0.310	1.000	
	20%	0.372	0.910	
	40%	0.434	0.820	
	60%	0.496	0.730	
	80%	0.558	0.641	
	100%	0.620	0.551	

wj		1	0.910144928	0.820289855	0.730434783	0.64057971	0.550724638
		EC 2.2+0%	EC 2.2+20%	EC 2.2+40%	EC 2.2+60%	EC 2.2+80%	EC 2.2+100%
EC'	1.1	0.320	0.291	0.262	0.234	0.205	0.176
EC'	2.2	0.310	0.372	0.434	0.496	0.558	0.620
EC'	3.1	0.400	0.364	0.328	0.292	0.256	0.220
EC'	4.1	0.310	0.282	0.254	0.226	0.199	0.171
SC'	1.1	0.520	0.473	0.427	0.380	0.333	0.286
SC'	2.4	0.510	0.464	0.418	0.373	0.327	0.281
SC'	3.3	0.340	0.309	0.279	0.248	0.218	0.187
SC'	4.1	0.530	0.482	0.435	0.387	0.340	0.292
SC'	5.2	0.570	0.519	0.468	0.416	0.365	0.314
ENV'	1.2	0.590	0.537	0.484	0.431	0.378	0.325
ENV'	2.1	0.150	0.137	0.123	0.110	0.096	0.083
ENV'	3.1	0.280	0.255	0.230	0.205	0.179	0.154
ENV'	4.2	0.120	0.109	0.098	0.088	0.077	0.066

EC3.1	0.400			
	wp+deltap	w'p	1-w'p/1-wp	w'j = 1-w'p / 1-wp*wj
	0	0.400	1.000	
	20%	0.480	0.867	
	40%	0.560	0.733	
	60%	0.640	0.600	
	80%	0.720	0.467	
	100%	0.800	0.333	

wj		1	0.866666667	0.733333333	0.6	0.466666667	0.333333333
		EC 3.1+0%	EC 3.1+20%	EC 3.1+40%	EC 3.1+60%	EC 3.1+80%	EC 3.1+100%
EC'	1.1	0.320	0.277	0.235	0.192	0.149	0.107
EC'	2.2	0.310	0.269	0.227	0.186	0.145	0.103
EC'	3.1	0.400	0.480	0.560	0.640	0.720	0.800
EC'	4.1	0.310	0.269	0.227	0.186	0.145	0.103
SC'	1.1	0.520	0.451	0.381	0.312	0.243	0.173
SC'	2.4	0.510	0.442	0.374	0.306	0.238	0.170
SC'	3.3	0.340	0.295	0.249	0.204	0.159	0.113
SC'	4.1	0.530	0.459	0.389	0.318	0.247	0.177
SC'	5.2	0.570	0.494	0.418	0.342	0.266	0.190
ENV'	1.2	0.590	0.511	0.433	0.354	0.275	0.197
ENV'	2.1	0.150	0.130	0.110	0.090	0.070	0.050
ENV'	3.1	0.280	0.243	0.205	0.168	0.131	0.093
ENV'	4.2	0.120	0.104	0.088	0.072	0.056	0.040

EC4.1	0.310			
	wp+deltap	w'p	1-w'p/1-wp	w'j = 1-w'p / 1-wp*wj
	0	0.310	1.000	
	20%	0.372	0.910	
	40%	0.434	0.820	
	60%	0.496	0.730	
	80%	0.558	0.641	
	100%	0.620	0.551	

wj		1	0.910144928	0.820289855	0.730434783	0.64057971	0.550724638
		EC 4.1+0%	EC 4.1+20%	EC 4.1+40%	EC 4.1+60%	EC 4.1+80%	EC 4.1+100%
EC'	1.1	0.320	0.291	0.262	0.234	0.205	0.176
EC'	2.2	0.310	0.282	0.254	0.226	0.199	0.171
EC'	3.1	0.400	0.364	0.328	0.292	0.256	0.220
EC'	4.1	0.310	0.372	0.434	0.496	0.558	0.620
SC'	1.1	0.520	0.473	0.427	0.380	0.333	0.286
SC'	2.4	0.510	0.464	0.418	0.373	0.327	0.281
SC'	3.3	0.340	0.309	0.279	0.248	0.218	0.187
SC'	4.1	0.530	0.482	0.435	0.387	0.340	0.292
SC'	5.2	0.570	0.519	0.468	0.416	0.365	0.314
ENV'	1.2	0.590	0.537	0.484	0.431	0.378	0.325
ENV'	2.1	0.150	0.137	0.123	0.110	0.096	0.083
ENV'	3.1	0.280	0.255	0.230	0.205	0.179	0.154
ENV'	4.2	0.120	0.109	0.098	0.088	0.077	0.066

Figure Appendix 5-2 normalized weights of economic dimension in Sensitivity analysis

SC1.1	0.520				wj		1	0.783333	0.566667	0.35	0.133333	0.02083333
							SC	SC	SC	SC	SC	SC
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj			1.1+0%	1.1+20%	1.1+40%	1.1+60%	1.1+80%	1.1+100%
0		0.520	1	EC'		1.1	0.320	0.251	0.181	0.112	0.043	0.007
20%		0.624	0.783333	EC'		2.2	0.310	0.243	0.176	0.109	0.041	0.006
40%		0.728	0.566667	EC'		3.1	0.400	0.313	0.227	0.140	0.053	0.008
60%		0.832	0.35	EC'		4.1	0.310	0.243	0.176	0.109	0.041	0.006
80%		0.936	0.133333	SC'		1.1	0.520	0.624	0.728	0.832	0.936	1.040
100%		0.990	0.020833	SC'		2.4	0.510	0.400	0.289	0.179	0.068	0.011
				SC'		3.3	0.340	0.266	0.193	0.119	0.045	0.007
				SC'		4.1	0.530	0.415	0.300	0.186	0.071	0.011
				SC'		5.2	0.570	0.447	0.323	0.200	0.076	0.012
				ENV'		1.2	0.590	0.462	0.334	0.207	0.079	0.012
				ENV'		2.1	0.150	0.118	0.085	0.053	0.020	0.003
				ENV'		3.1	0.280	0.219	0.159	0.098	0.037	0.006
				ENV'		4.2	0.120	0.094	0.068	0.042	0.016	0.003

SC2.4	0.510				wj		1	0.791837	0.583673	0.37551	0.167347	0.01632653
							SC	SC	SC	SC	SC	SC
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj			2.4+0%	2.4+20%	2.4+40%	2.4+60%	2.4+80%	2.4+100%
0		0.510	1.000	EC'		1.1	0.320	0.253	0.187	0.120	0.054	0.005
20%		0.612	0.792	EC'		2.2	0.310	0.245	0.181	0.116	0.052	0.005
40%		0.714	0.584	EC'		3.1	0.400	0.317	0.233	0.150	0.067	0.007
60%		0.816	0.376	EC'		4.1	0.310	0.245	0.181	0.116	0.052	0.005
80%		0.918	0.167	SC'		1.1	0.520	0.412	0.304	0.195	0.087	0.008
100%		0.992	0.016	SC'		2.4	0.510	0.612	0.714	0.816	0.918	1.000
				SC'		3.3	0.340	0.269	0.198	0.128	0.057	0.006
				SC'		4.1	0.530	0.420	0.309	0.199	0.089	0.009
				SC'		5.2	0.570	0.451	0.333	0.214	0.095	0.009
				ENV'		1.2	0.590	0.467	0.344	0.222	0.099	0.010
				ENV'		2.1	0.150	0.119	0.088	0.056	0.025	0.002
				ENV'		3.1	0.280	0.222	0.163	0.105	0.047	0.005
				ENV'		4.2	0.120	0.095	0.070	0.045	0.020	0.002

SC3.3	0.340				wj		1	0.89697	0.793939	0.690909	0.587879	0.48484848
							SC	SC	SC	SC	SC	SC
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj			3.3+0%	3.3+20%	3.3+40%	3.3+60%	3.3+80%	3.3+100%
0		0.340	1.000	EC'		1.1	0.320	0.287	0.254	0.221	0.188	0.155
20%		0.408	0.897	EC'		2.2	0.310	0.278	0.246	0.214	0.182	0.150
40%		0.476	0.794	EC'		3.1	0.400	0.359	0.318	0.276	0.235	0.194
60%		0.544	0.691	EC'		4.1	0.310	0.278	0.246	0.214	0.182	0.150
80%		0.612	0.588	SC'		1.1	0.520	0.466	0.413	0.359	0.306	0.252
100%		0.680	0.485	SC'		2.4	0.510	0.457	0.405	0.352	0.300	0.247
				SC'		3.3	0.340	0.408	0.476	0.544	0.612	0.680
				SC'		4.1	0.530	0.475	0.421	0.366	0.312	0.257
				SC'		5.2	0.570	0.511	0.453	0.394	0.335	0.276
				ENV'		1.2	0.590	0.529	0.468	0.408	0.347	0.286
				ENV'		2.1	0.150	0.135	0.119	0.104	0.088	0.073
				ENV'		3.1	0.280	0.251	0.222	0.193	0.165	0.136
				ENV'		4.2	0.120	0.108	0.095	0.083	0.071	0.058

SC4.1	0.530				wj		1	0.774468	0.548936	0.323404	0.097872	0.04042553
							SC	SC	SC	SC	SC	SC
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj			4.1+0%	4.1+20%	4.1+40%	4.1+60%	4.1+80%	4.1+100%
0		0.530	1.000	EC'		1.1	0.320	0.248	0.176	0.103	0.031	0.013
20%		0.636	0.774	EC'		2.2	0.310	0.240	0.170	0.100	0.030	0.013
40%		0.742	0.549	EC'		3.1	0.400	0.310	0.220	0.129	0.039	0.016
60%		0.848	0.323	EC'		4.1	0.310	0.240	0.170	0.100	0.030	0.013
80%		0.954	0.098	SC'		1.1	0.520	0.403	0.285	0.168	0.051	0.021
100%		0.981	0.040	SC'		2.4	0.510	0.395	0.280	0.165	0.050	0.021
				SC'		3.3	0.340	0.263	0.187	0.110	0.033	0.014
				SC'		4.1	0.530	0.636	0.742	0.848	0.954	1.000
				SC'		5.2	0.570	0.441	0.313	0.184	0.056	0.023
				ENV'		1.2	0.590	0.457	0.324	0.191	0.058	0.024
				ENV'		2.1	0.150	0.116	0.082	0.049	0.015	0.006
				ENV'		3.1	0.280	0.217	0.154	0.091	0.027	0.011
				ENV'		4.2	0.120	0.093	0.066	0.039	0.012	0.005

SC5.2	0.570				wj		1	0.734884	0.469767	0.204651	0.111628	0.03488372
							SC	SC	SC	SC	SC	SC
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj			5.2+0%	5.2+20%	5.2+40%	5.2+60%	5.2+80%	5.2+100%
0		0.570	1.000	EC'		1.1	0.320	0.235	0.150	0.065	0.036	0.011
20%		0.684	0.735	EC'		2.2	0.310	0.228	0.146	0.063	0.035	0.011
40%		0.798	0.470	EC'		3.1	0.400	0.294	0.188	0.082	0.045	0.014
60%		0.912	0.205	EC'		4.1	0.310	0.228	0.146	0.063	0.035	0.011
80%		0.952	0.112	SC'		1.1	0.520	0.382	0.244	0.106	0.058	0.018
100%		0.985	0.035	SC'		2.4	0.510	0.375	0.240	0.104	0.057	0.018
				SC'		3.3	0.340	0.250	0.160	0.070	0.038	0.012
				SC'		4.1	0.530	0.389	0.249	0.108	0.059	0.018
				SC'		5.2	0.570	0.684	0.798	0.912	0.952	0.985
				ENV'		1.2	0.590	0.434	0.277	0.121	0.066	0.021
				ENV'		2.1	0.150	0.110	0.070	0.031	0.017	0.005
				ENV'		3.1	0.280	0.206	0.132	0.057	0.031	0.010
				ENV'		4.2	0.120	0.088	0.056	0.025	0.013	0.004

Figure Appendix 5-2 normalized weights of social dimension in Sensitivity analysis

ENV1.2	0.590				wj	1	0.712195	0.42439	0.136585	0.082927	0.02682927
						ENV	ENV	ENV	ENV	ENV	ENV
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj		1.2+0%	1.2+20%	1.2+40%	1.2+60%	1.2+80%	1.2+100%
0		0.590	1	EC'	1.1	0.320	0.228	0.136	0.044	0.027	0.009
20%		0.708	0.712195	EC'	2.2	0.310	0.221	0.132	0.042	0.026	0.008
40%		0.826	0.42439	EC'	3.1	0.400	0.285	0.170	0.055	0.033	0.011
60%		0.944	0.136585	EC'	4.1	0.310	0.221	0.132	0.042	0.026	0.008
80%		0.966	0.082927	SC'	1.1	0.520	0.370	0.221	0.071	0.043	0.014
100%		0.989	0.026829	SC'	2.4	0.510	0.363	0.216	0.070	0.042	0.014
				SC'	3.3	0.340	0.242	0.144	0.046	0.028	0.009
				SC'	4.1	0.530	0.377	0.225	0.072	0.044	0.014
				SC'	5.2	0.570	0.406	0.242	0.078	0.047	0.015
				ENV'	1.2	0.590	0.708	0.826	0.944	1.062	1.180
				ENV'	2.1	0.150	0.107	0.064	0.020	0.012	0.004
				ENV'	3.1	0.280	0.199	0.119	0.038	0.023	0.008
				ENV'	4.2	0.120	0.085	0.051	0.016	0.010	0.003

ENV2.1	0.150				wj	1	0.964706	0.929412	0.894118	0.858824	0.82352941
						ENV	ENV	ENV	ENV	ENV	ENV
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj		2.1+0%	2.1+20%	2.1+40%	2.1+60%	2.1+80%	2.1+100%
0		0.150	1.000	EC'	1.1	0.320	0.309	0.297	0.286	0.275	0.264
20%		0.180	0.965	EC'	2.2	0.310	0.299	0.288	0.277	0.266	0.255
40%		0.210	0.929	EC'	3.1	0.400	0.386	0.372	0.358	0.344	0.329
60%		0.240	0.894	EC'	4.1	0.310	0.299	0.288	0.277	0.266	0.255
80%		0.270	0.859	SC'	1.1	0.520	0.502	0.483	0.465	0.447	0.428
100%		0.300	0.824	SC'	2.4	0.510	0.492	0.474	0.456	0.438	0.420
				SC'	3.3	0.340	0.328	0.316	0.304	0.292	0.280
				SC'	4.1	0.530	0.511	0.493	0.474	0.455	0.436
				SC'	5.2	0.570	0.550	0.530	0.510	0.490	0.469
				ENV'	1.2	0.590	0.569	0.548	0.528	0.507	0.486
				ENV'	2.1	0.150	0.180	0.210	0.240	0.270	0.300
				ENV'	3.1	0.280	0.270	0.260	0.250	0.240	0.231
				ENV'	4.2	0.120	0.116	0.112	0.107	0.103	0.099

ENV3.1	0.280				wj	1	0.922222	0.844444	0.766667	0.688889	0.61111111
						ENV	ENV	ENV	ENV	ENV	ENV
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj		3.1+0%	3.1+20%	3.1+40%	3.1+60%	3.1+80%	3.1+100%
0		0.280	1.000	EC'	1.1	0.320	0.295	0.270	0.245	0.220	0.196
20%		0.336	0.922	EC'	2.2	0.310	0.286	0.262	0.238	0.214	0.189
40%		0.392	0.844	EC'	3.1	0.400	0.369	0.338	0.307	0.276	0.244
60%		0.448	0.767	EC'	4.1	0.310	0.286	0.262	0.238	0.214	0.189
80%		0.504	0.689	SC'	1.1	0.520	0.480	0.439	0.399	0.358	0.318
100%		0.560	0.611	SC'	2.4	0.510	0.470	0.431	0.391	0.351	0.312
				SC'	4.1	0.340	0.314	0.287	0.261	0.234	0.208
				SC'	3.3	0.530	0.489	0.448	0.406	0.365	0.324
				SC'	5.2	0.570	0.526	0.481	0.437	0.393	0.348
				ENV'	1.2	0.590	0.544	0.498	0.452	0.406	0.361
				ENV'	2.1	0.150	0.138	0.127	0.115	0.103	0.092
				ENV'	3.1	0.280	0.336	0.392	0.448	0.504	0.560
				ENV'	4.2	0.120	0.111	0.101	0.092	0.083	0.073

ENV4.2	0.120				wj	1	0.972727	0.945455	0.918182	0.890909	0.86363636
						ENV	ENV	ENV	ENV	ENV	ENV
	wp+deltap	w'p	1-w'p/1-w	w'j = 1-w'p / 1-wp*wj		4.2+0%	4.2+20%	4.2+40%	4.2+60%	4.2+80%	4.2+100%
0		0.120	1.000	EC'	1.1	0.320	0.311	0.303	0.294	0.285	0.276
20%		0.144	0.973	EC'	2.2	0.310	0.302	0.293	0.285	0.276	0.268
40%		0.168	0.945	EC'	3.1	0.400	0.389	0.378	0.367	0.356	0.345
60%		0.192	0.918	EC'	4.1	0.310	0.302	0.293	0.285	0.276	0.268
80%		0.216	0.891	SC'	1.1	0.520	0.506	0.492	0.477	0.463	0.449
100%		0.240	0.864	SC'	2.4	0.510	0.496	0.482	0.468	0.454	0.440
				SC'	3.3	0.340	0.331	0.321	0.312	0.303	0.294
				SC'	4.1	0.530	0.516	0.501	0.487	0.472	0.458
				SC'	5.2	0.570	0.554	0.539	0.523	0.508	0.492
				ENV'	1.2	0.590	0.574	0.558	0.542	0.526	0.510
				ENV'	2.1	0.150	0.146	0.142	0.138	0.134	0.130
				ENV'	3.1	0.280	0.272	0.265	0.257	0.249	0.242
				ENV'	4.2	0.120	0.144	0.168	0.192	0.216	0.240

Figure Appendix 5-3 normalized weights of environmental dimension in Sensitivity analysis