MULTIPLE CRITERIA DECISION ANALYTICAL TOOLS IN ASSESSING RISK FOR GREEN GROWTH: THE CASE OF OIL PALM BIOMASS IN MALAYSIA

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Abstract

The heightening world issues arises from climate change and energy security has created a strong resonance for sustainable development. The utilisation of biomass resources is amongst one of the best strategies to counter carbon emission and energy security issues for waste-to-wealth. Over the last decade, the Malaysian government has shown its clear intent to be a front-runner in the green economy through its various green economy policies and programs, particularly focus on oil palm biomass industry. However, it is observed that the diffusion rate of the industry remains relatively slow as compared to other developing countries such as Thailand and Philippine. Literature, anecdotal evidence, and advocates as well as businesses have identified that one of the non-technical factors that contributes to this problem is financing difficulties. The complication of biomass value chain creation often engaged with high risk profile, capital intensive and long payback period which is unfavourable for financing based on conventional risk assessment. Thus, this research focusses on developing a full range risk assessment model in aiding the industry stakeholder to comprehend the risk profile in managing and mitigating risk in biomass value chain in Malaysia. Multiple decision analytical tools have been employed and developed to integrate non-quantitative factors in risk assessment and design risk mitigation strategy based on the strengths and preferences of different stakeholders' role. The outputs can serve as policy recommendation to aid the authorities and policy makers to undertake policy reviews to effectively spur the biomass industry for green growth. Furthermore, financier and investor are recommended to utilise the information to enhance its

financing decision, to offer financial products that customised the need of sustainable projects without losing great business opportunity. Last but not least, the framework also offers industry stakeholders a practical decision analysis and making tool to integrate preferences as well as quantitative information to mitigate risks before any losses in venturing into the biomass industry occurred.

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List of Publications

Referred Journals

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Ngan, S.L., Promentilla, M.A.B., Yatim, P., Lam, H.L. (2018). A Novel Risk Assessment Model for Green Finance: the Case of Malaysian Oil Palm Biomass Industry. *Process Integration and Optimization for Sustainability*, 3(1), 75-88.

Yatim, P., **Ngan, S.L**., Lam, H.L, Er. A.C. (2017). Overview of the key risks in the pioneering stage of the Malaysian biomass industry. *Clean Technologies and Environmental Policy*, 19 (7), 1825-1839.

How B.S., **Ngan S.L.**, Hong B.H., Lam H.L., Ng W.P.Q., Yusup S., Wan Abd Karim Ghanie W.A., Kansha Y., Chan Y.H., Cheah K.W., Shahbaz M., Singh H.K.G., Raman Yusuf N., Ahmad Shuhaili A.Z., Ramlie J., 2019. An Outlook of Malaysian Biomass Industry Commercialisation: Perspectives and Challenges. *Renewable and Sustainable Energy Reviews*, 113, 109277

Leong W.D., Teng, S.Y., How, B.S., **Ngan S.L.**, Lam, H.L., Tan, C.P., Ponnambalam, S.G., 2019, Adaptive Analytical Approach to Lean and Green Operations, *Journal of Cleaner Production*, 235, 190-209.

Ngan S.L., How B.S., Teng S.Y., Leong W.D., Loy A.C.M., Promentilla M.A.B., Yatim P., Lam H.L., 2019. DEFANP method for prioritisation of risk mitigation strategies for biomass polygeneration systems. Renewable and Sustainable Energy Reviews (In Review).

Conference Proceedings

Yatim, P., **Ngan, S.L**., Lam, H.L., 2017. Financing Green Growth in Malaysia: Enabling Conditions and Challenges. *Chemical Engineering Transactions*, 61, 1579-1984.

Ngan, S.L., Promentilla, M.A.B., Lam, H.L., Yatim, P, Er. A.C., 2018. Developing Sustainability Index for Malaysian Palm Oil Industry with Fuzzy Analytic Network Process. *Chemical Engineering Transactions*, 70, 229-234.

Ngan, S.L., How, B.S., Promentilla, M.A.B., Lam, H.L., Yatim, P., 2018. Integrating stakeholder's role in mitigating risks for future cleaner production. *Chemical Engineering Transactions*, 70, 1327-1332.

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List of Abbreviations and Acronyms

3R	Reduce, Reuse, Recycle
ACA	Accelerated capital allowance
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BE	Bioeconomy
CAPEX	Capital expenditure
CCS	Carbon capture and sequestration
CDM	Clean Development Mechanism
CE	Circular economy
CGC	Credit Guarantee Corporation
CP	Cleaner production
CPO	Crude palm oil
CR	Consistency ratio
CSPO	Certified sustainable palm oil
CVaR	Conditional value-at-risk
DC	Decanter cakes
DEFANP	Decision and evaluation-based fuzzy analytic network process
DEMATEL	Decision-making trial and experimental laboratory
DG	Deceleration of growth
DOSM	Department of Statistics Malaysia
EFB	Empty fruit bunch
EPU	Economic Planning Unit
ESCO	Energy services companies
EU	European Union
EY	Ernst & Young
FANP	Fuzzy Analytic Network Process
FFB	Fresh fruit bunch
FiT	Feed-in-Tariff
G20	Group of Twenty

GDP	Gross domestic product
GE	Green economy
GGDN	Global Green New Deal
GHG	Greenhouse gas
GNI	Gross national income
GTFS	Green Technology Financing Scheme
HAZAN	Hazard analysis study
HAZID	Hazard identification study
HAZOP	Hazard and operability study
HHV	Higher heating value
HRSG	Heat recovery steam generator
IBA	Industrial building allowance
IEA	International Energy Agency
InRP	Indian Resource Panel
ISPO	Indonesian Sustainable Palm Oil Standard
ITA	Income tax allowance
KeTTHA	Kementerian Tenaga, Teknologi Hijau dan Air Malaysia
KPI	Key performance indicators
KPMG	Klynveld Peat Marwick Goerdeler
LCA	Life cycle analysis
LHV	Lower heating value
LOPA	Layers of protection analysis
MBIC	Malaysia Biomass Industry Confederation
MCDA	Multiple criteria decision analysis
MESTECC	Ministry of Energy, Science, Technology, Environment and Climate Change
MINLP	Mixed integer nonlinear programming
MoEFCC	Ministry of Environment, Forest and Climate Change
MPOB	Malaysian Palm Oil Board
MSC Malaysia	Multimedia Super Corridor
MSPO	Malaysian Palm Oil Standard

MYR	Malaysian Ringgit
NKEA	National Key Economic Area
NLP	Non-linear programming
NPV	Net present value
OPEX	Operating expenditure
PBP	Payback period
PHA	Process hazard studies
PKS	Palm kernel shell
POME	Palm oil mill effluent
PPF	Palm pressed fibre
PV	Prevent value
PwC	Pricewaterhouse Coopers
REDII	Renewable Energy Directive
ROI	Return on investment
ROI+20	2012 UN Conference on Sustainable Development that was held in Rio de Janeiro
RSPO	Roundtable Sustainable Palm Oil
SAP-LAP	Situation Actor Process-Learning Action Performance
SD	Standard deviation
SDGs	Sustainable Development Goals
SEDA	Sustainable Energy Development Authority Malaysia
SGD	Singapore Dollar
SME	Small-medium enterprises
t	Tonne
TAIEX	Taiwan Stock Exchange Capitalization Weighted Stock Index
TORO	Target-oriented robust optimisation
UN	United Nation
UNEP	United Nations Environment Programme
USD	United States Dollar
WEEE	Waste electrical and electronic equipment

Chapter 1. Introduction

1.1 Background Problem

Malaysia, which situated strategically in the middle of South East Asia is blessed with fertile land and all year-round summer weather, possessing the best condition and resources for agriculture. The agriculture sector plays a crucial role in the economic development of Malaysia, with a contribution of 7.9 % to the national Gross Domestic Product (GDP) as of year 2018 and encompasses 11.09 % of the total employment [1]. Oil palm is amongst the top contributors which produce about 20 million tonnes of crude palm oil per year. Besides, the oil palm biomass (i.e., oil palm trunk, oil palm frond, empty fruit bunches (EFB), palm oil mill effluent (POME), palm kernel shell (PKS), palm pressed fibre (PPF) and decanter cake (DC)) is expected to reach 100 million dry tonnes by 2020 [2]. Comparing to some developed countries such as United Kingdom who needs to actively planning woodland to secure the supply of the biomass source, Malaysia has the capacity to secure consistent supply of biomass feedstock from its main economic activities [3]. Thus, developing oil palm biomass industry by converting the organic waste into high value-added products is one of the best ways to creates synergy with the current economic activities in Malaysia [4].

Various initiatives have been initiated by the government to spur the growth of biomass industry, particularly on increasing the dependency on biofuel as well as the advancement of green technology. For example, the launch of (i) National Biofuel Policy which sets the platform for the development of biofuel industry; (ii) National Green Technology Policy to promote the application and development of green technology in accelerating the economy while minimising the impact to the environment [5]; (iii) Green Technology Financing Scheme (GTFS) that provides easier access to financing for the green technology project [6] etc. The Annual Federal Government Budget since 2016 also highlighted on increasing productivity, innovation and green technology and set them as the second priority of the national development. Despite the significance and potential of Biomass industry in Malaysia together with the proactive support from the government, the industry is yet to be popularized.

The biggest hindrance of the development of biomass industry in Malaysia, as pointed out by the stakeholders in this industry is financing difficulty [7]. Financing issues set up a high barrier for the stakeholders who are interested to venture into biomass industry, thus, decelerating the development of the industry to further contribute to the economy as a whole.

Recently, many researchers have gained interest in green finance to introduce new financing method to aid financing issues for the development of the green growth [8]. However, less attention is dedicated to assessing and mitigate the risk profile of sustainable project, which is the core step prior to any financing decision or investment decision. Risk management inclusive of risk assessment and risk mitigation is very crucial in equipping industry stakeholders, regardless of investors, financiers, entrepreneur, and project developers with the integrated information to develop the oil palm biomass industry. The lack of focus in this area limits the funds and investments to venture into this industry to governmental scheme, venture capitalist and angel investors. This situation is not economically sustainable across a longer period of time due to the characteristics of the respective investors. Thus, resulting in higher probability of project failure in which the project failed to survive through breakeven point to start generating profit. Poor success rate of precedent case can further intensify the financial difficulties of oil palm biomass related project due to higher chance of the project to fall into default status.

1.2 Problem Statement

One of the main factors that stakeholders of sustainable projects that contribute to green growth failed to attain financing from financial institution and investors is due to lack of information and capacity to evaluate the opportunity and risk associate with the industry. Conventional risk assessment method and lending structure that adopted by most of the local financial institution in Malaysia are highly profit-oriented. This often led to failure loan application or relatively high premium charged on the financing amount that caused the businesses unable to meet debt obligation to sustain its operation. With the increasing concern on sustainable development and risk management, it is necessary for the capital providers to incorporate environmental and social cost in its financing decision-making.

1.3 Research Objective

The main objective of this research work is to provide comprehensive risk profile of biomass industry, to develop a user-friendly risk assessment approach and to provide guidelines on the risk mitigation to spur the growth of the industry for sustainable development. It can be further broken down into several goals:

i. To identify the current state of green growth in Malaysia

With the world switches towards sustainable development and cleaner production, it is necessary to understand where Malaysia is, both in term of nation policy, future development blueprint as well as industry practices. Thus, the first objective of this work is to understand current state of green growth in Malaysia, inclusive but not limited to policy enablers, challenges, role of different stakeholders and recommendations for the country to excel in this direction.

ii. To develop a user-friendly risk assessment approach for Malaysian oil palm biomass industry

There is a lack of appropriate approach to evaluate the risk associated with the sustainable project in developing country, particularly oil palm biomass industry which has high growth potential in Malaysia. A comprehensive framework and guideline will be developed to aid the identification and evaluation of the risk associated with the industry. Furthermore, analysis tool will be developed to select the most effective risk mitigation strategy, depending on the top identified risk.

iii. To aid the oil palm industry to switch towards sustainable development

Sustainability of oil palm industry has been controversial across years as it is often claimed to cause deforestation, loss of biodiversity, violation of human right (i.e., child labour, lack of health and safety concern in plantation or mill), just to name a few. Prioritisation approach is introduced to aid the industry stakeholders to understand the complex relationship of sustainability indicators associated with different stages of the industry life cycle to initiate sustainability practices in its business or operation for sustainable development.

1.4 Research Scopes

The research is proposed to be carried out with the aid of a computational software (i.e., LINGO), multiple criteria decision-making software, (i.e., Superdecision) in correspond with spreadsheet software, Microsoft Excel with add in feature (i.e., Oracle Crystal ball) for simulation.

i. Identification of the key risks hindering the development of oil palm biomass industry

To address the high-risk profile of oil palm biomass industry which often claimed as one of the key factors hindering the growth of the industry, the first scope of this work is to identify the key risks associated with the industry based on industry life cycle approach. Unable to attain sufficient information related to the industry exposes the related stakeholders to high risk in making decision, whether to venture, invest, or finance biomass project. Thus, risk identification is carried out to provide a comprehensive information for industry stakeholder, regardless of project developer, financier, investors to aid its decision.

ii. Assessment of risks associated with oil palm biomass industry with multiple criteria decision analysis tool

Risk exerts in both tangible and intangible form, which increase the complication for quantification (i.e., probability of occurrences and consequences of risk events). Due to the lack of historical data in the industry, the conventional quantification method is almost made impossible. Thus, a user-friendly approach with Analytic Network Process is proposed in this work to access and evaluate key risks associated with the industry. Furthermore, the outcome is not merely based on single objective (i.e., maximise financial benefits, minimise accident rate, reduce environmental impact), it takes in consideration of all perspectives from major industry stakeholders (i.e., business related party, capital provider, policy maker, researchers).

iii. Prioritisation of sustainability indicators for oil palm industry towards sustainable development

Different stages of industry life cycle exert different characteristics for growth. Despite multiple international and domestic sustainability standards are introduced to provide guidance on enhancing the sustainability of the industry, knowing what to need to be changed is insufficient. In this work, sustainability indicators are prioritised based on different stages of industry life cycle. The outcome provide reference to help industry stakeholders to understand which indicators they can start to initiate sustainability practices to achieve the best effect, depending on the stages of the business/form. Furthermore, this work also helps policy makers to design suitable policies and incentives to enhance the overall sustainability of the industry.

iv. Development of a systematic evaluation approach to evaluate risk mitigation strategies for risk minimisation

Multiple attribute decision analysis tools are integrated to evaluate risk mitigation strategy to minimise the risk for oil palm biomass related project. The evaluation method incorporates the key elements of the industry (i.e., supply chain, technology, process) and the strength and weaknesses of stakeholder's (industry players, government agency) to select the most effective and influential action plan. The method also aims to minimise the risks (i.e., financing risk, regulatory risk, supply chain risk) associated with the project. Simulation of the financial performance of the project and sensitivity analysis are conducted to verify the effectiveness of the mitigation action plan on financial performance. The methodology is illustrated with the case study synthesized in Chapter 7 and 8.

Chapter 2. Literature Reviews

2.1 Palm oil and oil palm biomass industry in Malaysia

The palm oil industry is one of the main economic activities in the ASEAN region. Indonesia and Malaysia cumulatively accounted for 85% of the world palm oil production [9]. The significant growth of palm oil in Thailand has also grow begun to monopoly the other vegetable oil production within the country [10]. These three countries in total produce up to 91% of the total world palm oil [11] and this is followed by Colombia. Palm oil is amongst the most popular vegetable oil across the world, contributing about one-third of the global consumption. The consumption rate of the palm oil is expected to continue to increase up to 72 million tons per year [12]. Apart from being widely used as cooking oil, it can also act as the ingredient in food products (i.e., cookies, margarine, bread spread, pizza dough, bread), and further process to become cosmetic products (i.e., lipstick, lotion, soap) and bio-fuel. Malaysia, as the second world's largest exporter of palm oil after Indonesia and contributes about 1.605 x 10^7 t (i.e. 36.75 %) of world palm oil exports on a yearly basis [9]. The ratio of the production of palm oil to dry oil palm biomass waste is about 1:4, excluding palm oil mill effluent [4]. This signifies that for every tonne of the palm oil produced, 4 tonnes of dry biomass (i.e., oil palm trunk, oil palm frond, EFB, PKS, PPF and DC) are produced. Studies showed that by fully utilising the oil palm biomass into high-value-added products, it could increase the country's gross national income (GNI) by additional MYR 30 billion [2].

Agricultural activities are the backbone of Malaysia's economy. Thus, apart from oil palm biomass, there is a wide array of biomass available through other commercial agriculture activities (i.e., woody residues, paddy residues, sago biomass). Figure 2-1 shows a non-exhaustive view of the distribution of biomass produced in Malaysia in a yearly basis. The oil palm biomass is the dominant source, contributing up to 86.18 % of the total biomass produced in Malaysia annually. Given that the palm oil industry is expected to grow in the next decade, the oil palm biomass industry exerts high growth potential largely due to business opportunities in upstream expansion, exploitation of existing downstream palm oil activities as well as bio-energy production.

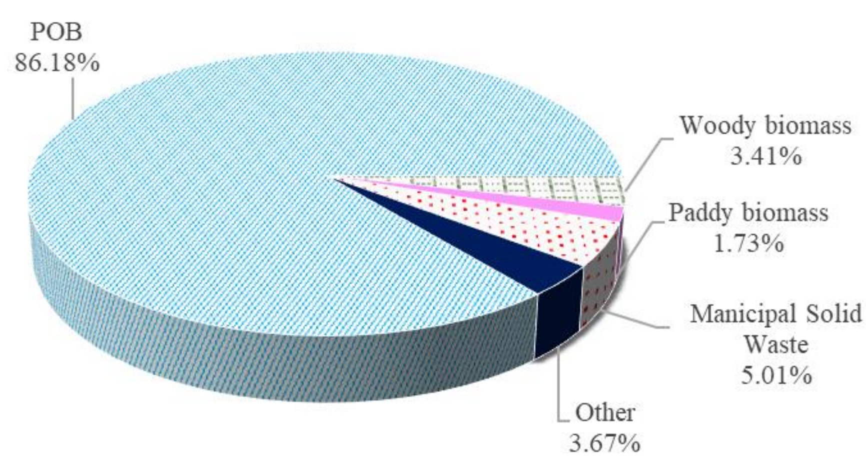


Figure 2-1 Distribution of the type of biomass produced in Malaysia on a yearly basis (Source: [13]*)*

2.1.1 Policy and Incentives

Since the introduction of 8th Malaysia plan, the Malaysia government has undertaken favourable politics to drive the biomass industry forward. These policies and actions were not specifically aimed for the development of biomass industry per se but reaching out to a larger scope under renewable energy, green technology and biotechnology. First, fifth fuel policy was introduced in 1999 to recognize renewable energy as the fifth primary fuel in national energy supply to reduce the dependency on the traditional fuel. Next, Small Renewable Energy Program (2001), National Biofuel Policy (2006), National Green Technology policy (2009), Renewable Energy Policy and Action Plan (2010), Renewable Energy Act (2011) are introduced to encourage the development of transforming biomass from a form of polluting wastes into economically valuable resources [14,15]. This transformation is mainly driven by the need to reduce carbon emission to mitigate climate change, reducing dependency on finite fossil-based resources as well as maturing of sustainable bioscience and biotechnology [3,16].

Since 2012, Biomass Industry Strategic Action Plan has been introduced to help small and medium enterprises (SMEs) in Malaysia to explore and convert local biomass resources into high value product. It is a joint program between Malaysia and European Union (EU) to encourage the development of biomass industry in Malaysia through sharing information, and technology[17]. In relation to that, Malaysia Biomass Industry Confederation (MBIC) has also been formed to represent SMEs to engage the Malaysia Government and other stakeholders (i.e. major feedstock owners, research institutes, and other local and international biomass stakeholders). The purpose of MBIC is to commercialise, market and utilise the applications of high value biomass products alongside the value chain with the final goal of leading Malaysia to be the international biomass hub [18]. National Biomass Strategy 2020 has been introduced since 2013 to promotes the use of agricultural biomass waste for high value products. It was initially focusing on the palm oil industry and now is extending to include all types of biomass sources such as rubber, wood and rice husk. In relation to this, government introduces multiple incentives specifically tailored for biomass industry, such as palletisation capacity incentive (under palm oil NKEA) to provide 10-15 % in CAPEX incentives to the first five successful applicants for new pellet plants in Malaysia [2].

2.1.2 International initiative towards green growth

Apart from the initiative at the national level, Malaysia also participates in various international initiative to combat global issues such as climate change, resource scarcity, energy security and food security. Even though the commitment to respective international treaty might not directly impact on the development of the oil palm biomass industry, the global movement towards cleaner production does increase awareness and demand of the utilisation of biomass. Malaysia had voluntarily become a signatory to Kyoto Protocol in the year of 2005 to put in place legislation and policies to mitigate climate change issues, particularly focusing on the take in environmental and social component in making climate-friendly investment decisions and the formation of a carbon market. Kyoto Protocol also encourages developed countries to aid developing countries to reduce net global greenhouse gas emissions at a much lower cost by financing emissions reduction projects in developing countries. Kyoto Mechanism, such as International Emission Trading, Clean Development Mechanism (CDM) and Joint Implementation are also introduced under this protocol to attract foreign investment and technology transfer in the biomass industry to reduce carbon emission in Malaysia [19].

2.2 Sustainable development

The concept of sustainable development is first introduced by United Nation back in 1972 [20] to achieve a balance between economic growth, environmental conservation and preservation and social well-being. It is not until 2010s that this movement received a strong resonance across the world, particularly with the launching of 2030 agenda for Sustainable Development Goal (SDGs). SDGs indeed is a big milestone for sustainable development, enlisted 17 objectives to serve as the core of this movement. SDGs cover a wide range of area, ranging from social concern (i.e., no poverty, zero hunger, good health and well-being, quality education, gender equality) to environmental protection (i.e., clean water and sanitation, affordable and clean energy, climate action, life on land), to economic development (decent work and economic growth, industry, innovation and infrastructure, sustainable cities and communities) [21]. As defined by the European Union, *sustainable development focus on the development which meets the needs of the present without compromising the ability of future generations to meet their own needs* [20]. This initiative also strongly emphasises on the cooperation at multiple levels, including local, national, regional and international to form a global partnership to combat the world issues together. In relation to that, different economic models and new concepts have been introduced and promoted to aid the transition towards sustainable development. Green economy (GE), Circular economy (CE), and Bioeconomy (BE) are amongst the most popular avenues that are gaining recognition in supporting SD initiatives.

2.2.1 Green economy

The notion of GE was officially introduced in the 2012 UN Conference on Sustainable Development held in Rio de Janeiro (ROI+20). It is defined as "*an economic system that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities.*" [22]. The definition of GE conveys the comprehensiveness as the "engine" for sustainable development, which fully covers the economic, environmental and social aspects. It is meant to create a low carbon, resource efficient and socially inclusive economy by investing in natural capital for green projects, and increasing energy/resource efficiency [23]. Loiseau et al. [24] described the principles of GE as enable environmental economics, that focuses on cleaner production, resource efficiency and ecological economics. The growth in income and creation of green employment to mitigate social inequality is also a core element in GE to improve the overall quality of life [22]. The most distinctive difference of GE with CE nor BE is that GE goes a step further to drive fund and investment, from both public and private source to kick-start such initiative [25,26]. Global Green New Deal (GGDN), a United Nations Environment Programme (UNEP) movement introduced in 2009 is one of the best example [27]. GGDN involves 20 most advanced economies (i.e., G20) in the world to invest at least 1% of their total GDP in GE related project. It successful draws a significant amount of investment (i.e., US$ 3.1 trillion) to fund the projects related to (1) energy efficiency in old and new buildings; (2) renewable energy technologies; (3) sustainable transport technologies; (4) the planet's ecological infrastructure; and v. sustainable agriculture [28]. GE heavily promotes the implementation of cleaner energy policy to increase the usage of renewable resources. Large-scale penetration of renewable energy acts as a remedy for climate change, substitution of fossil resources for energy saving, and increase employment of green job to eradicate poverty[29]. GE initiatives also include providing education to raise awareness and acceptance level on the needs of green growth and demand for green products and services. Different from the CE which is relatively new in the policy arena for developing countries, except China, GE has been adopted in multiple developing countries as development blueprint over the past decades [30,31].

2.2.2 Circular economy

The idea of CE started way back to 1960s and regained its popularity in industrial and policy arena in recent year. There is no clear indication that the concept of the circular economy is drawn from a single source, but is based on multiple ideologies that are well-established years ago. Some of the ideology that contributes to the key principle of CE is the "spaceman" economy – which proposed a cyclical system that encourages the reproduction of materials [32]; "steady-state economy" – maintain a constant amount of inputs (i.e., both materials, human resources, energy) through the product cycle [33], "industrial ecology" – promote the recycled loop of the materials in a designed industrial ecosystem [34] and last but not least, the “cradle-to-cradle” concept – promotes recycling with the emphasize on eco-efficiency [35].

However, the concept of CE is often obscure and vary according to different practitioners, field and geographical location [36–38], depending on the cultural, social and political background. For instances, the CE concept in developed nations such as US, UK, European Union nations mainly focus on the 3Rs, reduce, reuse, recycle of the resources, waste management and reduce environmental impact for sustainable development [39]. Meanwhile, developed country in Asia regions such as South Korea and Japan mainly adopt the CE concept on the raising public awareness on consumers responsibility on material use and waste [40]. China, on the other hand, adopted the concept of CE to promote urban development, to achieve a balanced growth of the development in the rural area as well as the urban area. The CE-initiative in China highly focuses on the replacement of conventional industrial culture with novel technology and process that significantly increase the efficiency and profitability of the production [41].

In general, CE promotes cyclical resources flows in the production-consumption system. The system is designed to be restorative and regenerative on its own like the cycle and can be applied on a different scale, from micro-level to meso-level as well as macro-system [42]. CE is not a minor change or modification to be added at a certain stage of the industry life-cycle. Rather, it is a fundamental systemic change, regardless of industry, location, scale, nature of business etc. [36]. It proposes a new type of economic growth that involve new business model creation and job opportunities that focus on reducing dependence on the supplier for supply of material, save materials' cost, dampening price volatility [43]. CE limits the throughput flow to a level that nature tolerates and utilises ecosystem cycles in economic cycles by respecting their natural reproduction rates [44]. The prominence action in transforming to CE consists of aspects of reduce, reuse, recycle and recovering material in production/distribution and consumption process to achieve cradle-to-cradle life cycle. Waste management also plays an important in the CE to overcome the negative impact of the linear economy, value lost and energy loss [45]. The intention of CE is to phase out "waste" by re-fitting biological and technical waste into the biological and technical materials cycle that designed for remarketing, remanufacture, disassembly or repurposing [46]. Murray et al. [47] also show the hierarchy of the usage of the biological and technical materials in order to keep the materials at their highest value and in use, served as a form of guidelines to ease the transition towards CE.

2.2.3 Bioeconomy

BE is defined by European Commission publication in 2012, "Innovating for Sustainable Growth: A bioeconomy for Europe" as *bioeconomy encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy [and] includes the sectors of agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries* [48]. BE promotes innovative, low-emissions economy while reducing the impact arising for the increasing demand for food, energy to ensure biodiversity and environmental protection [49]. Scarlat

[50] illustrate bio-economy as a new growth opportunity in both traditional and emerging bio-based sectors to counter global challenges (i.e., climate change, food security, energy security, scarce resources) with environmental constraints. Bugge et al. [51] categorized bioeconomy into three main groups, namely biotechnology vision, bio-resource vision and bio-ecology vision. Biotechnology vision maximises the usage of the resources to solve resource shortages and resource scarcity. Bio-resources vision minimises environmental impact in the process of value creation and bio-ecology vision prioritises on the hierarchy of the usage of the resources for sustainability. For example, reuse and recycle the waste prior to remanufacture or refurbish for other use. Different from CE's and GE's concept that emphasizes more on environmental preservation and conversation for environmental impact reduction, BE intends to create new opportunity to transform natural and renewable biological resources for energy, chemicals and materials application and substitution[52]. It is deemed to be more appropriate for rural development, rather than urbanization or industrialization [29]. A few works also described BE as a subset of GE, playing an integral role to aid the green growth initiatives [24,53]. Similar to CE, the definition and understanding of BE vary depending on the nature of the industry as well. It has been widely adopted in developed countries, particularly on European nations and America, and receive significantly less attention in developing country thus far.

2.2.4 Current state of green growth in Malaysia

As Malaysia strives towards becoming a developed nation by the year 2020, there has been rapid increase in energy consumption which has resulted in depletion of primary non-renewable energy resources and increase of greenhouse gases (GHGs). In response to the depletion of natural resources and environmental degradation problems, Malaysia has instituted several policies associated with renewable energy and climate change policies. These policies include National Renewable Energy Policy and Action Plan (2009), National Policy on Climate Change (2009), National Green Technology Policy (2009) and Renewable Energy Act (2011). Furthermore, Malaysia is also a signatory to several multilateral environmental agreements (MEAs) such as the Paris Agreement and Convention on Biological Diversity.

Malaysia launched 11th Malaysia Plan 2016 - 2020, an economic development blueprint for the next five years and defined six strategic thrusts to help Malaysia achieve the target of becoming an advanced economy by year 2020 in the year of 2015. Green growth is one of the strategic thrusts that will enable Malaysia to stay ahead of environmental challenges and opportunities in a fast-changing global and political landscape. The government has set out three strategies to promote the green growth agenda including strengthening governance to drive green growth, enhancing awareness to create share responsibility, and establishing sustainable financing mechanisms to promote and support green growth. Since green growth has become one of the policy agenda in Malaysia's sustainable economic development for the next five years, it is imperative that we look at key factors enabling green growth and challenges that may hinder green growth efforts. Although there are several enabling conditions necessary to increase the uptake of green growth in Malaysia, our primary focus is on the financing aspect of green growth.

The policy makers around the world have recognized that green growth can underpin industrial policy and macroeconomic goals as growing demand for green technologies, products and services provides opportunities for countries to develop new industries and markets. However, the policy commitments from the government alone is not enough; a long-term commitment from all stakeholders in the green growth nexus is a prerequisite to create the environment for green growth. In addition to clear green policy directions, easy access to financing facilities for green industries through fiscal and financial support systems are also equally important. Typically, government-led financing facilities are crucial at the initial stage of green growth process. However, as the participation of private sector in green growth increases, large external financing from financial institutions and capital markets become increasingly important for green industries seeking to commercially explore new ideas and clean technologies [54].

2.3 Sustainability of palm oil industry

Malaysia also voluntarily committed to Agenda 2030 of Sustainable Development Goals in 2015 in line with the national development blueprints with the 17 SDGs principles. Nonetheless, the sustainability of the palm oil industry is controversial in recent years. It is often claimed that the palm oil industry is associated with heavy deforestation which creates a serious impact on the loss of biodiversity. Furthermore, the neglection of the social benefit of labour issues, such as contracted part-time undocumented labour, child labour, women labour, poor working environment also often claimed as a violation of human right [55,56]. With that, a series of anti-palm oil movement has been launched by non-governmental organisations to increase the awareness of the sustainability of palm oil production and to avoid the consumption of palm oil-related products[57]. These create a huge impact on the demand for and price of the palm oil in a long run. The situation is worsened with the European Union's intention to exclude import of palm oil from Malaysia (i.e., REDII mandates) [9]. However, the substitution of palm oil with other vegetable oil (i.e., sunflower oil, soya oil etc) might not be a wise move as it required at least 50% more land consumption for the production required to meet the vegetable oil demand[12,57]. In relation to that, different sets of sustainability standards and certification have been introduced in conjunction with the increasing dispute for this industry.

2.3.1 International certification standard

Roundtable Sustainable Palm Oil (RSPO) is the most world-recognized certification standard for the time being. RSPO is the first international organization to develop and implement global standards for sustainable palm oil. It is a multi-stakeholder voluntary international standard that focuses on minimising the negative impact of palm oil cultivation on the environment and communities in palm oil-producing regions. It was first introduced in 2004 and formally recognized as accreditation in 2013 [58]. RSPO consists of three main impact goals and seven principles on creating sustainable palm oil supply chain, starting from the plantation (supply base) and mill, to the delivery of the palm-oil products to end user. The three impact goals enlisted in the RSPO standards are prosperity (i.e., economic), people (i.e., social) and planet (i.e., environmental) [59]. To ensure the standard is always relevant to the up-to-date context, the standards are revised every 5 years of implementation. Similarly, the RSPO certification owner will need to undergo the main assessment once every 5 years, and annual assessment for continued compliance. The standards and guidelines are also subjected to national interpretation due to the difference of law and regulations in different country. RSPO consists of seven principles in total. Impact goal “Prosperity” consists of three principles: first, to create a competitive, resilient and sustainable sector; second, to behave ethically and transparently; third, to operate legally and respect rights; fourth, to optimise productivity, efficiency, positive impacts and resilience. Impact goal “People” aims to create sustainable livelihoods and poverty reduction with the following three principles: respect community and human rights and deliver benefits; support smallholder inclusion; respect workers’ right and conditions. The last principle is categorized under impact goal “Planet” to conserve, protect and enhance the ecosystem that provides for the next generation through protect, conserve and enhance ecosystems and the environment [59].

2.3.2 Domestic certification standards

Another two sustainability standards that are commonly known across the industry are Malaysian Palm Oil Standard (MSPO) and Indonesian Sustainable Palm Oil Standard (ISPO). These two certifications are introduced as voluntarily basic by respective local government and later enacted as law to mandate compulsory compliance. MSPO was first launched in November 2013 and officially came into effect by 2015. MSPO consist of two major categories, oil palm management certification and supply chain certification. Oil palm management certification consists of three parts, for independent smallholders, oil palm plantations and organised smallholders and palm oil mill. The standards and criteria for the respective category are varied slightly. The first six (6) key principles for all these three categories are the same, management commitment and responsibility, transparency, compliance to legal requirements, social responsibility, health, safety and employment conditions, environment, natural resources, biodiversity and ecosystem services, best practices, except for the seventh, development of new plantings is excluded for palm oil mill as it is irrelevant [60]. On one hand, the supply chain certification under MSPO was just newly introduced and officially come into implementation on August 2018. Similar with RSPO certification, supply chain certification applies to industry players that process, trade or manufacture palm oil products. The Supply Chain Certification Standard focuses on the transparency and traceability of the information and material/product flow throughout the supply chain to ensure all stakeholders are responsible to the sustainability of the supply chain [61]. On the other hands, ISPO also consists of seven principles, namely licensing system and plantation management, technical guidelines for palm oil cultivation and processing, environmental management and monitoring, responsibilities for workers, social and community responsibility, strengthening community economic activities and sustainable business development [62]. ISPO contains 3 types for certifications which are grower certification, supply chain certification and holding certification.

2.4 Challenges on financing oil palm biomass-related project

Difficulties in attaining financing is one of the most commonly cited stumbling blocks for the slow development of oil palm biomass industry in Malaysia [63]. Renewable energy and other capital-intensive cleantech projects are highly leveraged and require large initial investments, moreover, they are also exposed to numerous risks such as market risk, credit risk, liquidity risk, operational and regulatory risks [64]. From the perspective of financial institutions' and investors' they would typically assess the revenue projections and major risks that can potentially impact the project when considering a project. If this risk-return analysis is not adequately performed, risks associated with cleantech projects will directly impact the amount, timing, cost and availability of financing [65]. Moreover, to achieve bankability, clean technologies need to be proven and reliable and scalable. As a result, the type of financing available to cleantech projects is largely dependent on risk management approaches employed by the project developers and the risk management tools available to mitigate real and perceived risks. The main factors that contribute to the financing issue are the capital-intensive nature of the industry, insufficient historical data for analysis, high risk profile, financing gaps in local financing framework. The explanation for each factor would be illustrated in the following section.

2.4.1 Capital intensive

Biomass industry, by nature is a capital-intensive industry [66] as it required a combination of expertise from various areas, inclusive but not limited to technology, material science, biology, bio-chemical, supply chain management and engineering [67]. While the government-led financing is necessary to stimulate the uptake of green growth, the government financing schemes are not able to match the investment costs required for scale-up clean technology projects. These projects are not able to obtain large amount of financing from financial institutions and capital markets partly because of their real and perceived risks. Lenders and investors alike will impose more stringent lending and investment criteria, making the financing cost higher than that of government financing schemes. Cleantech projects that are highly leveraged and complex, such as biorefineries, are more likely to pose high financing risks and the risk of delayed completion and discontinuation [68]. Depending on the biomass feedstock, the operational components starting with the construction of the plant and facility, implementation of technology, adoption of techniques to logistics arrangement contributed to high setup cost for the industry. Even though capital intensive industry creates high barriers of entry which minimise the competition of the industry, at the cons side, stakeholders are imperative to receive financing in order to start and sustain through the operation [69]. However, the financing for the project might not need to be limited to venture capital, capital markets, private equity and project finance, which are the commonly available financing medium in Malaysia. In Germany, financial citizen participant was introduced to finance renewable energy technologies or projects from citizens (i.e. private individual, individual enterprises or legal entities) in the form of equity. The investing members hold voting and control right over the technology or project that they are investing [70].

2.4.2 Insufficient historical data for analysis

Unlike common fossil fuel such as petroleum, natural gas, coal that are widely trade as commodity across world, biomass industry in Malaysia facing lack of historical data related to the cost, pricing and revenue for further analysis and interpretation [71]. Failure to attain of the mentioned information prevent the industry stakeholders to study about the historical trend to forecast the required cost, expected return and payback period for the project financing [72]. Stakeholders also unable prepare solutions and alternatives to manage and mitigate losses which can be observed based on the historical data trend. Furthermore, it also contributes to the high market volatilities in term of pricing, supply and demand of biomass feedstock type and end-product (i.e. bioethanol, green pallet, energy) [73]. Even though there are various institution in Malaysia such as Malaysian Palm Oil Board (MPOB), Sustainable Energy Development Authority Malaysia (SEDA), Department of Statistics Malaysia (DOSM), but the data are relatively scattered and challenging to consolidate for further usage.

2.4.3 High business risk profile

Given that biomass industry is a multi-disciplinary industry, has its own unique potentials and risk profiles [74]. Risk, in relation to biomass industry can be best described as positive or/and negative uncertainty that might have on the viability of the industry. With the government initiatives' that introduce regulations and policies to promote the renewable resources in Malaysia, it exposes the industry to regulatory risk. Changes or lack of clarity in the regulations and policies exposes the industry stakeholders to compliance issues as well as increase the costs of operation [15]. Besides, the on-going research and development efforts of biomass commercialisation in Malaysia are still facing commercial viability issues [75]. By relying on the imported technology from oversea which can be costly and obsolete, this contributes to high technology risk as the properties of biomass can be varied significantly depending on the biomass type as described above [76]. The willingness of industry players, particularly of plantation and oil mills owner, in committing a consistent and long-term feedstock supply also plays a crucial role in the development of biomass industry. Failure to prove a long term and sustainable feedstock supplies and reliable supply chain can give rise to the supply chain and feedstock risks [77]. Besides the financial risk and business risk that is commonly seen in other industry, regulatory risk, technology risk, and supply chain risks intensify the overall risk profile of biomass-related project which makes the financing from conventional sources (i.e. bank loans, project finance) more challenging [78].

2.4.4 Financing gaps in local financing framework

Financial institution refers the financing decision by credit decision. Credit risk model and credit scoring scorecard are the most common tools developed and utilised by bank to assess credit risk of the borrowers based on different portfolios (i.e. hire purchase, mortgage, credit card, personal loan, corporate loan, and SME loan). The rating parameters and the weightage of each parameters in the credit risk model and credit scoring scorecard are varied for each portfolio and financial institution, but it should incorporate both quantitative and qualitative components [79]. The importance of qualitative components, particularly human judgements is also emphasized in The Basel Accord (i.e. Basel I, Basel II and Basel III), which is a global, voluntary regulatory framework that help to strengthen the regulation, supervision and risk management of the banking sector [80].

Conventional risk assessment focuses on the business and financial risks faced by the industry. With the world's initiative in promoting green and low carbon project, the necessity to incorporate environmental cost in the risk assessment is also reflected on the emerging trend in overseas that incorporate environmental factors in the evaluation of corporate and sovereign credit risk [81]. As biomass industry is relatively new in Malaysia and possessing unique risk profile, financial institutions are not familiar with these projects and thus have insufficient capacity to evaluate them. By maintaining the traditional lending structure and conventional risk assessment in making credit decision tend to be resulted in higher cost of capital (i.e., high premium in lending rates, higher guarantee amount) or jeopardizing the bankability of biomass-related projects, in the worse cases [82]. In the meanwhile, this also led to an impasse between industry stakeholders, where capital provider and capital lender could not agree on valuations of green project [72]. As a result, they offer few, if any, financial products designed specifically to finance renewable energy projects and require substantial technical assistance to develop such products from technology experts. Financial institutions prefer cleantech projects with high certainty of expected profits and require greater collaboration between borrowers and technology experts to ensure the feasibility of a project. Moreover, lack of "near cash" collateral and poor credit standing also contribute to the difficulty of obtaining credits by many green technology companies [83]. Banks consider much of the equipment and technology for renewable energy projects inadequate collateral due to the fact that the technology and equipment are new and unproven with limited life span.

Thus, it is necessary for financier to aware of the need to create an integrated risk assessment framework and method to aid the credit decision making for environmentally friendly and sustainable project [84]. In China, adopting green finance policy in lending has shown as the best way to sustain the banking business in the competitive market. At the same time, it can also gain reputation as taking up social responsibility to offer financial products and services to environmentally responsible and low carbon technologies, projects as well as companies [85]. Furthermore, risk assessment is also essential in showing the integrated risk profile for green project to allow industry stakeholder to understand the risks associated with green business at the early stage. Consequently, stakeholders able to prepare strategy and solution to reduce, transfer, and mitigate the risk before it becomes a real loss.

2.5 Multiple criteria decision analysis in risk assessment

The development of information technology has made the world become ever connected than before with the easily accessible and attainable information. The unlimited access to information has also increased the complexity of decision-making process, thus increasing the need for multiple criteria decision analysis tools. Multiple criteria decision analysis (MCDA) supports decision making process that involve complex relationship and correlation. The application of MCDA has experienced rapid growth in the recent years, as reflected through the number of publications based on Scopus database literature search in years 2008 – 2018 (i.e., Figure 2-2).

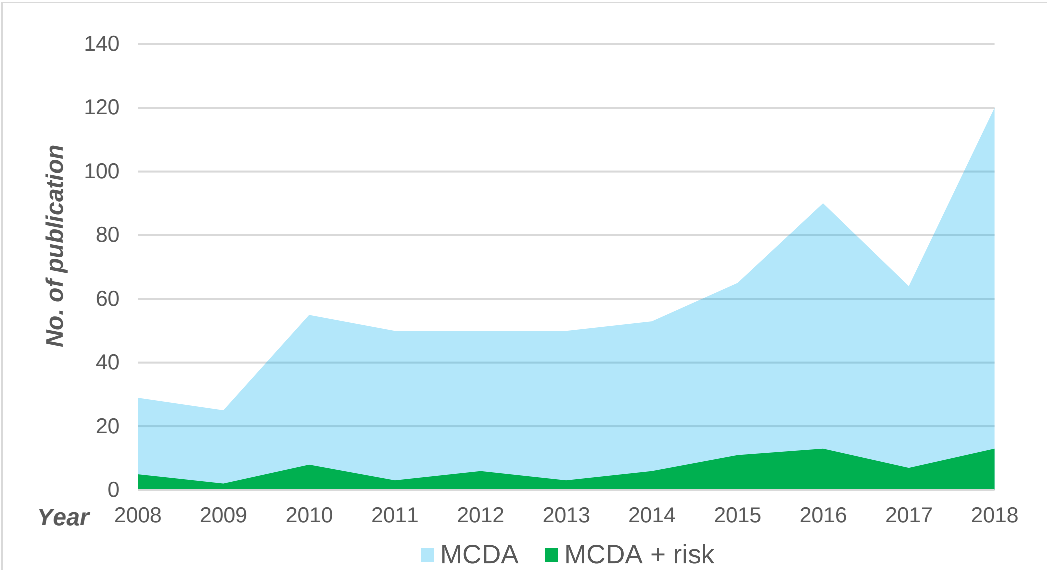


Figure 2-2 No. of publication of MCDA and MCDA on risk related studies from 2008 - 2018

MCDA tools have been widely applied in various areas, particularly in computer science, engineering, decision sciences, mathematics, business, management and account, environmental science and social sciences. Although there are a lot of developed techniques or modified approaches available, the capability of using these methods to assess the risks of an industry by taking in consideration of the complex relationship between all stakeholders is remain minimal, as illustrated through the huge gaps in Figure 2-2.

In engineering arena, traditional risk assessment methodologies, such as the most commonly used risk assessment matrix, relies on qualitative data. The risk assessment matrix is a method that identifies risk based on the severity of risks and its likelihood. The method is commonly used for general project planning and management, as shown in the works of Wambeke et al. [86]. Markovski and Mannan [87] have extended the risk assessment matrix to enable quantitative studies by incorporating fuzzy analysis. The study has shown that the fuzzy risk assessment matrix was able to be implemented in process hazard studies (PHA) and layers of protection analysis (LOPA). For engineering process risk assessment, the hazard identification study (HAZID) is most commonly used for an initial identification study [88]. Consecutively, hazard and operability study (HAZOP) and hazard analysis study (HAZAN) are human-input systematic tools that can be later used to mitigate risks within systems [89]. For a more detailed study of the interaction between risks, the logic tree approach can be used for risk analysis and mitigation. Researchers such as Faber and Stewart [90] have demonstrated the use of the logic tree approach for managing risks in an engineering facility. For risk mitigation strategy selection, Webster [91] has demonstrated the usefulness of the risk level assessment table and spectrum of risk in a case study for drug testing.

In term of the application of MCDA approaches in risk management, Mustafa and Al-Bahar [92] have used the analytic hierarchy process (AHP) methodologies to analyze and manage project risks using pair-wise scoring. In Gandhi et al. [93], DEMATEL is adopted to evaluate and select the best practice in the green manufacturing and supply chain management. Dehdasht et al. [94] applied ANP and DEMATEL in assessing the six main risk associated with the oil and gas construction project (i.e., technical, financial, environmental, design and construction, contractual, policy and political). Furthermore, AHP also combined with SWOT strategy to select and evaluate strategy to overcome biomass supply risks [95]. In research front end, an integrated fuzzy multi-criteria decision-making (MCDM) approach is pro-posed based on the technique in order of preference by similarity to ideal solution (TOPSIS) and criteria importance through inter-criteria correlation (CRITIC) method is proposed for supply chain risk management [96].

In this work, Analytic Network Process (ANP), Fuzzy Analytics Network Process (FANP) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) are adopted to develop risk assessment model and integrate the key components of risk management (i.e., process, stakeholders) in managing risk associated with oil palm biomass industry in Malaysia. All the MCDA tools reviewed in section 2.5.1 to 2.5.3 are adopted in this study, with the detailed steps demonstrated in the respective chapters (i.e., Chapter 5 – ANP; Chapter 6 – FANP; Chapter 7 and 8 – DEMATEL)

2.5.1 Analytic Network Process

Analytic Network Process (ANP) is a generalization of AHP that proposed by Saaty in year1996 [97]. Different with AHP, ANP is represented by a network, which does not only take in account of the dependency of lower level elements on higher level elements, but also includes the "bottom-up" dependence of the higher-level elements on lower level elements and the inner dependency of elements within each cluster. The flexibility that ANP offered in structuring the problem and converting subjective judgements into objective measure has enabled a wide range of application, both in the research and business arena [98]. Furthermore, ANP that refrain the unidirectional problem is also more applicable for real life issue that associates with complex relationship and correlation between multiple variables and level. The influence of the elements between cluster, or within the cluster will then be represented and calculated with supermatrix, converting intangible factors into quantitative factors [97,99,100]. Weightage (i.e. limited weightage and global weightage) will be assigned to represent the importance of elements and clusters [101]. ANP is a relatively new method in Malaysia that is rarely being used by researchers or business to enhance decision making process, particularly in risk assessment. As risk exerting in both qualitative and quantitative criteria and form, ANP enables a clear indication of the relationship and interaction for both tangible and intangible factors, and able to prioritise/rank the importance of the variables based on the objectives of the study.

2.5.2 Fuzzy Analytic Network Process

Despite of the mathematically simplicity and flexibility offered by the ANP, the crisp value input for the pairwise comparison based on Saaty's traditional 9-point fundamental scale has been controversial. It is argued that human judgement can be vague and ambiguous at the same time [102]. In relation with that, fuzzy set theory has often been combined with AHP or ANP for a comprehensive representation of the judgements. Fuzzy set theory was first introduced by Zadeh [103] to overcome constraints of limited information and data. It was later applied to aid decision making, particularly those associated with personal or subjective opinions that involve high degree of uncertainty and imprecision. Fuzzy set theory is incorporated with ANP and AHP by replacing the crisp input for pairwise comparison with fuzzy membership function. Fuzzy membership function does not only enable the level of dominance relationship to be implied more precisely with the inclusion of upper and lower bound, the range of lower bound and upper bound also indicates the confidence level of experts in giving such judgements [104].

2.5.3 Decision-Making Trial and Evaluation Laboratory

DEMATEL method has long established back in 1970s by the Geneva Research Centre of the Battelle Memorial Institution to analyse the casual and effect relationship of complex problem or system [105]. It is well recognized as a powerful tool in analysing interdependency to identify causal and effect factors out of a group of variables [106]. It enables visualisation of the relationship through the representation of matrices and digraph. Similar with ANP and FANP, the expertise of stakeholders is incorporated in the method to identify the primary causal and effect factors that greatly affect the rest of the model. Meanwhile, it also helps to evaluate the activeness of the factors in the whole model. It is widely used as a problem structuring tool, and in recent years, expands its application as multiple decision criteria analysis tools.

Chapter 3. Research Strategy & Methodology

3.1 Introduction

The overall methodology of this work is illustrated in Figure 3-1.

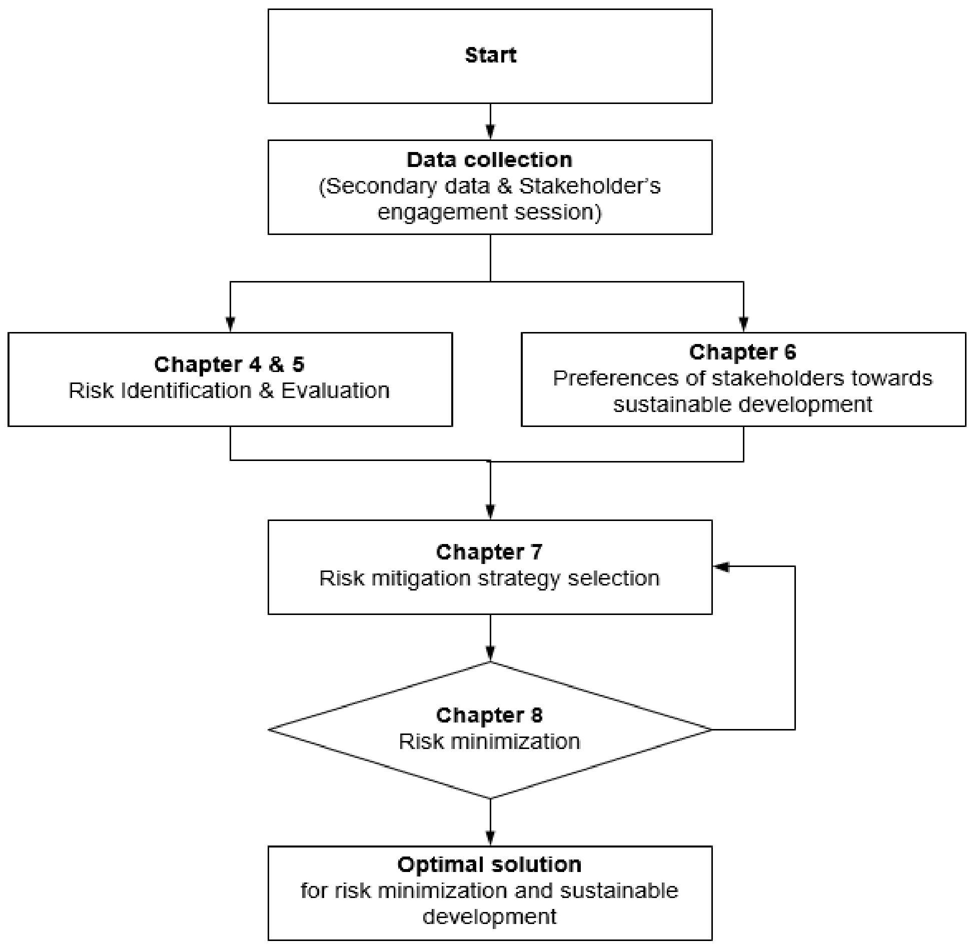


Figure 3-1 Methodology flow chart

Multiple Criteria Decision Analytical Tools are adopted to access risks for the green growth in Malaysia, focusing on the case of oil palm biomass industry. As risk exert in multiple forms, it can be challenging to assess the risk for an emerging industry based on conventional definition, which is the multiplication of the probability of occurrences of risk events with its magnitude. This is because the emerging industry is often lack of sufficient historical data to calculate and estimate the probability of occurrences of risk events and its consequences. In relation with that, a comprehensive framework is introduced by adopting multiple MCDAs to integrate the qualitative input from the experts and experienced stakeholders with available quantitative information to assess the risk for emerging industry and to come out with the best mitigation strategy to achieve optimal solution. This work is mainly divided into four stages, and the detailed information with case study is demonstrated in the respective chapters, from Chapter 4 to 8.

3.2 Overall methodology

As illustrated in Figure 3-1, the work begins with stakeholder's engagement session for data collection. The information is gathered based on two different dimensions, with the first part focuses on the risk associated with the industry, and second part on the preferences of the stakeholders towards sustainable development. As the risks and the preferences of stakeholders are both involving human judgements which could be ambiguos and vague in time, the segregation of pathway is to systematically analyse and prioritise the dominant factors in each main group. Chapter 4 recorded the method and outcome of the identification of risks based on industry life cycle method. Given that different stage of the industry in the life cycle involves different challenges and competitive advantages, the risk associated with different stage is varied as well. Thus, in order to effectively design risk mitigation and management strategy to tackle the real issue (e.g., financing difficulties, unable to fulfil debt obligation, technology failures, disruption of supply chain), it is important the risk identification is done in a comprehensive manner on the predetermined specific scope. Chapter 5 is the continuous work of risk identification, to evaluate all the identified risks and prioritise the key risk. Analytic Network Process (ANP) is adopted at this part of the work to model the risks into multiple cluster and analyse the interdependency relationship of each risk for prioritisation.

On the other hands, Chapter 6 reported the preferences of stakeholders on sustainability indicators that motivate the transition towards sustainable development. Similar with the method adopted in Chapter 4, industry life cycle analysis, the prioritisation of sustainability indicators is done based on the four stages (i.e., pioneering/emerging stage, rapid growth stage, maturity and stable growth stage, and deceleration of growth stage). A modified version of ANP, Fuzzy ANP (FANP) is utilised at this stage to analyse and produce priority weights of each sustainability indicators at different stages, and as the whole industry. FANP is the combination of Fuzzy set theory and ANP, which is believed to better address the vagueness of human judgement through the replacement of ANP traditional 9-point scale with fuzzy membership function. Humans can give satisfactory answers, but it rarely can be claimed as an absolute answer due to the existence of much fuzzy knowledge in the real world. The elements that closely associate with human judgements such as expertise and experience tend to have neither clear boundary nor single standard to represent by a single crisp value between 1 to 9. Thus, the replacement of the fuzzy membership function to crisp value is deemed to produce a more realistic output [102].

After gathering the information on the key risk and supplementing with the preferences of stakeholders, the work is continued with the selection of the risk mitigation strategy which is reported in Chapter 7. This step focuses on integrating the role of different industry stakeholders (i.e., industry players, government agency), as well as the key element of an industry (i.e., process and technology, supply chain) to select the best strategy that can simultaneously reduce the risk level of the respective case. Two MCDA tools, FANP and DEMATEL are integrated to access both the structural dependency, as well as causal-effect relationship of model's elements. The preference of the stakeholders plays a crucial role in this stage to avoid unnecessary waste of energy (i.e., cost, effort) to execute the action plan which has least impact on the risk minimisation and transition towards sustainable development.

Chapter 8 demonstrated the optimisation of the case study for risk minimisation, net present value (NPV) maximisation and payback period (PBP) reduction. It is done by performing Monte-Carlo simulation (i.e., 10,000 times) on the financial performance of the case. The simulation is performed for each mitigation strategy, as well as a combination of strategies at the same time. Sensitivity analysis is performed to identify the impact of each action plan on NPV and PBP. The objective function is to identify the optimal solution which involve the minimum cost with the best outcomes. It also served as a verification of the output generated from DEFANP model. In the event that the outcomes of the simulation is different with the strategy selected from DEFANP model, it is recommended to revisit the input for the DEFANP to make sure that all the information are reflected in the judgements of the questionnaires respondent. Table 3-1 summarizes the methods applied in each chapter with its contribution.

Table 3-1 Summary of the method and contribution

Methodology	Summary	Contribution
Industry life cycle analysis	To identify the key risks (i.e., regulatory risk, technology risk, financing risk, supply chain risk, social and environmental risk) associated with the pioneering stage of palm oil biomass industry.	• Comprehensive risk profile of the pioneering stage of oil palm biomass industry. • Framework to identify key risks associated with different stages of the industry. • Definition of regulatory risk, technology risk, financing risk, supply chain risk, social and environmental risk
ANP	To apply ANP to rank the importance of the five (5) risk categories and twenty-seven (27) risk events to investigate the top risks to be mitigated to resolve the financing difficulties of oil palm biomass related project.	• Risk assessment framework that incorporate both quantitative data and qualitative factors.
FANP	To employ FANP to prioritise the preferences of stakeholders in adopting sustainability practices in their operation at different stages of industry life-cycle.	• Guidelines for industry stakeholders to initiate and to improve the sustainability of the palm oil related project to compliance with the sustainable certification (i.e., RSPO, MSPO, ISPO)
DEFANP	To integrate DEMATEL and FANP to form DEFANP to evaluate and select the best risk mitigation strategy.	• Risk mitigation strategy selection framework to assess the effectiveness and efficiency of the strategy based on the role of stakeholders as well as the key element of the industry. • New formulation that expand the scopes of structural dependency of FANP with causal dependency offered by DEMATEL.

Chapter 4. Risk identification

4.1 Introduction

Despite biomass industry has great potentials in Malaysia, it remains largely under-invested and has had limited success thus far. For instance, the target in the Renewable Energy Policy and Action Plan for renewable energy generated from biomass source was set at 330 MW by year end 2015. Due to several constraints, only about 63 MW was achieved in 2015 [107]. In order to meet the national target for biomass to energy at 1,340 MW by 2030 here is a need to accelerate the growth of the industry [2]. Despite institutional arrangements and policy frameworks being put in place coupled with funding mechanisms and incentives offered to private sectors to participate in the industry, the industry has yet been able to create value along its value chain. While there are many attractive reasons to venture into the biomass industry, there also are potential risks associated with it. Therefore, it is imperative that the perceived concerns of risks should be addressed. Thus, this chapter attempts to identify and reviews several key risks that are related to the biomass industry in Malaysia.

4.2 Industry life cycle approach

Life cycle models are not just applied to life sciences. Industries and product lines also experience a similar cycle of life. In general, an industry life cycle starts with pioneering/emerging stage, followed by growth, maturity and declining stages. There are two related streams of literature that have evolved separately and constitute the backbone of industry lifecycle theory. Starting from a management of technology and operations background, Abernathy and Utterback [108] describe the evolution of an industry's technology over time and how the industry evolution shape firms in the industry. Gort and Klepper [109] examine industry life cycle from the evolutionary economics perspective and provide several important findings, including that a new product has a five-stage life cycle and an industry, to a large extent, is shaped by technical changes and flow of information among existing and potential producers. Porter[110] proposes five competitive forces - threat of new entrants, bargaining power of suppliers, threat of substitute products, bargaining power of customers, and intensity of rivalry – which is a framework for analysing the nature of competition within an industry. A more recent stream of literature has derived a similar life cycle model by focusing on demand characteristics, such as performance thresholds and types of preferences, interact with technological change lead to the evolution of technology and competition during the life cycle of an industry [111–113].

Every industry has its own risks, mostly generated by uncertainties or events that are inherent to that industry [114]. An industry risk analysis is commonly performed by businesses and investors to determine the viability of the industry. Firms conduct risk management process to ensure that every important decision is made with full understanding of the associated risks, trade-offs and shortcomings. With integrated risk management process, businesses not only can reduce costs, but also can enhance business resilience and help them maintain business sustainability in adverse conditions [115]. One approach to industry risk analysis is by assessing industry-related risks throughout the life cycle of the industry. Another approach is carrying out risk assessment at each stage of the industry life cycle.

The biomass industry represents different industries brought together with common goal to utilise renewable organic matters including oil palm waste, timber waste, rice husk, municipal waste and others. These organic materials have potentials to be used in the manufacturing of various value-added products such as biochemical and the generation of renewable energy. Although Malaysia has enormous untapped potentials for commercialisation, the utilisation of biomass in the market has yet to be realized. As the biomass industry in Malaysia is an emerging industry, it is therefore important that industry players recognize and understand several inherent industry risks and challenges faced by the industry. There are various stages to the life cycle of the biomass industry, each with their own applicable risks. Existing industry life cycle literature, thus far has not addressed the link between risks associated with each stage of industry life cycle.

4.3 The pioneering stage of biomass industry and key risks involved

Risk in relation to the biomass industry can be described by the negative or positive impact which future events may affect the viability of the industry. Although both risk and upward potential are related to the uncertainty of future events, risks tend to play a more dominant role in business decisions since investors are generally risk averse. Risk often varies in the likelihood of its occurrence and its impacts from one industry to another and risk changes its nature during the life cycle of an industry [64].

With regard to risks associated with the biomass industry, six key risks seem to play the most dominant role. Typically, most risk assessment approaches focus on business and financial risks. As an emerging industry, the biomass industry is not only exposed to business and financial risks, it also faces several risks that are unique to the industry. These risks include technology, supply chain, environmental, and regulatory risks [78]. As developing countries have increasingly recognized the economic significance of the biomass and renewables, it is imperative that industry players not only understand the risks associated with the biomass industry and but also know sources of these risks so that they can put in place mitigation strategies to reduce and hedge these risks away. The following section reviews several key risks associated with the biomass industry in Malaysia.

4.3.1 Regulatory Risk

Regulatory risk is the risk that a change in regulations and policies will materially affect a business, industry or market. A change or lack of clarity in regulations and policies can increase the costs of operations, reduce the attractiveness of an industry, and/or change the competitive landscape and slow the growth of that industry. The industry's institutional structure, which include the governance of the industry and the regulatory regime is crucial for an industry such as the biomass industry where government subsidies and support policies are integral part of the revenue stream. Conducive regulatory environment and government support will therefore shape the future of the industry and its potential to contribute to Malaysia's efforts to diversify its economy and its path towards a more secure and sustainable energy future. In contrast, fragmented governance and lack of clarity of regulatory framework hamper efforts to promote the growth of the biomass industry. The natural tendency of responsible agencies to develop and pursue their own agendas and organizational structures often ignores issues of coordination with others [15]. Further, resistance to coordination efforts can also contribute to fragmented governance in the Malaysian biomass industry.

In line with the National Renewable Energy Policy and Action Plan (2009), which is the renewable energy roadmap, Malaysia enacted the Renewable Energy Act 2011 and Sustainable Energy Development Authority Act 2011. The Renewable Energy Act 2011 provides the feed-in-tariff (FiT) mechanism which allows electricity produced from renewable resources (i.e. solar, biomass, biogas, small hydro and geothermal) to be sold to power utilities at a fixed premium price for specific duration. By guaranteeing access to the power grid and setting a favourable price per unit of renewable energy, the FiT mechanism does not only support rapid renewable energy deployment but also enhances energy security as well as addresses climate change challenges. Table 4-1 shows the current FiT rates for various renewable energy sources in Malaysia while Table 4-2 provides the feed-in-tariff rates for various Asia Pacific countries for 2014. The feed-in-tariff rates for select European countries are also provided in Table 4-2 for benchmarking purposes.

Table 4-1Current basic feed-in-tariff (FiT) rates for renewable resources in Malaysia. Source: [116]

Capacity of Renewable Energy Installation	FiT Rate (Ringgit Malaysia per KWh)	Effective Period
Solar Photovoltaic		
≤ 4kW	0.7424	21 years
Above 4kW – 24kW	0.7243	21 years
Above 24kW – 72kW	0.5218	21 years
Above 72kW – 1MW	0.5041	21 years
Biogas		
≤ 4MW	0.3184	16 years
Above 4MW – 10MW	0.2985	16 years
Above 10MW – 30MW	0.2786	16 years
Biomass		
≤ 10MW	0.3085	16 years
Above 10MW – 20MW	0.2886	16 years
Above 20MW – 30MW	0.2687	16 years
Small Hydro		
≤ 2MW	0.2600	21 years
Above 2MW – 10MW	0.2500	21 years
Above 10MW – 30MW	0.2400	21 years
Geothermal		
≤ 30MW	0.4500	Yet to be determined

Energy and utility companies are operating in a dynamic market and are continually under pressure from various influences including regulators and government. This has resulted in more rules and regulations governing energy and utility industry, whether environmental protection regulations or industry-specific such as FiT rate and quota policies. Renewable energy companies are likely to face regulatory risk as a change in energy policy such as FiT rate reduction may adversely affect their profitability. Further, macroeconomic uncertainty also entails significant financial risk, political, and regulatory risk as governments may reduce financial support for renewable energy projects as part of austerity measures. This will slow down the growth of the industry and making renewable energy projects less attractive for investors.

Table 4-2 Feed-in-tariff rates for renewable sources for various Asia Pacific countries and selected European countries. Source: [117]

Selected Regions and Countries	Renewable Resources			
	Hydropower	*Wind*	*Solar*	*Biomass*
Asia-Pacific Countries				
China				
RMB/kWh	0.29 to 0.45	0.51 to 0.61	1 to 1.15	0.65
USD/kWh	0.05 to 0.07	0.08 to 0.10	0.16 to 0.19	0.11
Indonesia				
IDR/kWh	656	Yet to be	2,918 to 3,502	940 to 1,700
USD/kWh	0.06	introduced	0.25 to 0.30	0.08 to 0.15
Japan				
JPY/kWh	25.92 to 36.72	23.76 to 59.4	30 to 37	14.04 to 42.12
USD/kWh	0.25 to 0.36	0.23 to 0.58	0.29 to 0.36	0.14 to 0.41
Malaysia				
MYR/kWh	0.00	Yet to be	0.00 to 3.46	4.05
USD/kWh	0.00	introduced	0.00 to 1.09	1.27
Mongolia				
MNT/kWh	64.69 to 143.75	115 to 215.63	215.63 to 431.25	Yet to be
USD/kWh	0.03 to 0.08	0.06 to 0.11	0.11 to 0.23	introduced
Philippines				
PHP/kWh	5.90	8.53	9.68	6.63
USD/kWh	0.14	0.20	0.22	0.15
Thailand				
THB/kWh	0.8 to 1.5	3.5 to 4.5	6.5	0.3 to 0.5
USD/kWh	0.03 to 0.05	0.11 to 0.14	0.20	0.01 to 0.02
Vietnam				
VND/kWh	Yet to be	1,614	Yet to be	Yet to be
USD/kWh	introduced	0.08	introduced	introduced
European Countries				
Germany				
EUR/kWh	0.034 to 0.127	0.35 to 0.19	0.18 to 0.244	0.06 to 0.25
USD/kWh	0.05 to 0.17	0.05 to 0.25	0.02 to 0.33	0.08 to 0.33
Italy				
EUR/kWh	0.096 to 0.257	0.127 to 0.291	0.00	0.125 to 0.257
USD/kWh	0.13 to 0.34	0.17 to 0.39	0.00	0.17 to 0.34
United Kingdom				
GBP/kWh	0.0299 to 0.1901	0.0307 to 0.16	0.0638 to 0.1438	0.092 to 0.11
USD/kWh	0.05 to 0.32	0.05 to 0.27	0.11 to 0.24	0.15 to 0.18

Energy policies are an important policy issues for all countries, particularly for developing countries. Many developing countries, including Malaysia have subsidized their energy sector for a variety of reasons, focusing particularly on improving growth and equity. However, energy subsidies do not only have negative economic and environmental effects, they can also distort investment cost decisions [82]. Transport fuel has been heavily subsidized in Malaysia since 1983 and now accounts for more than 40 percent of the country's gross development expenditure. Fossil fuel subsidies gradually grew from MYR8.154 billion in 2005 to MYR 24.73 billion and MYR 23.46 billion for 2012 and 2013, respectively [118]. In 2013, in response to Malaysia's fiscal deficit and rising national debt, the government began the fuel subsidy rationalization efforts which have resulted in an increase of retail fuel prices in recent years. However, despite the fuel subsidy reforms, the implementation of the reform remains politically sensitive. The continued use of fossil fuel subsidies presents a major barrier to the development and deployment of renewable energy technologies and discourages investment in renewable energy sources [16]. In this context, and faced with the regulatory challenges described above, policy makers looking to encourage renewable energy development may attempt to further reform fossil fuel subsidies to create a level playing field for renewable energy companies or may employ other measures to promote renewables and achieve cost competitiveness [119].

Solar power electricity generation has increased rapidly in recent years and in 2016 accounted for 52 percent of all renewable electricity in Malaysia (SEDA, 2017). However, other renewable sources such as biogas, have been neglected. For instance, the power generated from biogas was about 46GWh while the power generated from solar was about 249.35GWh (SEDA, 2017). Biogas, as a source of renewable energy should be viewed as superior compared to other renewable sources such as solar PV as it offers more than just power. Malaysia generates about 60 million tonnes of POME every year and it is expected to increase to 70-110 million tonnes by 2020. POME is an attractive feedstock for bio-methane production and is abundantly available in all palm oil mills, hence it ensures continuous supply of substrates at no or low cost for biogas production [2]. Utilisation of POME for biogas production does not only address a serious environmental issue but it also promotes “waste-to-wealth” concept [4]. Although there is a high energy potential from POME, the utilisation of POME for biogas production in Malaysia remains low because there is no standard technology for POME management and treatment. Majority of palm oil mills treat POME using ponding system due to its low operational costs. A suitable regulatory framework of capturing methane gas from anaerobic digestion of POME is likely to help promote the shift from the open ponding system to biogas plant for methane gas capture. Further, financial and fiscal incentives provided by the government to renewable energy producers may also help them with the high capital investment typically associated with the biogas power generation plant [120].

In summary, supporting policies, renewable energy subsidies, investment and tax incentives for the biomass industry are likely to enhance the economic viability at the early stage of the industry, thus reducing regulatory or policy risk of the industry. Consistent, adequate and predictable regulatory framework is also essential to the success of the biomass industry, so that the industry players can easily manage their regulatory risk more effectively [121].

4.3.2 Financing risk

Financing risk relates to risk of insufficient access to capital. Financing risk also arises from inability of project developers meet debt obligations such as interest payments, particularly during the project’s initial years of development and operations. At the pioneering stage of life cycle, funding for a biomass project is a particular challenge. High financing risks are seen especially in capital intensive and highly leveraged and complex biomass projects such as biogas power plants and large-scale bioenergy storage. Further, financing amount typically depends on the costs of innovation process relative to its expected future revenues which in turn determined, among others, by the maturity of the technology in question and the technology's dependence on other innovations or infrastructure to be built [122]. Grubb (2004) argues that the cost of a project or innovation is likely to increase the closer the technology is to deployment.

Bank lending is often linked to biomass projects with high certainty of expected annual profits. Small plant and standalone project developers have traditionally attempted to finance their projects by bank debts. However, a large financing gap exists because the lending structure of the banking sector has not expanded their scope of financing beyond traditional financing in sectors such as consumer and public infrastructure projects. Depending on the circumstances, financial institutions and capital markets may demand a premium in lending rates for financing of biomass-related projects, making cost of capital expensive, for instance renewable energy projects because more capital is at risk upfront compared to conventional energy projects [124]. Moreover, lack of collateral and poor credit worthiness also contribute to the difficulty of obtaining credit, particularly for poorly capitalized project developers whose projects and technologies are at the early stage of development. As a result, obtaining bank debt has become more challenging and costly.

In addition, financial institutions often lack standardized scoring and risk assessments for biomass-related projects and technologies, thus jeopardizing the bankability of these projects. Given that the biomass industry in Malaysia is relatively new, financial institutions have neither the experience nor adequate knowledge about the industry. Available bank loans may also be too short relative to the equipment or investment horizon of a project. Shorter tenure loans inevitably entail a refinancing risk. As projects increase in scale and complexity, financing risk rises too. During credit crunch period, financing risk is even more acute as credit supply is significantly constrained and lenders tend to discriminate between project developers who do and do not have cash flows problems.

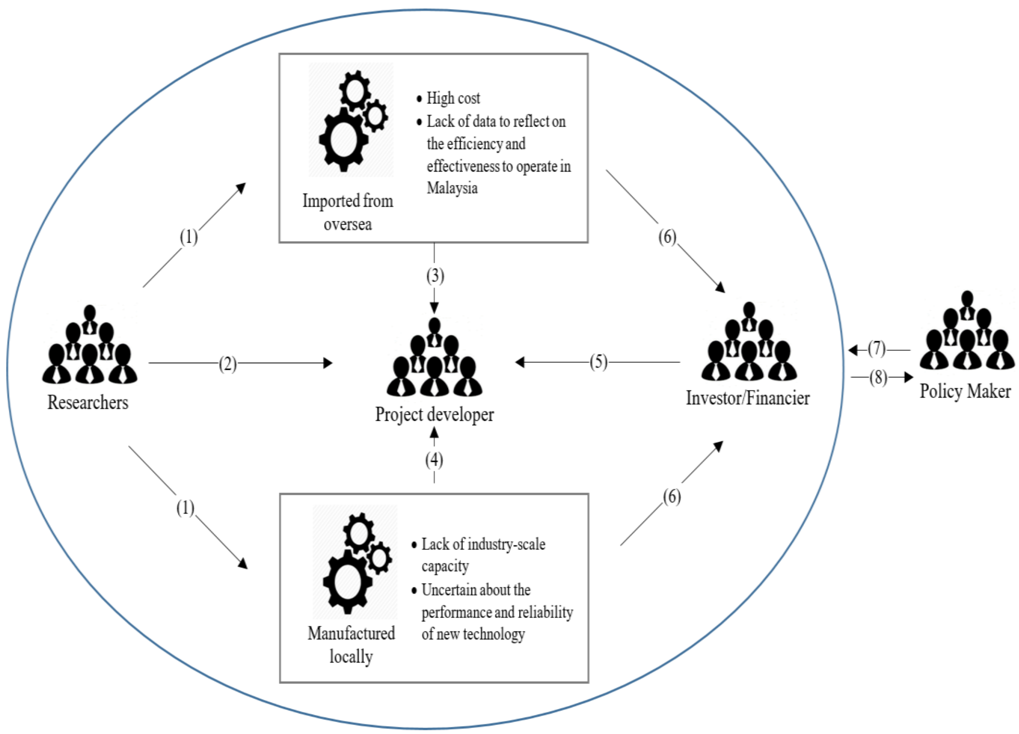
To overcome financing risk and to ensure continuing flow of funding opportunities for the successful implementation of biomass investments, alternative sources of financing other than those from financial institutions and government are crucial. Several possible financing means are currently available for project developers to seek such as venture capital, capital markets, private equity and project finance. Venture capital and private equity investors are particularly important to biomass-related projects as they provide the early stage financing needed to commercialise new clean technologies to the market [125]. Bond issuance could supplement bank lending and bond market has largely been untapped for renewable energy finance though it takes time for the market to grow as investors take conservative approach to new asset classes and need time to develop valuation expertise [126]. Further, large utilities companies which have better access to bond markets can take small equity participation in start-up firms to share investment costs. In recent years, project finance has also emerged as a leading financing alternative to clean energy projects [127]. The basic premise of project finance is that financiers lend money for the development of a project primarily based on the project's risks and future cash flows while the assets of the project serve as the collateral for the loan [128]. As various policies are created and implemented, it is important that policy makers recognize financing difficulties faced by project developers and pay attention to the impacts of biomass-related policy design on financing.

4.3.3 Technology risk

Technology risk arises as a result of a technology does not operate or perform as effectively and efficiently as expected. Examples of technology risks include unproven technology, bad design, engineering failure, and poor technology implementation or execution. A bad technology decision can derail or destroy an otherwise a compelling biomass-related project. As the biomass industry is an emerging industry in Malaysia, project developers primarily rely on technology imported from abroad which can be costly. Although there are ongoing research and development efforts to develop new efficient routes to biomass-derived chemicals and improve existing green technologies, the efforts appear to have scalability issues which can affect the commercial viability of the technologies [75]. Industry stakeholders such as investors may not consider unproven technology in their investment decision making because they are not able to evaluate the reliability and stability of the technology over time. Recognizing various risk associated with new technologies, investors are likely to demand higher premium for their investment which in turn increase cost of financing for project developers [54]. In addition, the uncertainties of future technology development and application in sustainable development-related industries may also increase the technology risk of the biomass industry even when the technology may work well in a laboratory or scientific setting [129]. Therefore, the degree of techno-economic attractiveness of a technology (i.e., efficiency, quality, cost-effectiveness, environmental performance) plays an important role in its uptake.

Despite a wide range of policy initiatives to push for clean technologies adoption, the progress in development and deployment of these technologies in Malaysia has been relatively slow. The diffusion of existing technologies also advances at a very slow pace. This could be explained by the lack of capacity at the industry level to innovate and to change to new technologies due to high cost of replacing production process in sectors such as transport and energy sectors [130]. Insufficient availability of expertise in clean production and inadequate institutional support to drive technological capacity building also contribute to slow clean technologies advancement in Malaysia [131]. As a result, slow adoption and diffusion of clean technologies pose greater technology risk to project developers, investors and other stakeholders in the biomass industry.

Further, lack of familiarity with green and renewable energy technologies throughout the value chain and among stakeholders of the biomass industry increases the equipment procurement and maintenance costs. Unlike renewable energy sources, conventional production methods have already experienced cost reductions through technology deployment (i.e., project learning curve). Moreover, the number of suppliers for latest technologies is relatively limited which results in a number of risks related to the availability of a technology's components for maintenance purpose and increases the probability of delay in project completion. At a pioneering stage of industry life cycle, proven and state-of-the-art as well as economically feasible technology can significantly reduce technology risk. Technology risk requires attention of various stakeholders in the biomass industry. These stakeholders include researchers, technology and project developers, financiers/investors, and policy makers. It is therefore imperative that there is a need for these stakeholders to improve existing technologies or develop innovative mechanisms to manage and mitigate this risk. Figure 4-1 illustrates the relationship of stakeholders and uncertainties that contribute to technology risk.



Research: (1) Provide and scientific and technical support, enhances and contributes to development and improvement of technologies; (2) facilitates knowledge transfer and shares scientific and technical inputs; **Project developer**: (3) requires support for import tax exemption and import tariffs; (4) incentivized with favorable bonus feed-in-tariff rates; **Investor/Financier**: (5) Provides financial support for technology development and deployment; (6) Requires proven technology and operation data when evaluating technology performance (e.g. reliability, stability, profitability); **Policy Maker**: (7) Formulates clear policies that promote the green growth agenda and provides governmental support and incentives to promote the uptake of clean technologies; (8) Sets regulation of compliance with environmental standards and guidelines for sustainability best practices

Figure 4-1 Relationship between stakeholders in the biomass industry and uncertainties that contribute to technology risk.

4.3.4 Supply chain risk

In general, supply chain risks relate to the probability and impact of internal and external events that could adversely affect the supply chain and interrupt the flow of goods, information, processes and finances of businesses in an industry [132]. The growth of the biomass industry depends largely on the management of supply chain risk through coordination or collaboration among supply chain actors in the industry to ensure a guaranteed biomass feedstock and minimises supply interruptions. Several types of biomass sources are bulky, voluminous and often seasonably available. These biomass characteristics create serious concern in the logistics and reliability of supply of the feedstock. Industry players often raise their concerns on the difficulty in obtaining a guaranteed biomass feedstock and consequences of supply interruptions which hinder project development and pose financial risk to capital providers [73].

Feedstock logistics plays a critical role in the biomass industry's supply chain as it links to feedstock production and conversion. The economics of bioenergy is highly dependent on feedstock costs which include types, yield, location, physical and chemical properties and logistics – harvesting/collection, pre-processing, transport and storage [77]. Contrary to fossil fuels industries (e.g.., oil and gas and coal), biomass feedstock ownership is highly fragmented. For instance, Malaysia Palm Oil Board [133] reports that 61 % of the oil palm plantations belong to the private estates, 22.2 % are owned by state schemes/government agencies, while independent smallholders own the remaining 16.8 % of total oil palm plantations. Dispersed ownership of plantations coupled with remote locations of these plantations complicate the feedstock logistics. For example, in the absence of temperature-controlled storage facilities, the physical and chemical properties as well as the moisture levels of the pre-processing feedstock may be detrimentally altered [134]. Therefore, feedstock logistics represents a major risk factor in the industry's supply chain. It can also be the highest cost component of the supply chain depending on types of feedstock.

Furthermore, given that oil palm biomass is not traded widely as a commodity, a supply chain has not yet been established, it increases operational risks for biomass project developers. They need to source the feedstock from plantations using their own resources such as transportation and processing and storage facilities. In the absence of a liquid market, suppliers are likely to look for long-term procurement agreement from, for instance renewable energy power companies to support their investment case [135]. Moreover, the lack of clarity regarding sustainability requirements, regulatory regime, and subsidies as well as incentives has led to the current cautious levels of supply chain investments despite the potential opportunities. The operational costs associated with oil palm biomass supply chain can have an impact on profit margin and operational efficiency. Without evidence of long-term and sustainable feedstock supplies and reliable supply chain, obtaining financing from traditional sources such as bank loans and project finance becomes even more difficult. Venture capitalists are also likely to shy away from investing in biomass-related projects.

Currently, there is minimal infrastructure in place for biomass supply chain in the Malaysian biomass industry. A key priority for project developers, particularly those in early stage of the industry, is to mitigate supply chain related risks. Innovative arrangement such as strategic partnerships with plantation owners and millers and vertical integration between upstream and downstream industry players can minimise risks along the biomass supply chain [136]. Strategic partnerships with other industries such as paper or pulp industry which potentially use the same fuel but already have an established supply chain can also be further explored to achieve supply chain synergies such as cost savings [137]. Decentralized biomass collection and processing facilities (hubs or depots) which linked to the overall biomass feedstock supply chain may also help reduce costs associated with feedstock logistics [138]. The support structure for developing a robust supply chain network, particularly for an emerging industry, is crucial in the management and mitigation of supply chain risk so as to ensure long-term viability of the biomass industry. In addition to the development of a robust supply chain network, industry players also can manage risks in a holistic manner by using, for instance, supply chain risk management (SCRM) approach. The steps involved in determining biomass supply chain using the SCRM include identifying the risks, analysing the risks, and developing mitigation strategies [139].

4.3.5 Social and environmental risk

Environmental risk can be broadly defined as actual or potential threat of adverse effects on general and ecological aspects of environment and well-being of human beings by effluents, emissions, wastes, resource depletion and other pollutants which arise from an organization's activities. In general, renewable forms of energy are considered "green" because sources such as wind, solar and wave cause little depletion of natural resources and emit zero emissions during power generation. Biomass energy is renewable but shares several characteristics with fossil fuels. Similar to fossil fuels, biofuels can be transported and stored and can generate power on demand. Biomass power plants raise similar though not identical environmental concerns about air emissions at the conversion stage and water use as for fossil fuels power plants [140]. In addition to air emissions at conversion stage, there are also other environmental risks surrounding biomass-related industries, particularly risks associated with producing biomass. Environmental concerns include the sustainability of increasing crop yields and intensifying agriculture which have significant impacts on food production and food security [141] and damage land use change [142].

Environmentalists have long argued that oil palm agriculture is the greatest immediate threat to deforestation and environmental degradation in Indonesia and Malaysia [143]. As forests are being cleared and converted to oil palm, the extent of biodiversity losses associated with this process has increased [144]. For biomass-related projects to deliver their potentials, it is essential that project developers adhere to sustainability and ethical business practices and environmental policies. It is also important to note that complying with environmental regulations adds to project developers' operational risks and subsequently increase their costs. Although there are compliance costs, compliance with sustainability standards is a pre-requisite for government subsidies and tax incentives. Further, to minimise negative perception on their feedstock production practices, adoption of voluntary certification schemes such as the Roundtable of Sustainable Palm Oil (RSPO) certification and adherence to them are likely to attract and boost investor confidence [145]. Economists traditionally view that environmental regulations add costs to companies and slow down productivity and growth. More stringent environmental regulations may affect the competitiveness of newly emerging industries such as the biomass industry. An alternative view is that stricter environmental regulations may induce innovation in clean technologies and help firms achieve technological leadership and boost broader economic growth. Although Malaysia has enacted several environmental laws and policies, these laws and policies have not been properly implemented due to several problems such as non-coordination, weak enforcement and customary attitudes [146]. Given the uncertainty surrounding the future environmental and sustainability regulations, one option that project developers could consider is embedding sustainability criteria and best practice principles into the company's operations and processes ahead of time before more stringent environmental laws and policies are properly enforced.

In general, social risk arises from business and operational activities and interactions with various stakeholders in the biomass industry, particularly employees and general public. These activities and interactions may result in labour and human right violations and environmental degradation which could adversely affect the standard of living and livelihood of affected communities. The vast majority of biomass resources in Malaysia are the by-product of other main economic activities such as timber and palm oil industries. Developing new industries such as the biomass sector does not only reduce dependence on traditional commodities but also helps create employment opportunities in rural areas and along the value chain of the industry from the biomass production or procurement, to its transport, conversion, distribution and marketing [147]. The emergence of biofuel markets is expected to directly affect the livelihood and economy of rural population, given that almost all biomass feedstock are cultivated in rural areas. In 2015, biofuel employment in Thailand, Malaysia, and the Philippines reached 76,900, 31,800 and 9,700 jobs, respectively [148].

Despite recent government efforts, there are a number of social challenges associated with the biomass industry. There is considerable lack of public and industrial awareness regarding sustainable and green technologies and the benefits they can provide to businesses and communities [149]. Although public awareness does not directly affect the viability of the industry, it certainly impedes the growth of the biomass industry as adoption and market acceptance determines the demand of biomass-derived products. The use of low-cost bio-wastes may also result in little public acceptance due to environmental fears that such fuels are in general considered as dirty and contaminated [150]. In general, sustainability issues and environmental awareness among consumers in developing countries including Malaysia are relatively lower than those in developed countries. For instance, Ramayah, Lee, & Mohamad, (2010) find that environmental consequences are not a significant factor of environmentally responsible purchase intention among consumers in Malaysia. Thus, general lack of awareness of the importance, benefits, and potential of renewable energy, for instance, both among general public and major stakeholders' constraints rapid deployment of renewable energy. The implementation of sustainable construction practices for the built environment sector in Malaysia is also low due to lack of environmental awareness, poor environmental law enforcement, and high compliance costs [152].

Awareness programs and the development of technical and safety standards are needed to encourage the acceptance of proven technologies and environmentally friendly products in the marketplace so that industries related to clean technologies and its products can be successful. Having proven technologies and products with market acceptance does not only help companies, particularly young companies in an emerging industry, accelerate revenue streams but also attract investors and financiers. Table 4-3 summarizes the definition of key risks generally associated with the biomass industry, based on a systematic and throughout review.

Table 4-3 Definition of key risks associated with the biomass industry

Type of risks	Description	References
Regulatory	Risk arises from the probability that regulatory agencies will make changes in the existing laws and regulations (or will impose new rules and regulations) that will negatively affect the industry.	[15,16,119–121,153]
Financing	Risk arises from the lack of access to credit and guarantee facilities, particularly those tailored for green technologies and investment projects.	[122,123,126,127,153]
Technology	Risk relates to uncertainty surrounding the implementation and performance of technologies that are currently in use.	[54,129–131,154]
Supply chain	Risk arises from the occurrence of disruptions of supply of raw materials, information, and products from suppliers in the supply chain that adversely affects process flows and delivery of final products to end users.	[77,134–136,139,155]
Social and environmental	Risk arises from an organization's business activities that may present threats to environment (atmosphere, water, and land, biodiversity, and community livelihood) and socio-economic welfare and well-being of its stakeholders (employees, regulators, consumers, suppliers, and investors)	[64,140,150–152,141–147,149]

4.4 Conclusions and Future works

The potential for biomass to contribute to the Malaysia's future energy needs and overall economic diversification is significant. Recognizing the potentials, the government has put in place institutions and introduced policies to facilitate and promote renewable energy and green technologies industries. While renewable energy projects from solar have high visibility and acceptance in the marketplace, biomass-related projects are not as readily recognized in Malaysia. Many challenges remain in place in order for the biomass industry, particular when the industry is at an early stage, to grow. The industry is susceptible to several risks including regulatory, financing, technology, supply chain, and environmental and social risks. While project developers remain keen to de-risk some of these risks in order to unleash the growth potential of the industry and make the sector investment financially attractive, de-risk mechanisms such as institutional supports and incentives need to be put in place. For an emerging industry such as the biomass industry, policy de-risking instruments that address and seek to remove underlying barriers that cause these risks are needed. For instance, comprehensive biomass database is necessary for the formulation of effective and robust biomass policy and strategic plan to promote the green growth and renewable energy development and deployment. Biomass-related industries can also benefit from the database by identifying the size and capacity of biomass available in their vicinities so that they can make appropriate investment decisions. Collaborative efforts between the biomass industry players and other stakeholders in the industry such as logistics providers and scientific and technical expertise in order to achieve an integrated supply chains, develop consistent technical standards for the industry, identify training needs and programs, and share information.

Our work contributes to the existing knowledge of risk assessment and management by providing an overview of key risks associated with a specific industry, namely the biomass industry which is relatively new in developing countries including Malaysia. The study offers several noteworthy contributions for business management and decision making in the biomass industry in the form of understanding several specific risks and recommendations to manage and mitigate these risks. Despite this work mainly focus on identify and understand the key risks associated with the biomass industry at pioneering stage, this framework is also applicable in other industry at different stages of industry life-cycle (i.e., rapid growth, maturity, declining of growth). Thus, the study serves as reference for understanding risks using the industry life cycle approach.

Chapter 5. Risk Estimation and Evaluation

5.1 Introduction

Risk assessment can be divided into three stages: (i) identification; (ii) estimation and (iii) evaluation. The result of risk identification (i.e., Chapter 4) served as the basis for the development of questionnaires and the construction of the network model for risk estimation and evaluation. Even though the market for green bonds and other types of financing options with environmental and climate-related benefits has grown rapidly in recent years, less attention is being paid to assessing the risk profiles of sustainable projects that contributes to green growth. Risk assessment is a critical component for project financing, but generic risk assessment methodologies may not apply to sustainable projects. Consequently, the risk profile of different categories (e.g., energy sector, building sector, waste management sector, transport sector) of projects will also vary considerably, so a tailor-made risk analysis approach will be required for sustainable projects. Financial institutions and financial markets play a key role in assessing financing risk, originating loans and underwriting the issuance of equities and debt for various investments, particularly for green investments. However, generic risk assessment models and scorecard approaches currently being employed in many financial institutions, particularly in developing countries including Malaysia are mostly appropriate for other types of investment such as public infrastructure and commercial projects rather than specifically tailored for risk assessments of sustainable project investments [30]. Limited understanding and lending experience of green financing among local financial institutions may create biases in their lending decisions, causing viable projects to be rejected for financing. Therefore, it is imperative to develop a user-friendly evaluation tool to assess the identified risks in a comprehensive manner to help industry players to address these risks by putting in place appropriate risk management and mitigation measures. In this chapter, ANP is employed to access the total 27 key risks associated with oil palm biomass, based on Chapter 4. The calculation is done with spreadsheet software, Microsoft Excel.

5.2 Methodology

The framework of developing the risk assessment model is illustrated in Figure 5-1. The detailed explanation for each stage is as follows:

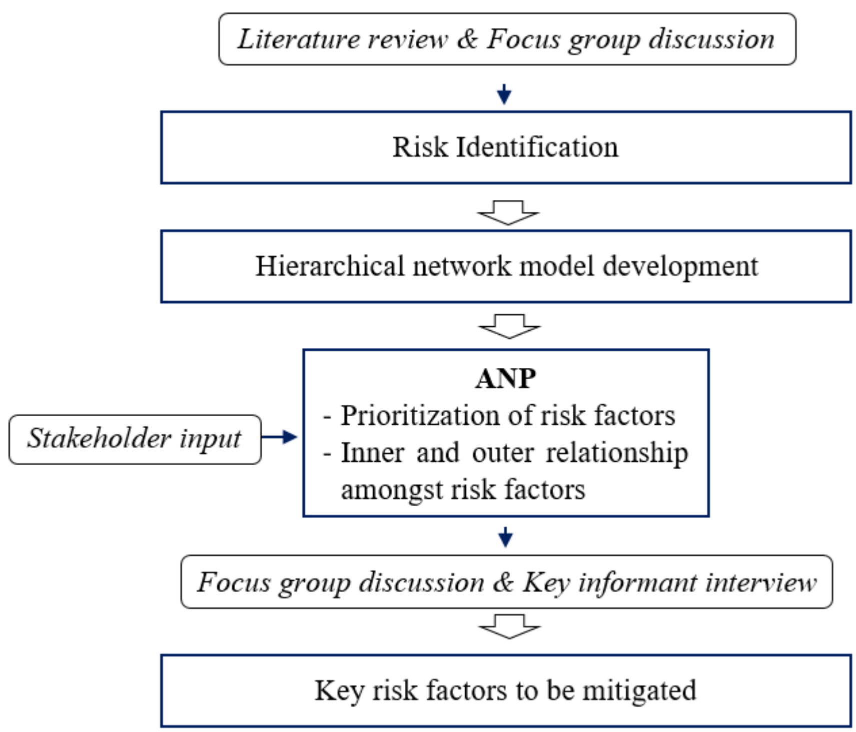


Figure 5-1 The flowchart of the methodology

Step 1: Risk Identification - Literature reviews and focus group discussion are performed to gather inputs from the experts to understand and identify the risks (i.e. internal and external events) that closely associated with the industry.

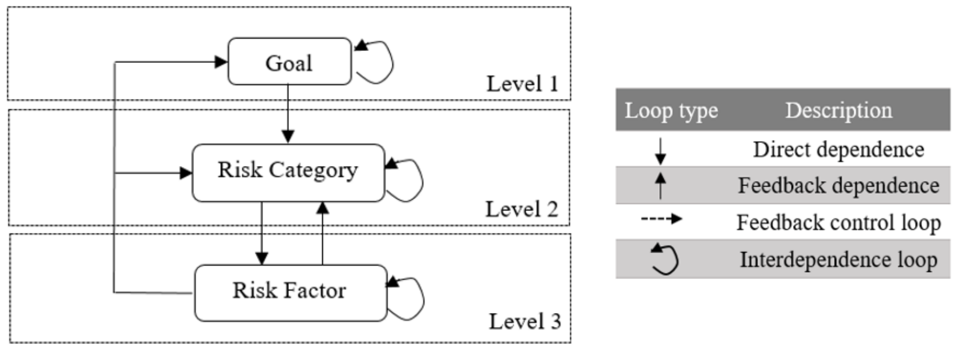


Figure 5-2 The illustration of risk assessment hierarchical network model

Step 2: Hierarchical network model development - The model is formed with combination of clusters and elements in hierarchical network to entail the objective of this study. As illustrated in Figure 5-2, the hierarchical network consists of three level, where level 1 represent the goal, followed by level 2, risk category, and level 3, risk factor. The relationships of the clusters and elements are indicated by arrows. The downward arrow from one cluster to another implied that the element(s) in lower level cluster is depending on the element(s) in upper level cluster. Meanwhile, upward arrow indicates the feedback dependence of the element(s) in the lower level cluster with element(s) on upper level's cluster. The looping arrow in cluster itself showed the mutual influence of elements within its own cluster. There are two types of inner dependence loops, which are independence loop and interdependence loop. Independence loop apply for clusters where the elements only depend on itself, while for interdependence loop, the element(s) is affected by other elements in the same cluster. Last but not least, feedback control loop is the structural dependence connecting all the elements and clusters back to the goal [102,156].

Step 3: Elicit judgements with pairwise comparisons' survey – Experts of the subject matter are required to compare the dominance relationship of the elements within its cluster and other clusters in pair (i.e. importance, preferences, likelihood and influence) based on pairwise comparison method. The 9-point fundamental scale of AHP developed by Saaty [157] is adopted in this survey to represent the intensity of the dominance relationship. The description of the scale is as following: 1–equally important; 3–moderately more important; 5–strongly more important; 7–very strongly more important; 9–extremely more important.

$m =$

	e_1	e_2	$\cdots$	e_n
e_1	1	w_{12}	$w_{1\ldots}$	w_{1n}
e_2	$1/w_{12}$	1	$w_{2\ldots}$	w_{2n}
$\vdots$	$1/w_{1\ldots}$	$1/w_{2\ldots}$	1	$w_{\ldots n}$
e_n	$1/w_{1n}$	$1/w_{2n}$	$1/w_{\ldots n}$	1

a. Generalized local priority matrix

$S =$

i/j	L1	L2	L3
L1	1	e^T	e^T
L2	S_{21}	S_{22}	0
L3	0	S_{32}	I

b. Generalized Supermatrix

Figures 5-3 An example of the generalized local priority matrix and supermatrix

Step 4: Formation of pairwise comparisons matrix – This step consists of the calculation of eigenvectors of elements and clusters to form local priority matrices. Experts' judgements serve as the input for upper right part of the matrix (i.e. w_{12}), and the lower left is the inverse of the upper right value (i.e. $1/w_{12}$) as illustrated in the Figure 5-3a. Geometric mean method is used to combine the input from multiple experts. AHP eigenvector method involved the multiplication of the local priority matrix by itself, until the normalized priorities weightage become stable. This method also provides a measure for the consistency of the experts' judgement, to make sure the decisions of respondents are logical and rational in term of being self-consistent. Consistency ratio (CR) is calculated by dividing the consistency index (CI) by random index (RI). The consistency ratio is recommended to be less than or equal to 0.1 [157], otherwise, it is suggested the respective expert(s) to revisit his/her pairwise comparisons judgements.

Step 5: Formation of supermatrix – Arranging the eigenvectors of each local priority matrix based on the hierarchical network model to form unweighted supermatrix [S] as illustrated in Figure 5-3b. The input to the supermatrix [S] represents the relationship between the clusters and elements in the model. S_{ij} is interpreted as the direct relationship of the elements in cluster j with respect to cluster i. For example, S_{21} is the eigenvector representing the priority weightages of elements in level 2 cluster (i.e. risk category) depending on level 1 cluster (i.e. goal). If there is no direct relationship between the two clusters (i.e. level 1 with level 3), then the block matrix (i.e. S_{31}) will be represented by null block matrix (i.e. [0,…,0]). S_{ij} for all i=j represents the inner dependence relationship of the elements on its own clusters. In the events of independence loop, where the element only depends on itself, the input will be represented by identity block matrix (I). e^T is the block matrix of unit row vector (i.e. [1,…,1]) that represent the feedback control loop that make sure the whole model is strongly connected, as every decision elicited by experts should be based on the goal of this study. Normalize the unweighted supermatrix with the total sum of the column to make it column stochastics resulting in weighted supermatrix.

Step 6: Formation of the limit matrix – The supermatrix is then raise to power until it converged to same value across all column (i.e. same figure up to 4 decimal places). By doing so, the limit matrix captured all the possible interaction of elements and clusters in the model.

5.3 Problem structuring and model development

The outcomes from previous chapter, risk identified in pioneering into Malaysian biomass industry that consists of five main risk categories, namely technology risk, financing risk, supply chain risk, regulatory risk and environmental and social risk are served as the backbone of the assessment model. It served as the basic of the hierarchical network model, with further verification and validation from other literatures and outcomes from focus group discussion. The summary of the final risk category and factors included in this work are illustrated in Table 5-1

Table 5-1 List of identified risk factors

Risk category	Risk factors
Technology	T1 Poor performance of technology
	T2 Lack of resources and capability to scale up to industrial level
	T3 Slow pace of technology development, deployment and application
	T4 Poor techno-economic attractiveness
	T5 Uncertain on the availability and duration of support and incentive
	T6 High research and development cost
Financing	F1 High upfront capital
	F2 Long pay back periods
	F3 Low return of investment
	F4 Lack of information to assess performance of biomass project
	F5 Inappropriate risk assessment and lending structure of financier
	F6 Poor macroeconomic condition
Supply chain	S1 Underdeveloped supply chain and logistics infrastructure
	S2 Inconsistent feedstock supply
	S3 High logistics cost
	S4 Complication in feedstock logistics
	S5 Unclear sustainability requirements, regulatory regime for biomass industry
Regulatory	R1 Unstable political environment
	R2 Unclear regulations and policies related to biomass industry
	R3 Lack of control on quality and pricing of biomass feedstocks
	R4 Tightening standard of CO2 emission
	R5 Poor governance of biomass related institutions
Environmental and social	E1 Impacts on the environment
	E2 Threats for social well-being
	E3 Lack of technical and safety standards for biomass plant
	E4 Low awareness of the potential of biomass industry
	E5 Low public acceptance on value-added bio-based products

As illustrated in Figure 5-4, the risk assessment model for Malaysian biomass industry consist of three levels. Level 1 is the goal of the study, to identify the key risks associated with Malaysian biomass industry to ease financing. Level 2 consists of the five main risk categories as described above and level 3 comprises 27 identified key risk factors closely connected with the development of the industry. The details of the 27 risk factors and references are described in Chapter 4. The relationship of the levels (i.e. cluster) and elements are delineating with different arrow. Level 1, 2 and 3 is aligned in hierarchy, where elements in level 2 is directly depend on level 1, and elements in level 3 is directly depend on level 2. Inner dependency relationship is also studied to understand the power of influence of the elements within its own clusters. Feedback control loop is included to make sure all the elements in the model are strongly connected.

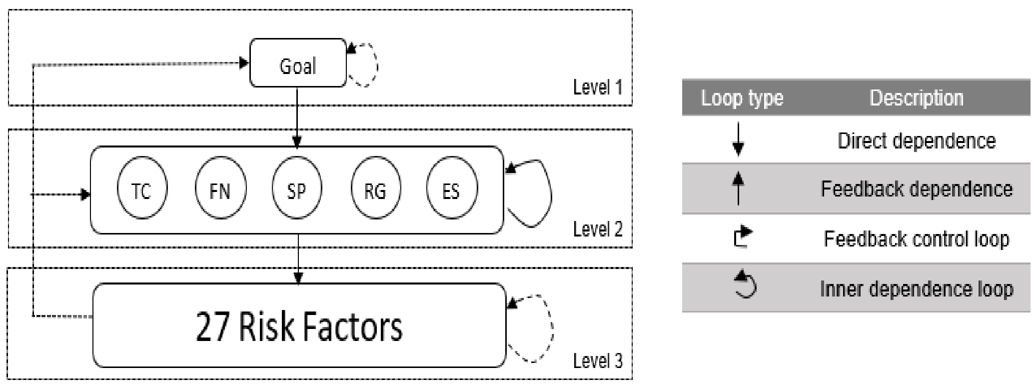


Figure 5-4 Illustration of the Malaysian biomass industry risk assessment hierarchical network model

In this study, a total of 15 experts that research on biomass related areas were gathered in a focus group to discuss and respond to the survey. Their research areas inclusive of bioscience - the pre-treatment techniques to enhance the efficiency and yield of value-added bio-product; chemical engineering - development of process for biomass conversion, development of technology to pre-treat and pre-process biomass feedstocks; process system engineering - enhancement of the overall biomass supply chain in Malaysia; business and social science – economic, social and environmental impact of biomass industry in Malaysia.

Pairwise comparison question is structure as “in relation to financing biomass project, which of the risk is more important and by how much?”. The questions are varies slightly depending on the dominance relationship (i.e. importance, influences power, dependency). Table 5-2 shows an example of the pairwise comparison matrix with the derived eigenvector of risk category with respect to the goal (i.e. level 2 with respect to level 1). The eigenvector is then served as one of the column entries in block of the initial unweighted supermatrix. An example of the unweighted supermatrix is illustrated in the Figure 5-5. For instances, the eigenvector that representing the priority weightage of different risk category with respect to goal (i.e. Table 5-2) is inserted to the *L2L1* of the initial supermatrix (i.e. Figure 5-5).

Table 5-2 Consolidated pairwise comparison matrix of risk category with respect to goal

Goal	TC	FN	SP	RG	ES	eigenvector
TC	1.00	0.76	1.58	1.37	1.37	0.2211
FN	1.31	1.00	2.54	2.70	1.61	0.3247
SP	0.63	0.39	1.00	1.66	1.34	0.1694
RG	0.73	0.37	0.60	1.00	1.19	0.1368
ES	0.73	0.62	0.75	0.84	1.00	0.1479

CR = 0.0203

	Goal	TC	FN	SP	RG	ES	T1	T2	T3	T4	T5	T6	F1	F2	F3	F4	F5	F6	S1	S2	S3	S4	S5	R1	R2	R3	R4	R5	E1	E2	E3	E4	E5
Goal	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TC	0.2211	0.5000	0.2508	0.1848	0.1432	0.1374	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FN	0.3247	0.2058	0.5000	0.1684	0.0962	0.1258	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SP	0.1694	0.1441	0.1406	0.5000	0.1450	0.1400	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RG	0.1368	0.0706	0.0592	0.0721	0.5000	0.0968	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES	0.1479	0.0795	0.0495	0.0747	0.1155	0.5000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T1	0	0.1519	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T2	0	0.2080	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T3	0	0.1180	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T4	0	0.1757	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T5	0	0.1387	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T6	0	0.2076	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F1	0	0	0.1947	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	0	0.2315	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F3	0	0	0.2102	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F4	0	0	0.1490	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0.1224	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F6	0	0	0.0922	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S1	0	0	0	0.2463	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S2	0	0	0	0.2788	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S3	0	0	0	0.2679	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
S4	0	0	0	0.1141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S5	0	0	0	0.0928	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
R1	0	0	0	0	0.0987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
R2	0	0	0	0	0.2976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
R3	0	0	0	0	0.2719	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
R4	0	0	0	0	0.1356	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
R5	0	0	0	0	0.1962	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
E1	0	0	0	0	0	0.2090	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
E2	0	0	0	0	0	0.1407	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
E3	0	0	0	0	0	0.2826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
E4	0	0	0	0	0	0.2426	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
E5	0	0	0	0	0	0.1252	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Figure 5-5 An example of the supermatrix of the hierarchical network model

5.3.1 Result and discussion

Analysis based on risk category

The distribution of the weightage based on risk categories after normalized from the limit supermatrix is illustrated in Figure 5-6. Respondents rank the financing risk as the most important risk in impeding the financing for biomass related project in Malaysia (30.39 %), followed by technology risk (23.64 %), supply chain risk (18.21 %), environmental and social risk (13.44 %) and lastly, regulatory risk (14.35 %). The ability to hedge financing risk are deemed to be the key to guarantee a successful loan application of a biomass project. Biomass industry is a multidisciplinary industry that required a combination expertise on technology, material science, biology, biochemical, supply chain management and engineering [158]. The required corporation amongst multiple expertise for the industry created high barriers of entry and resulting in high upfront cost to purchase and build the plant, equipment, technology, long payback period and relatively low return of investment in short investment period. Furthermore, the information about the supply, demand, cost related with biomass industry in Malaysia are rather scattered, lack of centralized data system to consolidate them. This increase the difficulties for financier to accurately analyse and forecast the industry's financial performance. Thus, financier is lack of information and capacity to evaluate the opportunity and risk associate with the industry to customise financial services and products that suit the industry's attribute.

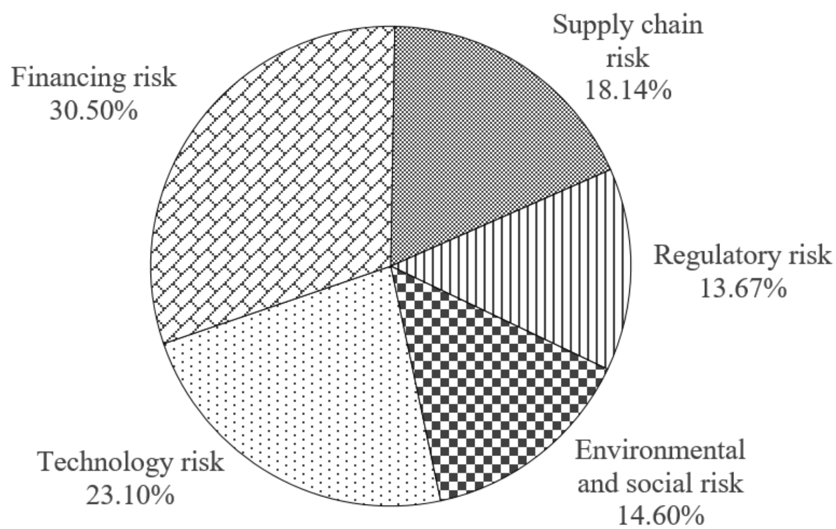


Figure 5-6 Distribution of priority weightages for risk category

Based on the inner dependency matrix, it is observed that financing risk is strongly dependent on technology risk (i.e. 0.4116) and supply chain risk (i.e. 0.3369) as shown in Table 5-3. The numbers are interpreted as the dependency power of risk category aligned in left column on risk category aligned in the top row. For example, "0.4116" indicates that 41.16 % of the fluctuation of financing risk is caused by the changes of technology risk and so on. "1" indicates that the risk category is self-dependence, as the increase or decrease of the respective risk category will affect the risk in the same category. The unknown factors in technology and supply chain related components also made the feasibility performance analysis on the project almost impossible, which resulting in higher financing risk.

Table 5-3 Initial interdependence matrix of risk category's relative dependency weights

	TC	**FN**	**SP**	**RG**	**ES**
TC	1.0000	0.5016	0.3695	0.2864	0.2747
FN	0.4116	1.0000	0.3369	0.1924	0.2516
SP	0.2883	0.2811	1.0000	0.2901	0.2800
RG	0.1412	0.1184	0.1441	1.0000	0.1937
ES	0.1589	0.0989	0.1494	0.2311	1.0000

As biomass industry is still an emerging industry in Malaysia, the industry is heavily relying on the imported technology from oversea. However, not all imported technology is proven effective, some are also unideal for commercialisation due to the high capital expenditure [159]. Meanwhile, locally manufactured technologies are mainly still in laboratory or pilot phase which is yet to be scale up to commercialise level. Consequently, the industry experiences a very limited choice of technology which indirectly made the cost of technology even higher. Lack of operational data to assure the performance, stability, efficiency and effectiveness of the expensive technology further intensify the technology risk.

Thirdly, biomass supply chain in Malaysia remains largely underdeveloped with uncertainties on the supply of feedstocks to the demand of the value-added bio-based products. Dispersed ownerships of palm oil miller and plantation increase the difficulties to compile biomass feedstock in a large scale for further usage. Furthermore, distances between plantation, palm oil mill, pre-treatment plant, and biorefinery also add constraint for the supply of feedstocks as CO_2 emitted by transportation activities should not contribute excess carbon footprint for the biomass supply chain [160]. Variety of biomass feedstocks, inclusive but not limited to oil palm biomass (i.e. empty fruit brunch, palm kernel shells, mesocarp fibre, POME, trunk, fronds), paddy residues, rice husk, coconut shell etc. exerting different characteristics (i.e. density, weight, shape) also add complication to the logistics component [161]. These issues contributed to a higher cost of logistics, which made logistics cost could be the highest cost component in the biomass supply chain, ranging from 15 % to 60 % of the total cost of the production [2]. Furthermore, the potential carbon emission due to the transportation of the

Regulatory risk category appeared as the least important risk in affecting the financing for biomass industry. This is in line with the expectation as Malaysian government is showing a clear intent to want to be a front runner of green growth in Southeast Asia through initiate multiple efforts in spur this industry. Thus, the threat of changing or imposing new rules and regulations not in favour with biomass industry is very unlikely, for the time being.

Analysis based on risk factor

In order to get a deeper grasp on the risk factor that hindering the financing for biomass industry, limit priorities of individual risk factors are analysed. Table 5-4 shows the overall result of the network model with the priority ranking. The limit matrix value indicates the priority weightage of the risk factors in relation to the whole network model while the normalized by cluster value shows the degree of importance of risk factor in relative to other risk factors within the same level. The top 3 risk factors that hindering the financing for biomass project in Malaysia are all dependent elements of financing risk category, which is “F2 Long payback periods”, “F3 Low return of investment” and “F1 High upfront cost”. Generally, investors can be separated into two main groups, which are risk taking and risk averse. Venture capitalist and private equity players are willing to invest in high risk industry, but expecting 50 % to 500 % return in 3 to7 years [162]. On the other hands, public or commercial banks and institutional investors are risk averse investors, which prefer low return with known risks and longer payback period [7]. Biomass related project which associates with high upfront cost and required long payback period fall on the intersection are of risk taking and risk averse investors, which made it challenging to attain financing.

“S2 Inconsistent feedstock supply” is the rank fourth factor that hindering the financing of biomass project in Malaysia. Based on forecast, biomass residues in Malaysia will continue to increase, with an estimation of 100 million tonnes by end of 2020 [2]. Nonetheless, the consistent and reliability of the long-term supply of biomass feedstocks to support a biomass project life-cycle (i.e. average 20 years) is still remain unknown. There are a few factors that contributed to this issue. First, as biomass feedstocks are still not widely trade as commodity, the fluctuation of feedstock price across time is huge. Feedstocks supplier unwilling to commit into a long-term supply contact as there might be opportunity to sell at a higher price in the near future. Next, some biomass feedstocks are only seasonably available. Its price and quality are highly volatile depending on availability, weather, location of the processing plant, storage and logistics. Thus, a well-coordination and collaboration among supply chain players is very important to ensure a guaranteed biomass feedstock in a long term to avoid supply interruptions.

The risk ranked fifth and sixth are “T2 Lack of resources and capability to scale up to industrial level and resources” and “T6 High research and development cost”. As described in the previous section, technology for biomass industry in Malaysia is still highly depend on the imported technology, that are extremely expensive and almost inaccessible for project developers. Ideally, locally manufactured technology need to be made available in order to resolve the cost constraint for biomass related project. Unfortunately, there are very limited resources (i.e. money, human capital) and capability (i.e. technical skills) to scale up the local technology into industrial level [130]. The high research and development cost also contributed to the slow progress of the locally manufactured technology. The industry also lacks with local expertise that capable to solve the technical hurdles associated in this industry [16]. Some example of the technical issues that project developers will potentially face are high energy consumption in the pre-treatment and conversion process, inconsistent quality of biomass, high moisture content of the feedstock which reduced the efficiency of thermal conversion process and etc. [163]. Furthermore, technologies show satisfactory result when operating in laboratory or scientific setting does not guarantee the performance when scale up to industry level, further intensify the technology risk in the industry [129].

Table 5-4 The derived priority weights and ranking of risk factors

Risk group	Risk factor	Limit Matrix	Normalized by cluster	Ranking
Technology risk	T1 Poor performance of technology	0.0080	0.0359	15
	T2 Lack of resources and capability to scale up to industrial level	0.0109	0.0492	5
	T3 Slow pace of technology development, deployment and application	0.0062	0.0279	20
	T4 Poor techno-economic attractiveness	0.0092	0.0415	10
	T5 Uncertain on the availability and duration of support and incentive	0.0073	0.0328	17
	T6 High research and development cost	0.0109	0.0491	6
Financing risk	F1 High upfront capital	0.0132	0.0592	3
	F2 Long pay back periods	0.0156	0.0704	1
	F3 Low return of investment	0.0142	0.0639	2
	F4 Lack of information to assess performance of biomass project	0.0101	0.0453	8
	F5 Inappropriate risk assessment and lending structure of financier	0.0083	0.0372	13
	F6 Poor macroeconomic condition	0.0062	0.0280	19
Supply chain risk	S1 Underdeveloped supply chain and logistics infrastructure	0.0100	0.0449	9
	S2 Inconsistent feedstock supply	0.0113	0.0508	4
	S3 High logistics cost	0.0108	0.0488	7
	S4 Complication in feedstock logistics	0.0046	0.0208	22
	S5 Unclear sustainability requirements, regulatory regime for biomass industry	0.0038	0.0169	26
Regulatory risk	R1 Unstable political environment	0.0029	0.0132	27
	R2 Unclear regulations and policies related to biomass industry	0.0089	0.0399	12
	R3 Lack of control on quality and pricing of biomass feedstocks	0.0081	0.0365	14
	R4 Tightening standard of CO2 emission	0.0040	0.0182	24
	R5 Poor governance of biomass related institutions	0.0058	0.0263	21
Environmental and social risk	E1 Impacts on the environment	0.0067	0.0300	18
	E2 Threats for social well-being	0.0045	0.0202	23
	E3 Lack of technical and safety standards for biomass plant	0.0090	0.0406	11
	E4 Low awareness of the potential of biomass industry	0.0077	0.0348	16
	E5 Low public acceptance on value-added bio-based products	0.0040	0.0180	25

"S3 High logistics cost", "F4 Lack of information to assess performance of biomass project", and "S1 Underdeveloped supply chain and logistics infrastructure" factors are the 7th, 8th, and 9th risk factors based on the result, which made the top

9 risk factors solely from financing risk, supply chain risk and technology risk category. Based on the pareto graph in Figure 5-7, it is observed that the weightage of the first 9 risk factors cumulative up to 50% of the total risk factors assessed in this study. In other words, by able to mitigate the top 9 risks, the success rate of biomass project receiving financing can be increased significantly, (i.e. 50% higher success rate).

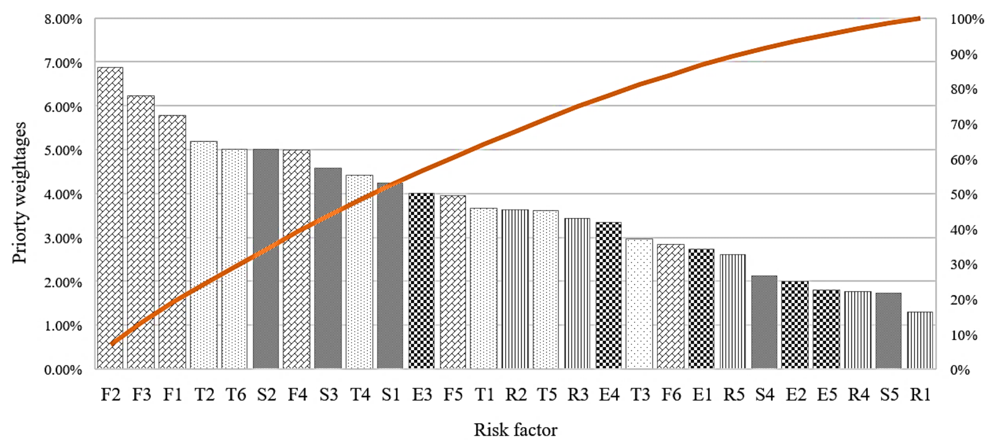


Figure 5-7 Pareto graph of the priorities of risk factors in descending order

5.4 Conclusions and Future works

In conclusion, a novel methodology with ANP approach is proposed to assess risk factors, regardless of tangible or intangible in the same scale to determine the dominance risk factors associated with green financing in Malaysia. The proposed methodology is illustrated with Malaysian biomass industry case study. Based on researchers' perspectives, financing risk is the main concern that hindering the financing for the Malaysian biomass industry, followed by technology risk and supply chain risk. The key risk factors are "F2 Long payback periods", "F3 Low return of investment" and "F1 High upfront cost". Based on the nature of biomass industry with its unique characteristics, it is observed that conventional lending frameworks are inappropriate to assess the bankability of such project. Unfavourable attribute of the industry (i.e. high upfront cost) that contributes high barrier of entry could be shaped into competitive advantages in generating higher return in the future. Thus, it is necessary for financier and investors to understand the nature of the industry to customise financial products and service for biomass related project. Green finance does not only offer financier the increasing reputation benefits as taking up social responsible to promote environmental friendly business, it also proven to be a way to sustain banking business in the competitive market nowadays. Meanwhile, it also helps to unleash the potential of an industry while gaining both economic and social benefits.

The outcomes provide a comprehensive risk profile of biomass industry for industry stakeholders to establish more effective risk management and mitigation strategies to directly tackle the key risks. Policy makers will be also equipped with sufficient knowledge and information to undertake policy reviews to encourage investment from private sources. The future works will focus on extending the current model to gather the perspective from other industry stakeholders, such as industry players (i.e. oil palm miller, plantation owner, logistics company), investors and government agency to develop a comprehensive risk index of biomass industry in Malaysia. In the next part of this work (i.e., Chapter 7), the scope of the risk assessment model is further expanded with additional component – to select and evaluate risk mitigation strategy to determine the most effective risk mitigation strategy in relation to the dominant risks. It should be noted that the proposed methodology is only serve as general purpose, the structure of the network model can vary depending on the nature of the project.

Chapter 6. Prioritisation of indicators for sustainable development

6.1 Introduction

As one of the world's major exporters of crude palm oil, Malaysian palm oil industry plays a crucial role in the country's economic development, contributed up to an average 5 – 7 % of GDP annually [164]. The utilisation of palm oil biomass residues into high value-added products also has grown tremendously in recent years as well. Despite obvious benefits to the country's economy and welfare of its population, the oil palm industry also claimed to contribute to environmental degradation, both at the input and output sides of its activities. With the 2030 agenda for SDGs introduced by EU has created a strong resonance on a wide range of industry throughout the world, there has been increasing dispute on the "sustainability" of the palm oil production in Malaysia, both for oil palm plantations as well as the palm oil mills. Recently, EU Parliament in favour of the exclude the import of palm oil from Southeast Asia for production of biofuels and bioliquids due to the long term environmental impact created by the industry, it has created a higher urgency for industry stakeholders to initiate sustainable practices in its operation [165].

Furthermore, the adoption of various sustainable development, climate change policy without understanding on the stages of the industry life cycle, cultural, political, economic and business background of a country often lead to higher waste of resources and falling short of the target initially determined [166].

Thus, it is imperative to comprehend the structural dependence of the sustainable indicators at different stages of industry life-cycle to derive the priority towards transition for green growth. In this work, an analytical prioritisation methodology, FANP was used to quantify the complex relationship of the sustainable indicators, stages of the industry life cycle to spur the uptake of green economy in developing country context.

6.2 Industry life cycle

The industrial life cycle can be categorized as 4 different stages, which are the pioneering and emerging stage, rapid growth stage, maturity and stable growth stage, growth deceleration stage [167]. The corresponding industrial life cycle stages will be discussed in the subsections below from 6.2.1 to 6.2.4 respectively.

6.2.1 Pioneering and Emerging Stage

Start-ups, entrepreneur and SMEs are common in this stage of the industry life cycle [168]. Innovative and novel products and methodologies are often introduced in this phase by companies [109]. The economy of emerging markets often downcycles materials using low labour costs, high losses and poor working conditions [116]. The barrier to entry is the start-up capital and the eco-innovation demonstrated in product and technology [169]. Start-up funding can be obtained from the founder's own capital, subsidies and grant, Venture Capital, Angel investors, crowdfunding and bank loan [170]. In developing countries such as Malaysia, entrepreneur hubs are available in the Multimedia Super Corridor (MSC

Malaysia). Convenience to incentives is available in the hubs to support innovative start-up, which includes pioneer status, investment tax allowance (ITA), research and development grants, industrial building allowance (IBA), accelerated capital allowance (ACA) and other forms of deduction and allowances [171]. The GTFS has also pooled a 5 billion MYR of funding for green technologies in 2018 [6], which contributes to the development of green growth, as an overall. The success of the start-up is highly associated with industrial risks, which may include environmental, environmental, feedstock, technology and supply chain risks [78]. Yatim et al. concluded that the biomass industry in Malaysia was facing regulatory, financing, technological, supply chain, feedstock, business, social and environmental risks at the pioneering stage [78]. These risks are mainly caused by inconsistent regulations and policies, poor social awareness [16], lack of data for investment evaluation, poor understanding of systems by investors [172] and the requirement for supply chain infrastructure [4]. For the emerging solar cell industry in Korea, a few hypothesis tests were carried out by Park and Kang [173]. They concluded that the entry timing, collaboration activity and technology portfolio affected the product innovation performance during the emerging stage. In Europe, the emerging washing machine industry is reshaped by using sustainable design, pay-per-use business model, predictive supply chain and big data analytics [174]. Process integration was also carried out to improve energy efficiencies within commercial laundries process [175], showing that using up-to-date processing system can effectively debottleneck traditional industries.

6.2.2 Rapid Growth Stage

Gort and Klepper [109] proposed that the rapid growth stage is defined by a sharp increase in the numbers of producers. This is a period where the innovative industrial product or service has been validated and accepted by the market, causing a rise in competing interests. At this phase, the driving force for firms is the manufacturing innovation by high skilled workers, while manufacturing plants are compact and nearer to consumers [176]. McDougall et al. [177] argued that the sales growth of a company at this stage is critical in maintaining financial performance with the entrance of new competitors. The study also proposed that large-scale entry, speciality products, advertising and promotion, marketing expertise, channels of distribution, brand name and forward integration affected growth in this stage. Cleaner production auditing in companies at the pioneering and emerging stage can assess the sustainability of the initial product design and innovation. Involvement of the companies in eco-industrial network and eco-city requires them to be in rapid growth stage and maturity stage respectively to exhibit market volume and stability for business. At the declination stage, companies would need to choose between repositioning their market position or liquidate and decommission.

6.2.3 Maturity and Stable Growth Stage

The maturity stage is the period where the firms entering and exiting the industry is balanced, approximately zero [109]. Functional and technological standards are achieved by production automation, process equipment specialisation, cost reduction and quality improvement [176]. From works of Yuan et al. [178] the integration of firms into eco-city proposed at a maturity stage. Traditionally, eco-cities refer to cities that were constructed with ideas about urban planning, transportation, housing, economic development, public participation and social justice [179]. However, in the context of green economy, it refers to a city that has effort in minimalization of waste, energy and resources [178]. Fully matured industries such as the waste management industry have waste collection rate positively correlated to the GDP of the country [180], while additional investment costs are required when demand exceeds supply. Another fully matured industry is the waste-to-energy industry, where this technology can convert waste into heat and power while avoiding over-utilisation of landfills [181]. Up-to-date waste-to-energy technologies include thermal, energy and off-gas cleaning system which are designed based on rigorous engineering simulations to ensure optimal performance [182]. The matured development of the waste-to-energy industry has flourished beautifully to support the green growth, particularly circular economy on a global scale, and even commercial decision tools are developed [183] for this purpose. LCA [184] points out that waste-to-energy technologies perform better than carbon capture technology towards the circular economy, as the technology can utilise waste to replace fossil fuels. Still, challenges faced by firms at this stage of the industry life cycle are commonly production overcapacity, loss of production skill due to automation and price competition [176].

6.2.4 Deceleration of Growth Stage

The deceleration of growth phase is defined as the negative net entrant of firms in the industry [109]. Companies in this stage have a low level of product and process innovation, overcapacity in production, require manpower from countries of low labour cost [176]. At this point in the industry life cycle, production is rigid and difficult to cope with the varying environment [176]. Firms normally undergo process improvement, retrofit projects or decommission [185] and more research and development is carried out compared to the matured stage [186]. Management strategies that focus on improving system efficiencies such as “lean and green” [187] are suitable at this stage. Leong et al. [188] have developed a framework for managing manufacturing processing plants with the “lean and green” terminology. Total site utility methodologies can also be used for retrofitting projects [189] and cogeneration designs in total site systems [190] to improve the overall energy efficiency. Lakhal et al. [191] demonstrated an effective “Olympic” framework for environmental friendly decommissioning of an oil and gas facility. Cleaner efforts in the mining operation include automation and optimisation, improving efficiency, reducing waste (tailing, gangue and wastewater), water reuse and recycle. Mining is also carried out in group mode, ecological park mode or social wide circulation mode to reduce waste in an industrial symbiosis way [192]. The key to managing firms in declination stage is to either improve management and system efficiency or simplify products and service and move to a niche market [176].

6.3 Methodology

Fuzzy Analytic Network Process (FANP) is a combination of Fuzzy Set Theory [103] and Analytic Network Process [193]. ANP is a general form of AHP, which both were developed by Saaty back to 1980s. ANP and AHP are powerful MCDA that integrate the structural dependency of a network or hierarchy into a single index. AHP mainly cater to the problems that can be structured into a hierarchy, from top-to-bottom [157]. By structuring the decision-making process into a top-to-bottom form, starting from the goal, main criteria, sub-criteria and lastly alternatives, it allows an independent analysis on the structural dependency for every layer in deriving the final global priority for the alternatives. Unfortunately, most of the real-life issue cannot be structured into a unidirectional issue. It often associated with inner correlation and/or feedback dependence relation. Instead of deriving a single vulnerability index as proposed by AHP, ANP adopted the supermatrix approach to combine all possible relationship in the issue to derive final limiting value. Depending on the nature of the problem and the goal of the decision or study, both AHP and ANP can enhance the overall decision-making process. AHP and ANP have been widely applied in the field of Engineering, computer science, business, management and accounting [98,194].

On the other hand, Fuzzy set theory is first introduced to accommodate the "fuzziness" contained in human language (i.e., judgement, evaluation and decisions) [195]. Initially, it is another form "uncertainties theory" that help to deal with the vagueness and ambiguity associated with the real-life, regardless of the performance of technology, resources, materials associated with the human decision. Due to the desirable empirical validation of its output across years, it has been developed into a powerful tool both as a formal theory as well as integrated into different applications or methods to enhance the efficacy of the original method/application. Fuzzy set theory introduces approximate reasoning, release the constraint of binary systems in classical set theory, that only allow either "1" or "0" as an outcome. It permits the membership function-valued in the interval of [0,1], also known as the degree of membership. Fuzzy ANP is one form of the “enhanced” ANP as it replaces the traditional 9-point scale in the inputs for pairwise comparison judgements by fuzzy memberships. Humans can give satisfactory answers, but it rarely can be claimed as an absolute answer due to the existence of much fuzzy knowledge in the real world. The elements that closely associate with human judgements such as expertise and experience tend to have no clean boundary nor single standard to represent by a single crisp value between 1 to 9. Thus, the replacement of the fuzzy membership function to crisp value is deemed to produce a more realistic output [102].

Figure 6-1 is the overall methodology flowchart of this proposed work.

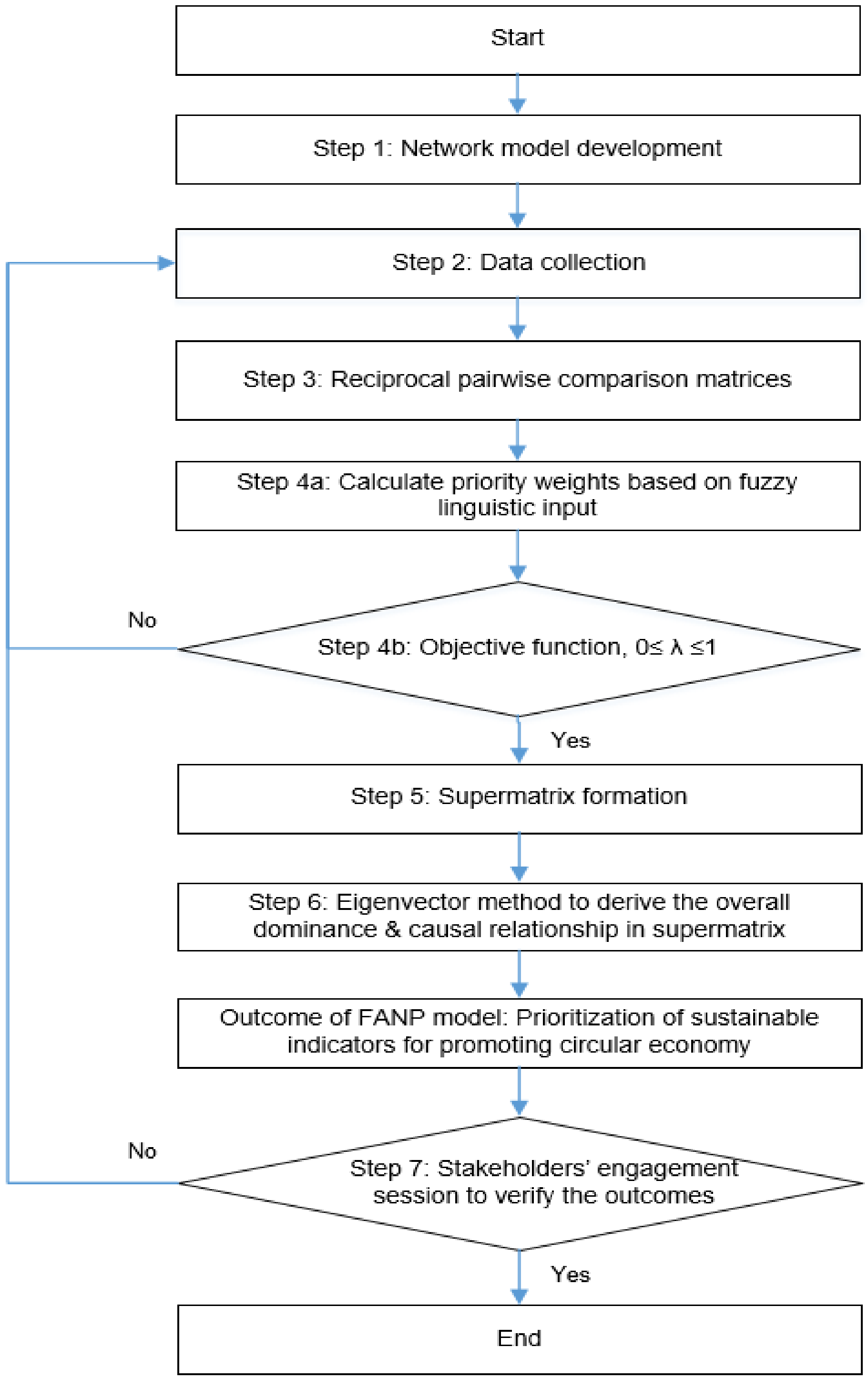


Figure 6-1 Methodology flow-chart

Step 1: Having addressed the distinctive characteristics and challenges of each stage in the industry life cycle, sustainable indicators are identified and gathered to develop the network model. The network model is illustrated in Figure 6-2. It consists of three different levels, with the first level as the goal, followed by second level, stages in the industry life cycle and lastly, sustainability indicators. The second level consist of 4 different stages of in the general industry life cycle, starting with pioneering/ emerging stage (PE), followed by rapid growth stage (RG), maturity and stable growth stage (MS), and finally, deceleration of growth stage (DG). In term of the sustainability indicators level, it is divided into three different clusters naming economic (EC), environmental (EN), and social (SC). Economic cluster consists of cost (CS) and profit (PT) element; Environmental impact is determined by carbon footprint (CF), water footprint (WF) and Ecology (EY) balance; Social dimension is evaluated in term of health and safety (HS), education and training (ET) and public acceptance (PA).

The purpose of the model is to prioritise the sustainability indicator to be emphasized for the successful transition to sustainable development. The direction of the arrows represents different dependency relationships of the elements in the network model. For instances, a downward arrow indicates the direct dependency of the lower level elements with respect to upper-level elements. Self-looping arrows in the cluster represent the interdependence of the elements within the same cluster. Feedback control loop arrows, the arrow that connecting level 2 and level 3 cluster back to the goal cluster (i.e., level 1) is to assure the strong connectivity of all the elements in the model in achieving the goal.

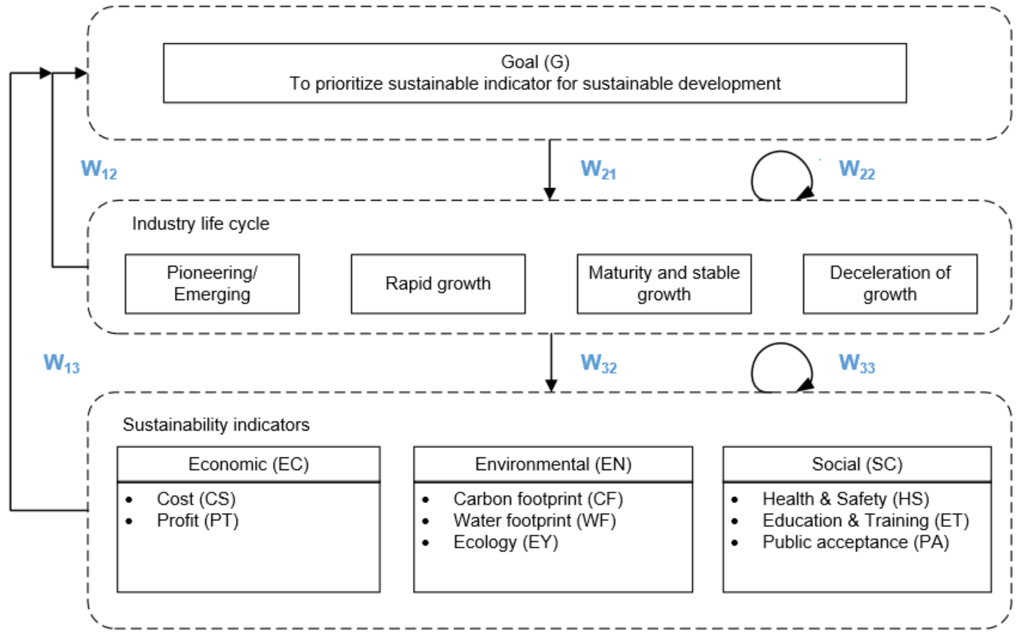


Figure 6-2 Representation of the relationships and elements in the network model

Step 2: Data is collected by gathering responses from 20 experts that have expertise and experience on SD-related research. The research areas included but not limited to social-economic benefits of SD, development of technology and process, optimisation for resources saving, energy policy and governance. The questionnaire consists of 3 main parts. Part 1 consists of 6 questions to determine the preference of the stage in the industry life cycle to initiate sustainability practices for SD. Part 2 consists 112 questions to access the importance of different sustainability indicators at a different stage. Part 3 consists of 168 questions to evaluate the interdependence of the sustainable indicator in affecting other indicators in the transition toward SD. The sample questionnaire is attached as a supplementary document for further references. The questions are formulated as pairwise comparison questions, which the researchers are required to compare two elements in pairs and determine the dominance relationship (i.e., preference, importance, influence etc.) based on fuzzy memberships. For example, the pairwise comparison question for Part 2 is formulated as: “For firm or business in the pioneering/emerging stage, which sustainability indicators play a more important role to encourage the transition toward SD and by how much?” Due to the high number of question, calibrated fuzzy scale comparative with its linguistics term introduced by Promentilla et al. [196] is adopted in the questionnaires to ease the responding process. The set of triangular fuzzy numbers and its associated linguistics term is shown in Table 6-1.

Table 6-1 Fuzzy scale for FANP pairwise comparative judgement

Linguistic scale	**Lower bound (l_{ij})**	**Modal value (m_{ij})**	**Upper bound (u_{ij})**
Equally	1.0	1.0	1.0
Slightly more	1.2	2.0	3.2
Moderately more	1.5	3.0	5.6
Strongly more	3.0	5.0	7.9
Very strongly more	6.0	8.0	9.5

Step 3: The pairwise comparisons inputs in linguistics scale are then converted into vectors, $\langle l, m, u \rangle$, representing the lower bound (l), modal value (m) and upper bound (u) of the judgement. It is worth to note that this set of calibrated fuzzy numbers follows Fibonacci sequences, where the range of upper bound and lower bound (i.e., u-l), also known as the degree of fuzziness for stronger dominance relationship (i.e., very strongly more) is larger as compared to weaker dominance relationship (i.e., slightly more). The geometric mean method is then used to aggregate the inputs from responses on the same question. The pairwise reciprocal matrix is illustrated as:

$$\hat{A} = \begin{bmatrix} \langle 1,1,1 \rangle & \hat{a}_{12} & \cdots & \hat{a}_{1n} \\ \hat{a}_{21} & \langle 1,1,1 \rangle & \cdots & \hat{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{a}_{n1} & \hat{a}_{n1} & \cdots & \langle 1,1,1 \rangle \end{bmatrix} \quad \text{where} \quad \hat{a}_{ij} = \langle l_{ij}, m_{ij}, u_{ij} \rangle \tag{6-1}$$

$$; \hat{a}_{ji} = \langle \frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}} \rangle$$

Step 4: The priority weights of a pairwise reciprocal matrix are computed based on the nonlinear fuzzy preference calibrated Promentilla et al. [197] in 2015. The formulas are as the following:

Maximise λ 6-2a

s.t.:

$$(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \leq 0, \forall i = 1, \dots, n-1; j = i+1, \dots, n \tag{6-2b}$$

$$(u_{ij} - m_{ij})\lambda w_j - w_i + u_{ij} w_j \leq 0, \forall i = 1, \dots, n-1; j = i+1, \dots, n \tag{6-2c}$$

$$(m_{ij} - l_{ij})\lambda w_i - w_j + l_{ji} w_i \leq 0, \forall j = j, \dots, n-1; i = j+1, \dots, n \tag{6-2d}$$

$$(u_{ji} - m_{ji})\lambda w_i - w_j + u_{ji} w_i \leq 0, \forall j = 1, \dots, n-1; j = j+1, \dots, n \tag{6-2e}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{6-2f}$$

$$w_i < 1, \forall i = 1, \dots, n \tag{6-2g}$$

The objective function is to maximise the degree of satisfactory, λ in calculating the weights of the respective element (i.e., w_i) in the matrix. In the meanwhile, λ also play as the consistency measurement to verify the priority weights calculated are in accordance to the initial response gathered from domains. The value of λ need in the range $0 \leq \lambda \leq 1$. $\lambda = 1$ is elaborate as perfect consistency while $\lambda = 0$ means the judgements are only satisfied at their boundaries [104]. In the event that

$\lambda < 0$, it is recommended for the respective expert to revisit their judgments as the inputs are contracted to itself and cannot be concluded.

Step 5: The priority weights derived for every reciprocal pairwise comparison matrices are integrated to form a supermatrix. The arrangement of the priority weights in the supermatrix is illustrated in Table 6-2:

Table 6-2 Supermatrix representation

i/j	L1	L2	L3
L1	$w_{11} = 1$	$w_{12} = e^T$	$w_{13} = e^T$
L2	w_{21}	$w_{22} = I$	$w_{23} = 0$
L3	$w_{31} = 0$	w_{32}	w_{33}

w_{ij} is priority weights presenting the direct dependency of the elements in the level i with respective to level j. For example, w_{21} is interpreted as the priority weights of the preference of the stages of industry life cycle (i.e., level 2) in prioritising sustainable indicator for SD (i.e., level 1). w_{ij} when i=j represents the independent relationship of the elements in the same cluster/level. There are two different types of inner dependence relationships, namely independence and interdependence. Independence relationship means the element only depends on itself, while interdependency means the elements in the clusters have influence power on the other elements as well. As the stages of industry life-cycle are independent of one another (i.e., independence relationship), w_{22} is represented by Identity matrix (i.e., I). The "0", null block matrix (i.e., [0, 0,…,0]) indicates there is no direct relationship between the elements in both clusters (i.e., w_{31}, w_{13}). w_{12} and w_{13} are the priority weights of the feedback control loop, which represented by unit row vector (i.e., [1,1,…,1]).

Step 6: Eigenvector method is then utilised to power the initial supermatrix until all the value across very column converged. This signifies that all the direct and indirect interaction of the elements in the whole model are taking into consideration in deriving the final weights of the sustainable indicators for promoting SD.

Step 7: The verification of the outcomes generated by the proposed FANP is done by communication with industry stakeholders in focus group discussion setting. The stakeholders' engagement session consist a total of 15 participants, included researchers, industry players, policy makers, and government agency that have expertise and experience in the subject matter to discuss and verify the outcomes from the proposed model. In the event that industry stakeholders failed to reach an agreement with the priority weights and ranking generated from the proposed model, it is recommended to start with the data collection process. It is worth to note that this method enables customisation and selection of the elements in the model to cater the generic as well as specific needs of a study, thus, the selection of the questionnaires respondents and verifiers of the result should be relevant with the goal.

6.4 Case study

There is a lot of effort has been directed by the local governments, volunteer organization such as RSPO to guide industry stakeholders to compliance with sustainable practices. However, the uptake level of the industry players voluntarily in compliance with such sustainability standards are still relatively low, especially small stakeholders, which accounted for 38% [198] and 40% [199] of the ownership of oil palm cultivation in Indonesia and Malaysia respectively. The stage of industry life-cycle which the firm/plantations are in also greatly affecting the cost and impact to uptake sustainability practice in its operation. Thus, this case study applied the proposed model in the palm oil industry to prioritise the sustainable indicators at each stage of the industry life-cycle to promote SD in developing countries.

First, the network model as illustrated in Figure 6-2 is adopted to prioritise the sustainable indicator for the palm oil industry to adopt CE for sustainable development. Palm oil industry stakeholder which consists of oil palm plantation owners, palm oil-related business/firm owners, sustainability standard certification auditors and researchers who working on sustainability studies are engaged to respond to the questionnaires. The sample of the questionnaires is attached in Appendix A-2. The pairwise comparison question is structure as "Based on the general palm oil industry life cycle, which stage of the project/business is more preferred to initiate sustainability practices in its operation for sustainable development?". The data collected is filtered to make sure completeness prior proceed with the calculation. The calculation to generate the priority weights for pairwise reciprocal matrices are computed based on the Equation 6-1 to 6-2 with LINGO 16.0 software (see codes in Appendix A-4).

6.5 Result and Discussion

The priority weights of every relationship derived from individual reciprocal pairwise comparison matrices and the final converged value and its ranking are shown in Figure 6-3. The value in the supermatrix can be interpreted in three different dimensions: i. priority weights of direct dependency relationships, as highlighted in blue and green colour; ii. Inner dependency relationship of sustainability indicators, as highlighted in orange; and the iii. comprehensive weights for the whole model, portraying at the final value column. The industry stakeholders concurred the results as illustrated in Figure 6-3, with additional comments included in the discussion.

	GO	L1-PE	L2-RG	L3-MS	L4-DG	EC-CS	EC-PT	EN-CF	EN-WF	EN-EY	SC-HS	SC-ET	SC-PA	**Final value**	**Ranking**
GO	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000		
L1-PE	0.2774	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**27.74%**	**2**
L2-RG	0.2285	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**22.85%**	**3**
L3-MS	0.4135	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**41.35%**	**1**
L4-DG	0.0806	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	8.06%	4
EC-CS	0.0000	0.2919	0.1391	0.0885	0.1838	1.0000	0.1368	0.2034	0.1984	0.1397	0.1556	0.1133	0.1530	**14.85%**	**1**
EC-PT	0.0000	0.1722	0.2032	0.0979	0.1259	0.2905	1.0000	0.1767	0.1984	0.1246	0.1379	0.1638	0.1190	**14.75%**	**2**
EN-CF	0.0000	0.0803	0.1149	0.1202	0.0853	0.1206	0.1392	1.0000	0.0919	0.1993	0.1148	0.1200	0.1077	10.95%	7
EN-WF	0.0000	0.0669	0.1091	0.1247	0.0839	0.1291	0.1677	0.1089	1.0000	0.1879	0.1148	0.1200	0.1657	11.47%	5
EN-EY	0.0000	0.0909	0.1048	0.1247	0.1316	0.1128	0.1246	0.1639	0.1984	1.0000	0.0956	0.1819	0.1724	12.11%	4
SC-HS	0.0000	0.1082	0.0863	0.1030	0.1361	0.0917	0.1085	0.0878	0.0817	0.0906	1.0000	0.1776	0.1752	10.39%	8
SC-ET	0.0000	0.0608	0.0899	0.1528	0.1338	0.1124	0.1460	0.0845	0.0869	0.0970	0.3037	1.0000	0.1070	11.36%	6
SC-PA	0.0000	0.1288	0.1528	0.1883	0.1195	0.1429	0.1772	0.1749	0.1442	0.1609	0.0775	0.1234	1.0000	**14.13%**	**3**

Note:
GO – Goal; L1-PE – Pioneering/ emerging stage; L2-RG – Rapid growth stage; L3-MS – Maturity and stable growth stage; L4-DG – Deceleration of growth stage; EC-CS – Cost; EC-PT – Profit; EN-CF – Carbon footprint; EN-WF – Water footprint; EN-EY – Ecology; SC-HS – Health and safety, SC-ET – Education and training; SC-PA – Public acceptance

Figure 6-3 The supermatrix table and its final value and ranking

Figure 6-4 illustrates the network relationship of the SD goal, industry life cycle phases, and prioritisation indexes. Weights of each node indicate the percentage importance value, while the thickness of each connection edge indicates the average dependency relationship. Based on the outcomes, “L3 - Maturity and stable growth” stage appeared to be the best stage to initiate and implement sustainable practices in its operation for SD, followed by “L1 – Pioneering/Emerging” stage, “L2-Rapid growth” stage and finally, “L4-Deceleration of growth” stage. The segmentation of the industry life cycle is adopted from Hill and Jones [200] which divided the industry life cycle into four different stages, with applications for both firm level as well as an industry as a whole system. The pioneering/emerging stage is described as the introduction of new technology or product in the market. This stage tends to associate with high upstart costs, with low demand due to the “newness” of the product and industry. It is also the surviving stage for the new entrant on whether able to play a role in this industry or market [201]. Firm and industry in rapid growth stage experience accelerated sales and profit. It is the stage where the market experience the highest level of heterogeneity between firms, such as product variation and market share instability for the emerging of market leader [202]. Maturity and stable growth stage occur when the competition started to wane as the firm identify and understand its competitive advantage in the market and fully utilise it. In most of the case, the firm will produce at its economic of scale to fully portray its competitive advantages. This stage also tends to be the longest stage in the life cycle whereby norm and standard will be formed, and the weak competitors will be eliminated in the market [112]. Porter [110] describe that the same force of competition will continue and intensify rivalry, until the industry experience lower intra-industry homogeneity, this is when the industry moves on to the last stage, the deceleration and declining stage. This stage is not a representation of the poor performance of the industry/ firm, it is the stage where the market is concentrated with few key players, with lack of variation for further innovation or breakthrough [203]. Thus, the growth rate started to remain stagnant or even slowing due to the satiation of demand. It is also the stage where the industry will experience a change in consumer preference and demand shifts to new products or substitutes.

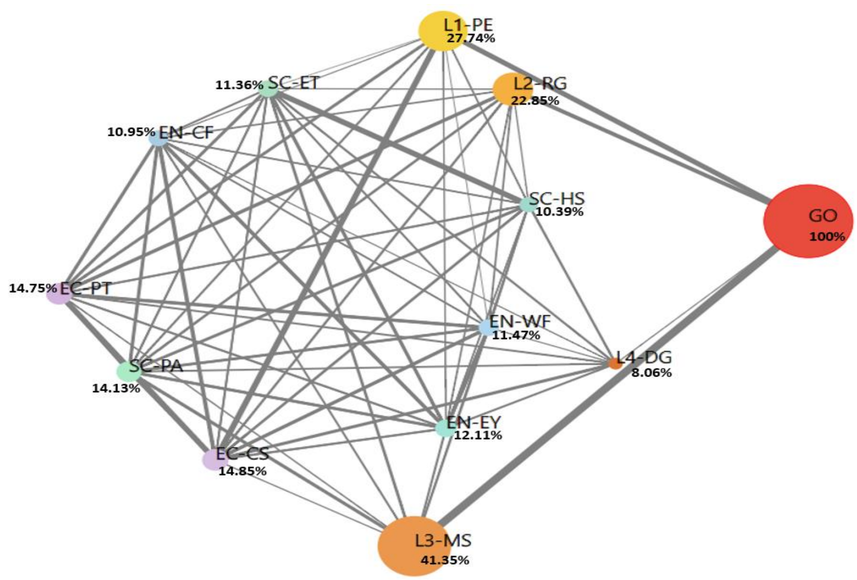


Figure 6-4 Network visualization of ANP relationship

The focus group participants concurred with the outcome in which maturity and stable growth stage is the best stage to uptake sustainability practices for SD. It is because the business and firm in this stage have sufficient capacity and ability, both in term of capital as well as human resources to sustain its operation. This enables the firm to divert it full attention from economic benefits to focus on environmental well-being and social responsibility. Furthermore, the firm in maturity and stable growth stage also contain sufficient data and information to undergo fundamental change proposed by one of the SD avenue, circular economy framework [204]. Some of the recommendations to initiate sustainability practices are the replacement of inefficient and less effective technology to cleaner technology, optimise the process through leveraging the history data for minimising waste of energy, reduce redundant parts, encourage sharing of resources etc. [44]. These efforts do not only help to reduce long-term operation cost, gain reputations as an environmental and societal responsible party, it also served as an alternative to prevent the company to fall into next stage, the deceleration of growth stage. Pioneering and emerging is ranked 2nd in the list. Business or firm in the pioneering/emerging stage is the most flexible stage across the industry life cycle to shape its competitive advantage to survive in the market [110,202]. Even though the risk profile for the sustainable business model in developing countries is higher as compared to the conventional model due to the lack of a successful precedent case, the long-term benefit is significant. Particularly, economic gain through reduced raw material and energy costs, waste management cost, emissions control cost, and blue ocean market creation and environmental preservation through reduction on virgin materials and resources input, while reducing the overall wastes and emissions [37]. These are deemed to be a powerful strategy in moulding the image and development blueprint of the business and firm. Furthermore, with the growing resonance of SDGs in a global arena, there is also a high possibility for mandatory compliance for sustainable standards in the near future. By adopting sustainable operation at the initial stage can reduce the compliance cost in the future.

In term of the importance of sustainability indicators in encouraging the transition toward SD throughout the whole industry life-cycle, cost (EC-CS) is top factor, followed by profit (EC-PT), and public acceptance (SC-PA). The first two indicators are from the economic cluster. This indicates that economic gain is still the key driver for the stakeholders in the palm oil industry to adopt and integrate sustainability components in its operation, across the palm oil supply chain. It is also often cited as one of the factors that hindering small stakeholders in Malaysia and Indonesia to voluntary compliance to MSPO and ISPO, as all the principles of the certifications merely focus on environmental and social aspects [60,62]. This finding can serve as a reference for local authorities and policymakers to incorporate economic element in is attract the uphold of such standards. For example, certified sustainable palm oil (CSPO) awarded by full compliance with RSPO is able to sell at a higher price (i.e., >10% premium) as compare to non-CSPO [205].

Public acceptance ranked 3rd in the sustainability indicators that should be prioritised to promote SD. The arousing confrontation on the environmental destruction caused by the palm oil industry has in recent years has intensified the anti-palm oil movement. This series of movement has, directly and indirectly, affected the demand and price of the palm oil [9], particularly the demand on developed nations where the community has high awareness on purchasing products sourced from sustainable palm oil [57]. One of the examples is the increasing demand for CSPO. Even though CSPO only accounted only less than one-fifth of the total world palm oil production, there has been a clear trend on the higher demand despite the need to pay a premium. A recent work, Pischke et al. [206] also further assure the importance of public acceptance in affecting the purchasing and consumption behaviours of palm oil, and the growth of the whole industry. Another example of the importance of public acceptance is reflected by the increasing trend at developed countries on community financing. With the high public acceptance and awareness on the need for renewable energy, community are willing to finance the renewable energy project which is deemed as high risk and low return investment [207]. Thus, in order to encourage the uptake of sustainability practices in the oil palm industry, there is a need to raise the public acceptance on the sustainable palm oil, but not based on the value of money. Ecology (EN-EY) and water footprint (EN-WF) is ranked 4th and 5th, followed by education and training (SC-ET), carbon footprint (EN-CF) and lastly health and safety (SC-HS). It is crucial to understand that the goal of this study focuses on prioritisation of the sustainability indicators to promote SD, thus, the indicators with lower weights are not insignificant for the overall development of the industry. It only provides recommendations for the industry players to design and select an action plan to spur the sustainability of the industry based on the indicators that have higher preferences.

The sustainability indicators that carry the highest weights for each stage of industry life-cycle are varied slightly as illustrated in Figure 6-5. For the pioneering/emerging stage, rapid growth stage and deceleration of growth stage, the top indicators are mainly dominated by economic cluster's elements, cost and profit. For maturity and stable growth stage, it is interesting to note that the preferences have shifted from economic benefits to environmental and social well-being. Public acceptance carries the highest weights, followed by education and training. Water footprint and ecology share the same weights to rank at the 3rd, simultaneously, with carbon footprint has slightly lower weights after water footprint and ecology. This further affirms the finding firm in the above section that firm or business at maturity and stable growth stage is the most suitable stage to initiate such transition as they have sufficient resources to shift its objective from profit-oriented to social and environmental oriented.

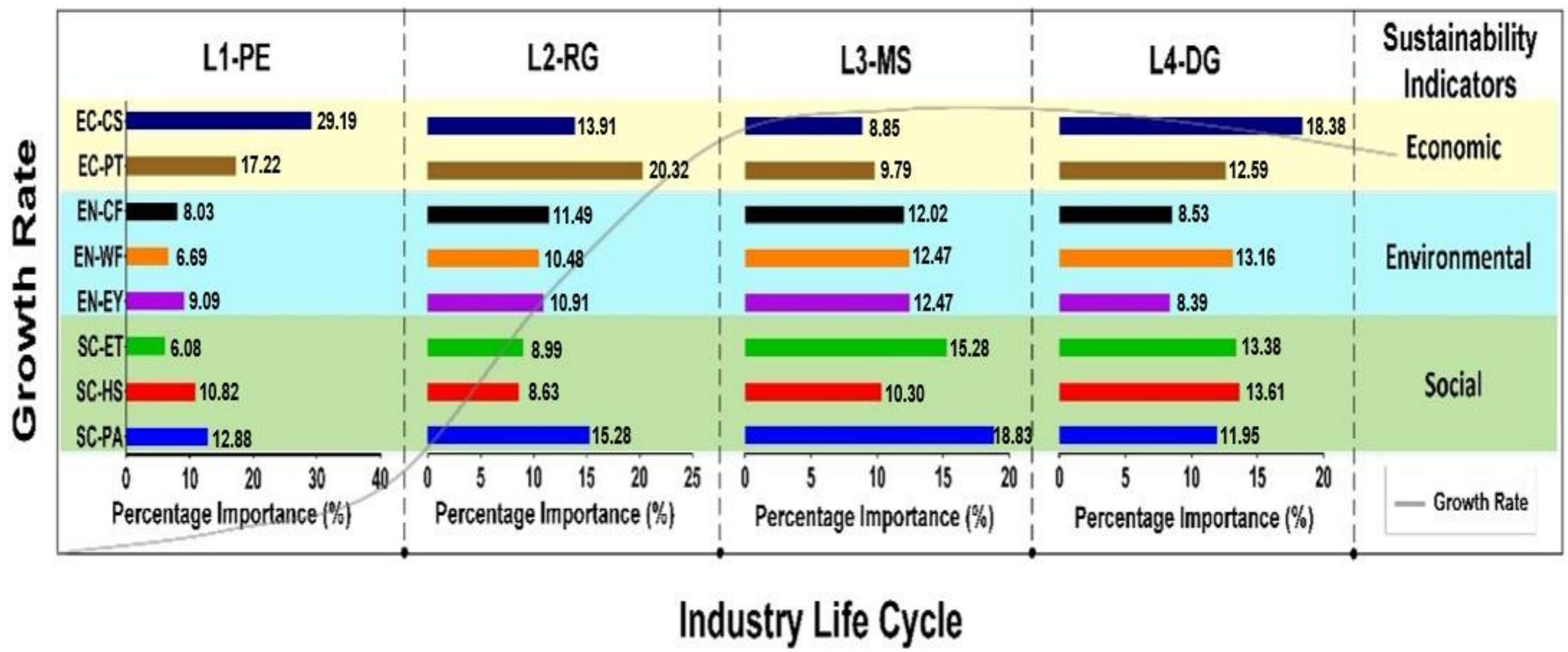


Figure 6-5 Importance of sustainability index in each stage of the industry life cycle

In term of the power of influence, it is observed that the economic cluster, both cost and profit are the indicators that have highest influences on other sustainable indicators. Ecology factors are next on the list. The analysis of the power of influence can serve as a reference for the industry stakeholder, particularly decision makers and policy makers to design and customise action plan and incentive or support to boost the indicators with a higher power of influence. By accelerating the performance of indicator which has a high power of influences is expected to improve the performance of other indicators, concurrently.

6.6 Conclusions and Future works

SD is no doubt the best solution for developing country to solve waste issues and simultaneously avoid further development bearing on the cost of environment and resources of the future generation. The work provides an in-depth analysis of the strength and weaknesses of feasibility and practicality of transition into the SD model in general industry life-cycle. A FANP model is proposed to prioritise the sustainable indicators to aid the industry stakeholders at different stages of the industry life cycle to ease the transition towards SD. The proposed method enables the incorporation of human preferences on sustainability indicators to provides a more feasible solution for the industry stakeholders to assess, monitor, and implement relative sustainability practices in its operation. Furthermore, it also helps to enhance decision making process on selecting technology and process that not only maximise economic performance, but also preserve and conserve the environment and improve social well-being. The results based on the oil palm industry case study shows that economic performance indicators (EC-CS, EC-PT) still play a dominant role in encouraging the industry players to adopt sustainable practices to promote SD, followed by public acceptance (SC-PA). This indicates that economic benefits and public acceptance play the prominent role in affecting the decision of industry players towards SD. The outcomes served as a reference for the government agency, policy makers or non-governmental organization to incorporate such elements in its policy and plan to encourage fast adoption for sustainable development. As the data for the model is gathered based on the expert's input, it is worth to note that the outcomes might varies depending on the background, expertise and experiences of respondents. Nonetheless, this is also one of the pros of the proposed model as it served as a generic decision-making model to take in complicated structural dependency (outer-dependency, interdependency) in deriving the final output, regardless for niche group (firm level) or an industry as a whole. The performed study and method can also be extended into other expects of SD development, such as comparison of the factors and priority in promoting SD between developed and developing countries.

Chapter 7. Risk management and mitigation

7.1 Introduction

In this chapter, the outcomes from Chapter 5 (i.e., the dominance risks) and chapter 6 (i.e., the priority of sustainable indicators of stakeholders to initiate sustainability in its operation) are integrated to evaluate and select the most effective risk mitigation strategy to reduce the overall project risks while promoting sustainable development. Biomass energy has been known as one of the attractive renewable energy which plays an important role in tackling global issues of energy supply security and climate change [208]. The utilisation of biomass does not only help these developing countries to meet their energy demands given their rapidly increasing populations but also offer significant potential for climate change mitigation [209]. For example, Nguyen et al. [209] shows that the utilisation of the excess bagasse and cane trash from the sugar industry using the polygeneration systems in Thailand has successfully substituted the electricity generated from conventional fossil-based power plants while significantly reducing the emission of greenhouse gases (GHG). Biomass is also considered as a renewable energy that results in a negligible net contribution of carbon dioxide [210]. Currently, oil palm residues (e.g., trunks and fronds) are being left in plantations or being composted as fertilizers to improve soil structure. With advanced polygeneration systems, the abundant availability of oil palm biomass presents vast opportunities for the utilisation of these agricultural wastes in various applications including bioenergy productions. According to the International Energy Agency (IEA), bioenergy has accounted for approximately 10.3% of world total primary energy supply and it is predicted to increase an average of 1.6% between 2010 and 2035 [211]. Furthermore, Enerdata [212] reports that energy consumption in Asian countries has grown strongly and steadily in past few decades partly due to the population growth and industrial expansion. Thus, the need for a more stable and secure supply of bio-based feedstock has become increasingly important to meet increases in energy demand.

7.2 Background

7.2.1 Development of DEMATEL and ANP

Decision-making trial and experimental laboratory (DEMATEL) was first developed by Gabus and Fontela [105] in Battelle Geneva Research Centre. The method is highly effective in identifying the intercorrelations between individual attributes, then identifying the most critical attributes by using an impact relationship map. DEMATEL allows the decision maker to systematically conclude key policies by comparing relations between attributes [213]. Moreover, the DEMATEL method is able to aid decision maker in understanding the complicated cause and effect relationship in the decision-making problem [106]. On the other hand, the AHP is a concise and simple method to analyse complex multiple criteria decisions introduced by Saaty in 1980 [157]. By structuring a complicated issue in hierarchy order, it allows the decision makers to visualize the problem and analyse from a mathematical and psychological perspective. The method utilised the concept of relativity to evaluate the dominance relationship of different parameters to generate global priority weights. In the later years, Saaty proposed a generic form of the AHP, which called ANP. ANP overcomes the limitation of AHP to further include feedback dependence, as well as inner correlations [97] to enhance the overall decision-making process. The work has also shown that ANP is used for prioritisation, resource allocation, benchmarking, quality management, public policy, health care and strategic planning. However, the traditional 9-point fundamental scale for pairwise comparison is a widely discussed argument as it is claimed as unable to fully reflect the human judgements [102]. In relation with that, Fuzzy set theory is integrated with AHP and ANP to overcome the human ambiguity by replacing the 9-point scale with fuzzy scale. Later, Dağdeviren et al. [214] apply the ANP framework with fuzzy logic to identify faulty behaviour risk systems. The similar Fuzzy ANP (FANP) framework was also utilised by Naghadehi et al. [215] to select an optimum mining method for Bauxite mining. In recent works, Promentilla et al. [216] have utilised a stochastic FAHP for the optimal selection of clean technology, showing that the method can be utilised for processing technology.

With the advancement of information technology, the tremendous amount of information has increased the difficulty to make decision or selection. Combination of MCDAs is often necessary in order to fully access the correlation the real-world problem prior to decision-making. DEMATEL method is categorized as causal dependency MCDA which is less applicable for complex problems that involves multiple level and stages. Whereas, ANP is a structural dependency MCDA that capable to access the interdependency and outer-dependency of one cluster with respect to another. Thus, the combination of

DEMATEL and ANP provides an additional dimension to derive both causal dependency and structural dependency in the system. In recent years, there has been an increase in the application of this method in both the business arena as well as the research world, both as for selection and evaluation tools [217]. Dehdasht et al. [94] adopted DEMATEL-ANP method to access the construction risks for oil and gas project while developed implementation plan for risk management. Fazli et al. [218] also apply the hybrid model to prioritise the most important risks in the crude oil supply chain to enhance the decision in Iran. Rezaeisaray et al. [219] have combined FANP and DEMATEL to increase the flexibility of the decision process in selecting a supplier for pipe and fitting manufacturing. Using the FANP-DEMATEL combination framework, Wei-shan Hu et al. [220] has evaluated stock trading strategies for trading in the Taiwan Stock Exchange Capitalization Weighted Stock Index (TAIEX). Büyüközkan and Güleryüz [217] has also shown that an integrated framework of DEMATEL and ANP is suitable for the selection of renewable energy. For biomass applications, Ngan et al. [221] have studied the integration of stakeholder's role in mitigating risks for biomass processing companies using the FANP-DEMATEL framework.

7.2.2 Methods for risk mitigation strategy evaluation for supply chain

Looking deeper into risk management for supply chain, the approach of using simulations that are mapped with risk mitigation strategies is studied by Talluri et al. [222]. The work mainly utilises a theoretical simulation framework with consideration of disruption, delay and distortion risks. Alternatively, Mangla et al. [223] have used a qualitative approach of the Situation Actor Process-Learning

Action Performance (SAP-LAP) model to mitigate risks within the supply chain. The model simulates the interplay of learning, action and performance for situations and response. Risk mitigation strategies generated by this approach is then compared using a dominance matrix, which ranks each strategy. Christopher and Peck [224] proposed that the simulation and building of a resilient supply chain will require the consideration of supply risk, process risk, demand risk, control risk and environmental risk. The work also discussed four important aspects for creating a resilient supply chain, which are the engineering of the supply chain, risk management culture, agility and collaboration of supply chain. In addition, Allen et al. [225] have highlighted the costs of fuel supply for logistics management in a supply chain. Kim et al. [226] have proposed that the simulation of supply chain models require nominal design and scenario design, hence Monte Carlo simulation is required to account for uncertainty. Additionally, Gebreslassie et al. [227] proposed the multiobjective stochastic programming model can be used to model biorefinery supply chains. The work evaluated designs of supply chain using conditional value-at-risk (CVaR) and downside risks using mixed integer nonlinear programming (MINLP) algorithms. Thus, risk mitigation strategies that consider the supply chain of biomass polygeneration systems are complex and therefore multiple criteria decision-making studies must be carried out.

Although various works have been performed to assess risk mitigation strategies in the supply chain as well as analysing the risk and challenges of biomass polygeneration system, risk mitigation and management related studies on biomass polygeneration system are relatively rare. Table 7-1 summarizes the literature of the risk-related studies on biomass polygeneration system.

Table 7-1 Highlights of previous works on risk on biomass polygeneration system

Author	Remarks
Sy et al. [228]	• Proposed Target-oriented robust optimisation (TORO) method to synthesize polygeneration systems, with a focus on reducing investment risk due to the high price volatile (i.e., both demand and supply)
Benjamin et al. [229]	• Developed criticality index to quantify the consequences of the failure of a component (i.e., technology risk) • Identify the high-risk components in the integrated energy system to design effective risk mitigation solution
Wang et al. [230]	• Introduced new MCDAs (i.e., a combination of fuzzy best-worst method and fuzzy network method) in assessing the sustainability of polygeneration system under uncertainties
Sy et al. [231]	• Proposed an enhancement of TORO method that takes into consideration of both profit and environmental footprint during optimization. • Introduced robustness index to represent the overall risk acceptance level of decision makers • Monte Carlo simulation is performed to show the robust optimal configuration

It is observed that most of the works are focusing on the evaluation of specific type of risks associated with biomass polygeneration system rather than the complete biomass polygeneration supply chain. In addition, there is still lack of works emphasizing on prioritisation of risk mitigation strategies to mitigate the comprehensive risks associated with biomass polygeneration supply chain. Overviewing the high operational risks that arise from the biomass industry, this work adopts the DEFANP framework to select the best strategy to enhance the overall performance of the project. Firstly, the operational risks for biomass polygeneration systems are complex and highly interrelated, which the DEMATEL fraction of the framework can identify. Next, the multiple levels of decision groups within the biomass industry is modelled by the FANP fraction of the framework. Therefore, this work demonstrates a comprehensive and concise DEFANP framework to rank and select risk mitigation strategy through repetitive simulations of the biomass system and market. Monte Carlo simulation is performed to concur the solution generated from the DEFANP model, to ensure the impact of the proposed risk mitigation action plans is reflected in the form risk minimisation. The risk measurement in this work is reflected in the form of higher net present value (NPV), shorter payback period (PBP) and less variation (i.e., smaller variance) in NPV and PBP over the project life cycle.

7.3 Methodology

The procedure of this work is illustrated in Figure 7-1. The detailed explanation for each stage is as the following:

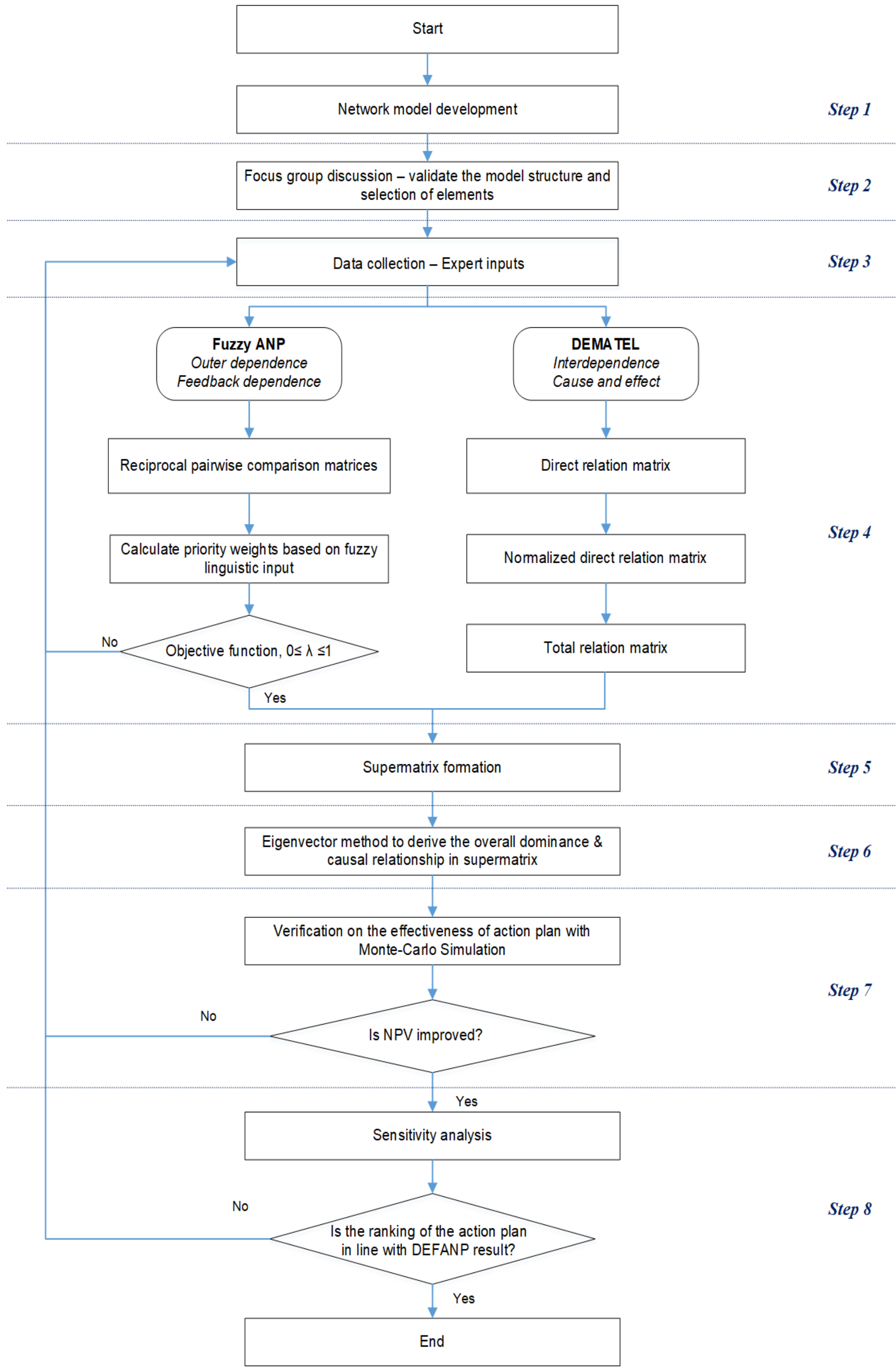


Figure 7-1 Procedure flow-chart.

This work consists of two major stages, which are: i) the development of FANP and DEMATEL hybrid model to integrate the strength and weaknesses of stakeholder's in determine the most influential and important strategy and ii) to run Monte Carlo simulation to verify the effectiveness of the respective mitigation plan through the comparison of the financial performance of the project as well as sensitivity analysis. The detailed procedures of each stage are elaborated in the following section:

Step 1: Literature review is performed to identify the main elements that contribute to the high operational risks for the biomass industry and its mitigation strategy and solution. The identified information is constructed into a network model as illustrated in Figure 7-2. The model consists of four main clusters (C), namely C_1 – Goal (GO), C_2 - Key components of biomass industry (KE), C_3 - Industry stakeholders (SH), and C_4 - Risk mitigation action plan (AP). The variables in each C are named as elements. Arrows are used to indicate the relationship of clusters and elements in the model. Arrows from C_A to C_B represents the dependence relationship of elements in C_B with respect to C_A. The self-looping arrow on a cluster indicates the inter-dependence and inner-dependence of the elements within the cluster. The arrow that connects all clusters back to the C_1 - Goal is called feedback control arrow. It represents the strong connection of the clusters with the goal of the study.

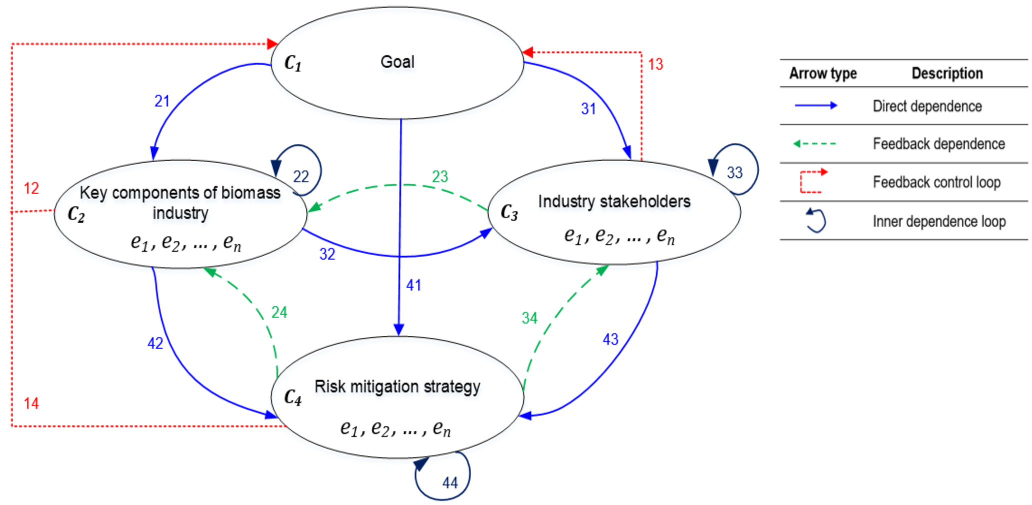


Figure 7-2 Development of the network model with its relationship

Step 2: Focus group discussion is held to gather experts of this industry to discuss and verify the network structure proposed based on literature review. A total of fifteen experts are invited to participate in the focus group discussion, which consist of policymakers (2), biomass-related business owners (3), oil palm plantation owners (3), palm oil millers (2), financial institutional representatives (2) and researchers (3) that have experience, competence and knowledges about the industry. The purpose of the discussion is for the industry stakeholders to verify and modify the model structure. Furthermore, the participants also contribute to provide and decide on the details for the respective action plan (i.e., duration, range etc.). This is to make sure that the proposed action plan is plausible and realistic to implement and adopt by industry stakeholders as a mitigation strategy.

Step 3: Data collection involved elicit judgements from experts through a structured interview with questionnaires. In this study, a total of 25 industry stakeholders have been interviewed to respond to two different sets of questionnaires (see Appendix A-5). The interviewees consisted of researchers from the University of Nottingham

Malaysia and University Technology Petronas and industry business owners that work on biomass polygeneration projects. The first set of questionnaires is to evaluate the outer-dependency and interdependency relationships of the problem follow the FANP pairwise comparison structure. The second set of questionnaires focus on the assessment of the causal and effect relationship with DEMATEL intensity of influence/dependence structure. Linguistic terms are adopted in both sets of questionnaires and the values associated with the linguistic term are described in Table 6-1 and Table 7-2.

Table 7-2 Measurement scale for DEMATEL

Linguistic scale	**Value**
No influence	0
Very low influence	1
Low influence	2
High influence	3
Very high influence	4

Step 4: The data collected are then evaluated with two different methods, FANP and DEMATEL. The fundamental mathematics operation for both methods is the same, which is by using matrices. The size of the matrix is depending on the number of elements in the cluster. Every relationship represented by the arrow in Figure 7-2 consists of its own matrix. The matrix size varies according to the number of elements in the respective cluster. For instance, assuming there are seven elements in C4, $arrow_{41}$ which interprets as the effectiveness of the action plan to improve the goal is a 1x7 matrix (i.e., 1 goal, 7 suggested action plans) etc. Inner dependency relationship is represented by a square matrix (i.e., matrix with dimensions of n x n).

In this work, FANP is adopted to evaluate the outer-dependency cluster with cluster (i.e., A_{11}, A_{21}, A_{31}, A_{41}, A_{12}, A_{32}, A_{42}, A_{13}, A_{23}, A_{43}, A_{14}, A_{24}, A_{34}) and inner-dependency of key elements (i.e., A_{22}) and industry stakeholders cluster (i.e., A_{33}). DEMATEL is utilised to assess the interdependency and cause and effect relationship of the action plan's cluster (i.e., A_{44}). As the implementation of action plans associated with different cost and consequences, the proposed method, DEFANP helps to prioritise the most important and influential action plan to achieve maximum outcomes with minimal input. The description of the relationship represented by the arrows are presented in Table 7-3.

Table 7-3 Description of the priority weights of relationship in the network model

Arrow	Description	Output
A_{21}	The dependency of key elements for biomass polygeneration project with respects to the goal	w_{21}
A_{31}	The dependency of the role of stakeholders with respects to the goal	w_{31}
A_{41}	The dependency of the effectiveness of action plans with respects to the goal	w_{41}
A_{12}	Feedback control loop – the strong connection of the goal with key elements for biomass polygeneration project	w_{12}
A_{22}	Inner and inter-dependency of the elements in of biomass polygeneration project	w_{22}
A_{32}	The dependency of the role of stakeholders with respects to the key elements in biomass polygeneration project	w_{32}
A_{42}	The dependency of the effectiveness of action plans with respects to the key elements in biomass polygeneration project	w_{42}
A_{13}	Feedback control loop – the strong connection of the goal with industry stakeholders	w_{13}
A_{23}	Feedback dependence of role of stakeholders with respect to the key elements in biomass polygeneration project	w_{23}
A_{33}	Inner and inter-dependency of the role of different stakeholders	w_{33}

Table 7-4 Description of the priority weights of relationship in the network model (continued)

Arrow	Description	Output
A_{43}	The dependency of the effectiveness of action plans with respects to industry stakeholders	w_{43}
A_{14}	Feedback control loop – the strong connection of the goal with respective action plans	w_{14}
A_{24}	Feedback dependence of effectiveness of action plan with respect to the key elements in biomass polygeneration project	w_{24}
A_{34}	Feedback dependence of effectiveness of action plan with respect to the role of stakeholders	w_{34}
A_{44}	Normalized total relation matrix generated from DEMATEL – interdependency and causal impact relationship of action plans with one another	w_{44}

For FANP, fuzzy non-linear programming (NLP) calibrated by Promentilla et al. [197] is adopted to quantify the priority vector for matrices with the aid of optimisation software, LINGO 16.0. The detailed explanation of the method and equation for the FANP is introduced in Chapter 6, equation 6-1 to 6-2

For DEMATEL, the inputs from all experts (k) are combined with arithmetic average prior populated into a square matrix, namely direct relation matrix (D) as illustrated in the following.

$$D_k = \begin{bmatrix} 0 & d_{12k} & \cdots & d_{1nk} \\ d_{21k} & 0 & \cdots & d_{2nk} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1k} & d_{n2k} & \cdots & 0 \end{bmatrix} \qquad 7\text{-}1$$

where D = Direct relation matrix; d_{ijk}= average of $d_{ij}$of k experts; k = total number of participants

Varying with the reciprocal local priority matrix as populated with FANP method, the value of the diagonal elements (i.e. i=j) is equal to zero, given that the element has no intensity of influence upon itself. Upper-right from the diagonal elements indicates the intensity of influence of elements in row i with respect to the elements in column j; while the lower-left part of the D represents the intensity of dependence of elements in column j with respect to row i.

Row sum is then calculated to identify the largest row sum value. Normalize D with the largest row sum value to form normalized direct relation matrix (M).

$$M = \left[m_{ij}\right]_{n*n} = \frac{D}{\max_{1 \le i \le n} \sum_{j=1}^{n} d_{ij}}, \text{ where } 0 \le m_{ij} \le 1 \quad \text{7-2}$$

Next step involves converting M to the total influence matrix, (T) with the following formula:

$$T = M + M^2 + M^3 + \cdots + M^n \approx M(I - M)^{-1}, \text{ when } n \to \infty \quad \text{7-3}$$

where M is the normalized direct relation matrix and I is an Identity matrix.

Calculate the prominence and net cause/effect values for each of the element by summing the row (R_i) and column (C_i) of the T. (R_i) represents the influence power of the row's element in the cluster while (C_i) represents the intensity of the column's element being influenced by other elements in the cluster. $(R_i + C_i)$ shows the prominence relationship of the elements in the overall problem structure, which in this case, the action plans. The net cause/effect factors are represented $(R_i - C_i)$ value. The element with positive values for $(r_i - c_i)$ is classified as cause factor, while element with negative values for $(r_j - c_j)$ is categorized as effect factor.

Step 5: Formation of supermatrix. Priority weights (i.e. w_k) derived from FANP and normalized total relation matrix (i.e. T_N) from DEMATEL are then populated into a supermatrix based on the order as described in Table 7-4, the description of the priority weights in the supermatrix is illustrated in Table 7-3.

Table 7-5 Supermatrix representation

i/j	1-GO	2-KE	3 - SH	4 - AP
1 - GO	w_{11}	w_{12}	w_{13}	w_{14}
2 - KE	w_{21}	w_{22}	w_{23}	w_{24}
3 - SH	w_{31}	w_{32}	w_{33}	w_{34}
4 - AP	w_{41}	w_{42}	w_{43}	w_{44}

Step 6: The eigenvector method is used where the supermatrix is incrementally raised in orders of mathematical power until all the values across the column are converged. During convergence, the final ranking and weights of elements in the model can be obtained. The converged values indicate all the direct and indirect influence of the elements with respect to the goal is taken into consideration in deriving final outcomes.

Step 7: As a form of verification, Monte Carlo simulation is adopted to simulate the financial performance of the project to make sure the outcome of the proposed DEFANP model is in line with the simulation result. The Monte Carlo simulation is performed using equation-based models which developed in Microsoft Excel.

The general model formulation for the Monte Carlo simulation is presented as follow:

NPV is an indicator that able to reflect the present value of cash inflow and cash outflow, which considers the monetary inflation rate over the operational lifespan, t (see Equation (7-4)). In this work, it is used to compare the effectiveness of each proposed action plan. Note that the NPV in t^{th} year is computed based on the summation of the monthly Prevent value (PV) of each month m, $PV_{m,t}$ (see Equation (7-5)).

$$NPV = \sum_t NPV_t \tag{7-4}$$

$$NPV_t = \sum_m PV_{m,t} \quad \forall t \in T \tag{7-5}$$

To obtain $PV_{m,t}$, Equation (7-6) is applied to convert the corresponding monthly net cash flow, $NCF_{m,t}$ into present values with the use of the discount rate, in.

$$PV_{m,t} = \frac{NCF_{m,t}}{(1+in)^t} \quad \forall t \in T, \forall m \in M \tag{7-6}$$

$NCF_{m,t}$ is determined using Equation (7-7), where $CF_{m,t}^{IN}$ and $CF_{m,t}^{OUT}$ refer to the input and output cash flow; TAX refer to the corporate tax rate; while the investment tax allowance which served as a tax exemption indicator is denoted as ITA. Note that the qualifying rate and the exemption limit used in this work are 80% and 85% respectively [232].

$$NCF_{m,t} = (CF_{m,t}^{IN} - CF_{m,t}^{OUT}) \times (1 - TAX) + ITA \times TAX \quad \forall t \in T, \forall m \in M \tag{7-7}$$

In a polygeneration plant, $CF_{m,t}^{IN}$ is usually contributed by two main components, i.e., (i) sales from selling bio-oil (first term of Equation 7-8) and (ii) profit obtained through feed-in-tariff (second term of Equation 7-8).

$$CF_{m,t}^{IN} = F_{m,t}^{OIL} \times C_{m,t}^{OIL} + Elec_{m,t}^{EXP} \times C^{FIT} \quad \forall t \in T, \forall m \in M \qquad \text{7-8}$$

where $F_{m,t}^{OIL}$ refers to the total bio-oil generated through pyrolysis process; $Elec_{m,t}^{EXP}$ indicates the generated power which channeled back to the electricity grid; while the bio-oil price and the FiT rate are denoted as $C_{m,t}^{OIL}$ and C^{FIT}.

$F_{m,t}^{OIL}$ and other pyrolysis products (i.e., syngas, $F_{m,t}^{GAS}$ and bio-char, $F_{m,t}^{CHAR}$) can be determined using Equations 7-9 to 7-11:

$$F_{m,t}^{OIL} = Biomass_{m,t}^{DRY} \times y^{OIL} \quad \forall t \in T, \forall m \in M \qquad \text{7-9}$$

$$F_{m,t}^{GAS} = Biomass_{m,t}^{DRY} \times y^{GAS} \quad \forall t \in T, \forall m \in M \qquad \text{7-10}$$

$$F_{m,t}^{CHAR} = Biomass_{m,t}^{DRY} \times y^{CHAR} \quad \forall t \in T, \forall m \in M \qquad \text{7-11}$$

where $Biomass_{m,t}^{DRY}$ refers to the amount of dried biomass consumed in the polygeneration plant; while the respective product yield for bio-oil, syngas and bio-char are denoted as y^{OIL}, y^{GAS} and y^{CHAR} respectively.

The generated $F_{m,t}^{GAS}$ which contained various high energy content gaseous, g (i.e., CO, H_2 and CH_4) are converted into electricity, $Elec_{m,t}^{GEN}$ and thermal energy, $Thermal_{m,t}^{GEN}$ via co-gen process. Based on commercial gas engine performance data, the amount of thermal energy recovered from a co-gen process is 1.2 times the amount of electricity being generated [233]. The amount of energy produced is computed in Equations 7-12 and 7-13:

$$Elec_{m,t}^{GEN} = \sum_g (F_{m,t}^{GAS} \times y_g^{PY} \times LHV_g) \times \xi^{ENGINE} \quad \forall t \in T, \forall m \in M \qquad \text{7-12}$$

$$Thermal_{m,t}^{GEN} = 1.2 \times Elec_{m,t}^{GEN} \quad \forall t \in T, \forall m \in M \qquad \text{7-13}$$

where y_g^{PY} refers to the composition of gas g; LHV_g indicates the lower heating value of gas g; while ξ^{ENGINE} represents the conversion efficiency of the gas engine unit.

$Elec_{m,t}^{GEN}$ is used to compensate for the electricity consumption of the pyrolysis process, $Elec_{m,t}^{REQ}$ (computed through Equations 7-14). External power, $Elec_{m,t}^{IMP}$ will be imported from grid if $Elec_{m,t}^{GEN}$ is insufficient to sustain the process. Contrarily, if there were excessive power, the energy will be supplied back to the grid. This can be defined as Equations 7-15:

$$Elec_{m,t}^{REQ} = Biomass_{m,t}^{DRY} \times \psi^{PY} \qquad \forall t \in T, \forall m \in M \qquad \text{7-14}$$

$$Elec_{m,t}^{GEN} + Elec_{m,t}^{IMP} = Elec_{m,t}^{REQ} + Elec_{m,t}^{EXP} \qquad \forall t \in T, \forall m \in M \qquad \text{7-15}$$

Similarly, $Thermal_{m,t}^{GEN}$ is used to compensate for the thermal energy required during the biomass drying, $Thermal_{m,t}^{REQ}$. Equation 7-16 is used to determine the $Thermal_{m,t}^{REQ}$ of the drying process. On top of that, $F_{m,t}^{CHAR}$ is also used as the solid fuel to generate thermal energy. Coal will be utilised as additional solid fuel if the generated thermal energy is insufficient to meet the energy consumption (see Equation 7-17).

$$Thermal_{m,t}^{REQ} = Biomass_{m,t}^{IN} \times \frac{(MC_{m,t}^{IN} - MC^{OUT})}{100} \times \psi^{THERMAL} \qquad \forall t \in T, \forall m \in M \qquad \text{7-16}$$

$$Thermal_{m,t}^{REQ} = \left(F_{m,t}^{COAL} \times LHV^{COAL} + F_{m,t}^{CHAR} \times LHV^{CHAR}\right) \times \xi^{DRY} + Thermal_{m,t}^{GEN} \qquad \forall t \in T, \forall m \in M \qquad \text{7-17}$$

where $Biomass_{m,t}^{IN}$ and $F_{m,t}^{COAL}$ refer to the amount of raw biomass sent to the polygeneratin plant and amount of coal used as the solid fuel; the moisture content before and after the drying process are expressed as $MC_{m,t}^{IN}$ and MC^{OUT} respectively; $\psi^{THERMAL}$ indicates the thermal energy required to remove a unit of water content; while the lower heating values of coal and char are represented as LHV^{COAL} and LHV^{CHAR} respectively.

$CF_{m,t}^{OUT}$ cis contributed by the capital expenditure (CAPEX), C_k^{CAPEX} (this is invested in *t*=0); operating expenditure (OPEX), $C_{k,m,t}^{OPEX}$ of each unit *k*; transportation cost, $C_{m,t}^{TR}$; procurement cost, $C_{m,t}^{PROCURE}$ (imported electricity, biomass and(or) coal); and carbon penalty, $C_{m,t}^{PENALTY}$.

$$CF_{m,t}^{OUT} = \begin{cases} \left.\sum_k C_k^{CAPEX}\right|_{t=0} \\ \left.\sum_k C_{k,m,t}^{OPEX} + C_{m,t}^{TR} + C_{m,t}^{PROCURE} + C_{m,t}^{PENALTY}\right|_{t>0} \end{cases} \quad \text{7-18}$$

$$\forall t \in T, \forall m \in M$$

$C_{m,t}^{TR}$ considers the cost associated with the materials transportation (including biomass and bio-oil). In this work, the transportation mode is assumed to be the conventional 10 tonnes truck, while all the required details (including fuel consumption, capacity constraint, dimension, etc.) can be obtained from How et al. [234] . It is expressed as follow:

$$C_{m,t}^{TR} = 2 \times \frac{\left(Biomass_{m,t}^{IN} \times d^S + F_{m,t}^{OIL} \times d^D\right)}{Cap^{TRUCK}} \times \psi^{FUEL} \times C_{m,t}^{FUEL} \quad \text{7-19}$$

$$\forall t \in T, \forall m \in M$$

where d^S and d^D refer to the travelling distance (i.e., from biomass source to polygeneration plant and from polygeneration plant to the demand respectively); $C_{m,t}^{FUEL}$ indicates the fuel price at month *m* in year *t*; while the vehicle capacity constraint and fuel consumption rate of the transportation mode are expressed as Cap^{TRUCK} and ψ^{FUEL} respectively. Note that the constant "2" in Equation 7-19 is used to indicate a complete trip (i.e., round trip).

Aside from that, $C_{m,t}^{PROCURE}$ can be determined by multiplying the capacity of the imported material to their respective unit cost:

$$C_{m,t}^{PROCURE} = Biomass_{m,t}^{IN} \times C_{m,t}^{BIOMASS} + F_{m,t}^{COAL} \times C_{m,t}^{COAL} + Elec_{m,t}^{IMP} \times C^{ELEC} \quad \forall t \in T, \forall m \in M \qquad \text{7-20}$$

where $C_{m,t}^{BIOMASS}$, $C_{m,t}^{ELEC}$ and C^{ELEC} refer to the unit cost of biomass, coal and imported electricity respectively.

In this work, carbon penalty which was introduced by Zhou et al. [235] and further implemented by How et al. [234], is used in this work to estimate the compensation cost required to recover the environmental damage caused by the carbon emission. It is computed through Equation 7-21:

$$C_{m,t}^{PENALTY} = C^{CO2} \times \left(2 \times \frac{(Biomass_{m,t}^{IN} \times d^S + F_{m,t}^{OIL} \times d^D)}{Cap^{TRUCK}} \times \psi^{FUEL} \times y^{CO2_{TR}} + Elec_{m,t}^{GEN} \times y^{CO2_{COGEN}} + F_{m,t}^{GAS} \times y^{CO2_{PY}}\right) \forall t \in T, \forall m \in M \qquad \text{7-21}$$

where y^{CO2_TR}, y^{CO2_COGEN} and y^{CO2_PY} refer to the carbon yield during transportation, co-gen unit and pyrolysis process; while C^{CO2} refers to the unit compensation cost.

During the Monte Carlo simulation, the following two supply and demand constraints must be fulfilled:

$$Biomass_{m,t}^{AVAILABLE} \geq Biomass_{m,t}^{IN} \qquad \forall t \in T, \forall m \in M \qquad 7\text{-}22$$

$$F_{m,t}^{OIL} \leq F_{m,t}^{OIL\_DEMAND} \qquad \forall t \in T, \forall m \in M \qquad 7\text{-}23$$

where $Biomass_{m,t}^{AVAILABLE}$ refers to the biomass availability at month m in year t; while the local demand of the bio-oil at month m in year t is indicated as $F_{m,t}^{OIL\_DEMAND}$. Note that Equation 7-22 is used to ensure the supplied biomass to the polygeneration plant is capped at the biomass availability; whereas the inequality in Equation 7-23 shows that it is not necessary to fulfil all the market demand.

It is worth to mention that, random inputs (based on the statistical data) are used to represent the supply uncertainty ($Biomass_{m,t}^{AVAILABLE}$), demand variation ($F_{m,t}^{OIL\_DEMAND}$), price fluctuation ($C_{m,t}^{BIOMASS}$, $C_{m,t}^{COAL}$, $C_{m,t}^{FUEL}$ and $C_{m,t}^{OIL}$), seasonal biomass quality ($MC_{m,t}^{IN}$) in this Monte Carlo simulation. 10,000 samples are generated through the simulation, while the NPV and the payback period of these samples are analysed. The effectiveness of the proposed action plans is evaluated based on the improvement of these two components (NPV and payback period).

Step 8: Sensitivity analysis is performed with the Oracle Crystal Ball add-in to Microsoft Excel. Vary with the Step 7, where the simulation is performed based on single action plan each time to observe the impact of the respective action plan on NPV and PBP, for sensitivity analysis, the seven action plans are presented as a distribution and executed simultaneously through 10,000 simulation. Thus, the sensitivity of the respective action plan towards the overall NPV and PBP throughout the project life-cycle can be observed.

Chapter 8. Risk minimisation

8.1 Case study background - Biomass polygeneration system

In general, thermochemical (e.g., direct combustion, gasification and pyrolysis) and biological conversion of biomass are common bioenergy conversion methods [236]. Pyrolysis is considered as one of the most effective technologies to convert biomass into tri-states products (e.g. biogas, solid char, and liquid bio-oil) without the need for expensive chemical reagent [237]. These products are found to have relatively higher heating value (HHV) and can potentially be adopted as intermediary products for Fischer-Tropsch process and biodiesel production [238]. For instance, Chen et al. [239] perform pyrolysis of cotton stalk to evaluate the effects of temperature reaction on the characteristics of tri-phase products and find the reaction temperatures ranging from 550 to 750 °C is the most suitable for the production [239]. Other studies on the effects of heating rates of other biomass sources can be found in Wan Alwi et al. [240].

Liu et al. [241] argue that polygeneration approach is a promising energy conversion technology because it enables high energy conversion and improves the economic attractiveness of the different products as well as has the potential to reduce the costs of carbon capture and sequestration. The effectiveness of polygeneration in biomass-conversion efficiency provides higher outcome value compared to open cycle generation [239]. In power generation, the gas turbine is the major components of the system. Typical modern gas turbine efficiency varies from 30% to 35% [242]. In order to increase the efficiency of the system, a heat recovery steam generator (HRSG) recovers energy from the gas turbine's exhaust gas. Recovered steam can be further used for process consumption or electric generation with a steam turbine. This will increase the overall system efficiency substantially. Furthermore, it is also proven that chemical and fuel synthetic can be recovered from polygeneration [241]. Chemical components such as hydrogen, methanol and synthetic natural gas can be recovered as value added products. In addition to its value as a fuel gas, hydrogen has a vast application spectrum including in the production of carbon steels, special metals and semiconductors. Moreover, it is also widely used in the electronic industry as a reducing agent and as a carrier gas [243]. However, the efficiency and reliability of conventional hydrogen production are delaying the development and progress of a hydrogen economy [210]. The development of an affordable method for hydrogen production with less environmental damage will contribute significantly to the hydrogen economy. Methanol is an important intermediate product for other chemicals such as formaldehyde and acetic acid. In addition, methanol is also identified as a potential alternative fuel source for an internal combustion engine. Synthetic natural gas consists of approximately 96% of methane which has similar properties with natural gas. In an area with limited access to natural gas, polygeneration can provide a convenient, consistent and high-quality supply of synthetic natural gas.

Polygeneration provides the advantages of processing a wide range of biomass without compromising environmental performance. Parraga et al. [210] point out the significant barriers to polygeneration are capital investment cost and plant performance when dealing with different biomass options. The study adds that the desire for a sustainable and flexible energy conversion system is critical to cope with environmental challenges. Tako et al.[244] view that the cost and complexity of the logistic operations hinder biomass utilisation for energy production. Jana and De [245] also point out that logistics of biomass causes the maximum environmental impact among all process units in polygeneration systems. Due to the complexity of the polygeneration system and the logistics challenges, the capital investment cost of the system will be intensive. However, economic attractiveness can be increased by switching the biomass and product based on market price and demand. The intervention of government in terms of policy and incentive will be one of the driving forces to ensure successful implementation of the polygeneration system.

8.2 Case description

In this work, a biomass pyrolysis-based polygeneration plant is used as an illustrative case study. EFB is collected from a nearby palm oil mill (located 10 km away from the plant). They are dried and used as the pyrolysis feed in the polygeneration plant. The produced bio-oil is valuable (demand point is assumed to be located 15 km away from the plant), while the by-products (i.e., syngas and biochar) can be used to generate utility energy (electricity and thermal energy) in the co-generation process and can also be used as solid fuels. These generated utilities can then be used to compensate for the heat and power requirement of the polygeneration plant. As mentioned, the generated excess electricity can be sent to the national grid in order to generate additional revenue. The visual illustration of this case study is presented as Figure 8-1, while all the important parameters used to develop the case study model (as introduced in Step 7) are summarised in Table

8-1. Next, Table 8-2 presents the explanation of each action plan while Table 8-3 illustrated the changes made according to the different action plans. Monte Carlo simulation is then performed based on these changes to validate the economic feasibility for each action plan.

Table 8-4 is the parameters of the action plan used for sensitivity analysis.

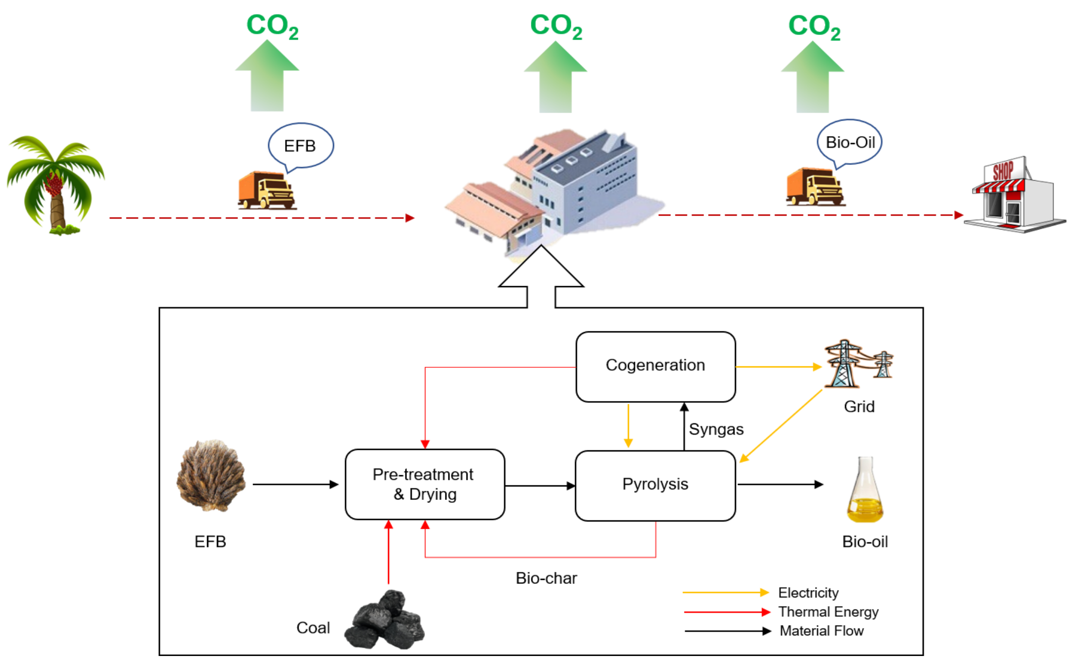


Figure 8-1 Polygeneration plant case study overview.

Table 8-1 Parameters used in this work.

Parameter	Remark	Value	Unit	Reference
		Random Inputs		
$Biomass_{m,t}^{AVAILABLE}$	Low Season[1]	9890.82 (Mean[2]) 323.69 (SD[2,3])	tonnes / month	[246]
	Mid Season[1]	11664.92 (Mean[2]) 203.37 (SD[2,3])		
	High Season[1]	13853.1 (Mean[2]) 350.30 (SD[2])		

Table 8-2 Parameters used in this work (continued)

Parameter	Remark	Value	Unit	Reference
Random Inputs				
$F_{m,t}^{OIL\_DEMAND}$	January[4]	918.60 (Mean) 90.86 (SD[3])	tonnes / month	[247]
	February[4]	915.60 (Mean) 65.80 (SD[3])		
	March[4]	926.70 (Mean) 82.86 (SD[3])		
	April[4]	927.75 (Mean) 69.03 (SD[3])		
	May[4]	960.00 (Mean) 66.95 (SD[3])		
	June[4]	957.45 (Mean) 48.72 (SD[3])		
	July[4]	984.27 (Mean) 63.89 (SD[3])		
	August[4]	978.95 (Mean) 59.60 (SD[3])		
	September[4]	970.77 (Mean) 61.26 (SD[3])		
	October[4]	936.82 (Mean) 68.21 (SD[3])		
	November[4]	929.18 (Mean) 92.27 (SD[3])		
	December[4]	924.95 (Mean) 89.10 (SD[3])		
$C_{m,t}^{BIOMASS}$	-	140 (Max) 290 (Min)	MYR/ tonnes	-
$C_{m,t}^{COAL}$	-	287.80 (Mean[5]) 79.57 (SD[3,5])	MYR/ tonnes	[248]
$C_{m,t}^{FUEL}$	-	2.13 (Mean[6]) 0.11 (SD[3,6])	MYR/ L	[249]
$C_{m,t}^{OIL}$	-	3.37 (Mean) 0.11 (SD[3])	MYR/ L	-
$MC_{m,t}^{IN}$	Dry Season	66.5 (Mean) 1.83 (SD[3])	%	[250]
	Rainy Season[7]	76.5 (Mean) 1.83 (SD[3])		

Table 8-3 Parameters used in this work (continued)

Parameter	Remark	Value	Unit	Reference
Other Parameters				
$MC_{m,t}^{OUT}$	Desired moisture content	10	%	-
Pyrolysis product yield	Oil, y^{OIL} Syngas, y^{GAS} Char, y^{CHAR}	27 24 49	%	[251]
y_g^{PY}	H_2 CO CH_4 CO_2	3.7 34.0 7.8 54.0	%	[251]
Carbon emission	Transportation, y^{CO2_TR} Co-gen, y^{CO2_COGEN}	2.68 0.525	kg CO_2/ L fuel kg CO_2/ kWh	[252]
LHV_g	H_2 CO CH_4	120.1 283.5 801.4	MJ/kg kJ/mol kJ/mol	[253,254]
Heating value of solid fuel	Coal, LHV^{COAL} Char, LHV^{CHAR}	23 26	MJ/kg MJ/kg	[255,256]
Efficiency	Gas Engine, ξ^{ENGINE} Drying, ξ^{DRY}	38.7 85	%	[233]
ψ^{PY}	-	240	kWh/ tonne EFB	[257]
ψ^{FUEL}	-	0.213	L/km	[234]
$\psi^{THERMAL}$	-	4	MJ/kg water removed	[258]
TAX	-	24	%	-
in	-	10	%	-

Table 8-4 Parameters used in this work (continued)

Parameter	Remark	Value	Unit	Reference
Other Parameters				
C_k^{CAPEX}	Pyrolysis processes Co-generation units	6.26 [8] 1.94	1,000,000 MYR	[259,260]
$C_{k,m,t}^{OPEX}$	Pyrolysis processes Co-generation units	171 0.25	MYR/tonne EFB MYR/kWh	[261]
C^{FIT}	-	0.4886	MYR/kWh	[107]
C^{ELEC}	-	0.55	MYR/kWh	-
C^{CO2}	-	0.20	MYR/kg CO_2	[234]
Cap^{TRUCK}	-	10	tonnes/trip	-
Distance Travelled	From biomass Source to plant, d^S From plant to demand, d^D	10 15	km/trip	-

[1]Classified based on the monthly palm crude oil production [71]. Low season: January to March; Mid-season: April to June; High season: July to December.
[2]EFB availability for a single 90 t FFB/h palm oil mill; assumed constant empty fruit bunch and crude palm oil (CPO) yield in respect to fresh fruit bunch (FFB), i.e., 0.23 t EFB/t FFB and 0.204 t CPO/t FFB respectively.
[3]SD = standard deviation
[4]The local bio-oil demand is assumed similar to the pattern of the oil production in Malaysia (historical data from year 2009 to 2018; obtained from U.S. Department of Energy Information Administration)
[5]Based on the data collected from October 2013 to May 2018.
[6]Based on the data collected from December 2014 to August 2018.
[7]Assumed moisture content of the EFB during rainy seasons is 10% more than that of during dry seasons.
[8]Estimated using six-tenths rule.

Table 8-5 Descriptions for each action plan

Code	Action plan	Description
AP1 – HD	Engage in demand contract	To hedge demand risk by committed into a supply contract with the consumer(s), to sell a fixed amount of product for a fixed duration, with fixed prices (≤3% of current market price).
AP2 – HS	Engage in supply contracts	To hedge supply risk by committed into a purchase contract with the supplier(s), to buy a fixed amount of raw materials for a fixed duration, with fixed prices (≥10% of current market price).
AP3 – FI	Introduce new financing incentive	To reduce financing risk by providing financing incentives in the form of interest rate reduction/annum to lower the debt obligation of industry players.
AP4 – SF	Substitute fossil fuel with biodiesel	To encourage the substitution of conventional fossil fuel which is less environmentally friendly with biodiesel to boost up the demand of end-products for the biomass polygeneration project.
AP5 – TI	Introduce new tax incentive	To reduce regulatory risk by showing favour in the form of tax exemption to encourage the utilisation of biomass for wealth generation and the development of the green growth industry.
AP6 – RF	Revise Feed-in-Tariff (FiT) rate	To promote higher utilisation of renewable energy by revising the FiT rate to a higher rate to make it attractive for new entrants and investors to venture into the industry.
AP7 – CM	Introduce carbon management systems	To promote sustainable development by introducing carbon management systems upfront to avoid high carbon emission which could potentially result in carbon penalties.

Table 8-6 Mode changes required for each action plan.

Action Plan	Description	Changes required
AP1-HD	Engage in demand contract	Contracted demand = 1700 tonne/year $C_{m,t}^{OIL}$ is 3% lesser than market price
AP2-HS	Engage in supply contract	Contracted supply = 10,000 tonne/year $C_{m,t}^{BIOMASS}$ is 10% higher than market price
AP3-FI	Introduce new financing incentive	in is reduced to 6%
AP4-SF	Substitute fossil fuel with biodiesel	$C_{m,t}^{FUEL}$ = 2.8 MYR/L y^{CO2_TR} = 2.1 kgCO_2/L
AP5-TI	Introducing new tax incentive (first 5 years)	TAX = 0% for $t \leq 5$
AP6-RF	Revise FiT rate	C^{FIT} increased by 10%
AP7-CM	Introducing carbon management system	CAPEX is assumed 60% more expensive [260] OPEX = 0.1505 MYR/kg CO_2 removed [261] Removal efficiency is assumed as 80%

The DEFANP model for this case study is illustrated in Figure 8-2. In order to quantify the effectiveness of the action plan, the goal (i.e., C_1 - Goal) is set to improve the NPV of biomass polygeneration project. C_2 - KE cluster consists of the technology and process (TP) (i.e., conversion pathway, technologies implemented) and supply chain (SC) (i.e., supply, demand, logistics). C_3 - SH cluster comprises the government agency (GA) and industry players (IP). Government agencies are defined as parties that are capable to propose, amend, change rules and regulations that govern or affect the overall development of the biomass industry. Industry players are referred to as the business owner, investors that directly or indirectly contribute to the growth of this industry. Finally, C_4 – AP cluster consists of seven

(7) risk mitigation strategies that potentially help to reduce the overall risk profile of the project through the NPV performance over a 20-years project life-cycle. The action plans are selected based on the risk identified in the biomass industry as presented in Chapter 4.

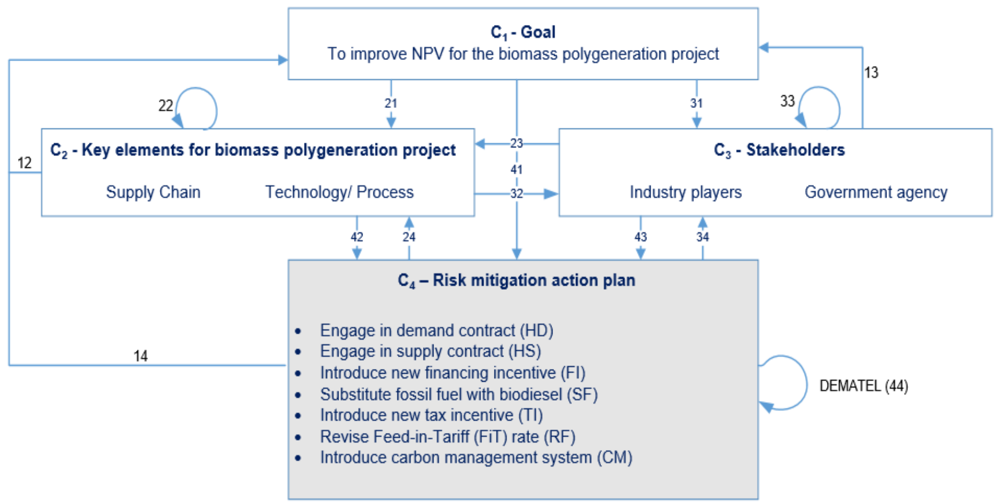


Figure 8-2 Development of the network model with its relationship for biomass pyrolysis-based polygeneration plant

The calculation for FANP and DEMATEL are performed based on equation 6-1, 6-2 and 7-1 to 7-3 as explained in the methodology. The priority weights generated based on FANP and total relation matrix from DEMATEL are then populated into a supermatrix as illustrated in Figure 8-3. The supermatrix is then raised to power until all the values converged, to attain the final value. Monte Carlo simulation is then performed based on the changes of the action plans as described in Table 8-3 to validate the economic feasibility for each action plan.

	GO	K-SC	K-TP	S-GA	S-IP	AP1-HD	AP2-HS	AP3-FI	AP4-SF	AP5-TI	AP6-RF	AP7-CM	Overall
GO	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
K-SC	0.7238	1.0000	0.4513	0.4819	0.5763	0.2958	0.4764	0.1667	0.7602	0.8540	0.8117	0.1935	**0.5465**
K-TP	0.2762	0.6452	1.0000	0.5181	0.4237	0.7042	0.5236	0.8333	0.2398	0.1460	0.1883	0.8065	0.4535
S-GA	0.5000	0.4016	0.6757	1.0000	0.2354	0.5587	0.3774	0.7576	0.3861	0.7813	0.8065	0.3378	**0.5034**
S-IP	0.5000	0.5984	0.3243	0.7863	1.0000	0.4413	0.6226	0.2424	0.6139	0.2188	0.1935	0.6622	0.4966
AP1-HD	0.1811	0.0860	0.2366	0.1470	0.0591	0.1125	0.1819	0.1576	0.1447	0.1448	0.1494	0.1673	0.1461
AP2-HS	0.1066	0.0572	0.1952	0.1020	0.1788	0.2408	0.1506	0.2244	0.1988	0.1902	0.1943	0.2133	0.1415
AP3-FI	0.2533	0.0860	0.2489	0.2718	0.1129	0.2087	0.1892	0.1269	0.1725	0.1606	0.1741	0.1838	**0.1927**
AP4-SF	0.0444	0.0777	0.1136	0.0515	0.0812	0.1697	0.1783	0.1629	0.1017	0.1094	0.1190	0.1630	0.0870
AP5-TI	0.1441	0.2744	0.0365	0.1886	0.1936	0.0682	0.0840	0.0955	0.1178	0.0903	0.1835	0.0905	0.1537
AP6-RF	0.1920	0.3427	0.0405	0.1875	0.1936	0.0731	0.0893	0.1008	0.1287	0.2180	0.0915	0.0957	0.1769
AP7-CM	0.0785	0.0760	0.1287	0.0515	0.1809	0.1269	0.1267	0.1320	0.1357	0.0867	0.0881	0.0863	0.1020

Note:
GO – Goal; **K-SC** – Supply chain; **K-TP** – Technology/ Process; **S-GA** – Government agency; **S-IP** – industry players; **AP1-HD** – Engage in demand contract; **AP2-HS** – Engage in supply contract; **AP3-FI** – Introduce new financing incentive; **AP4-SF** – Substitute fossil fuel with biodiesel; **AP5-TI** – Introduce new tax incentive; **AP6-RF** – Revise Feed-in-Tariff rate; **AP7-CM** – Introduce carbon management systems

Figure 8-3 The initial supermatrix heatmap populated with DEFANP method

By plotting the digraph based on $(R_i + C_i)$ against $(R_i - C_i)$ value as shown in Figure 8-4, it clearly illustrated the inter-correlation of the elements with clear indication of causal or effect factor.

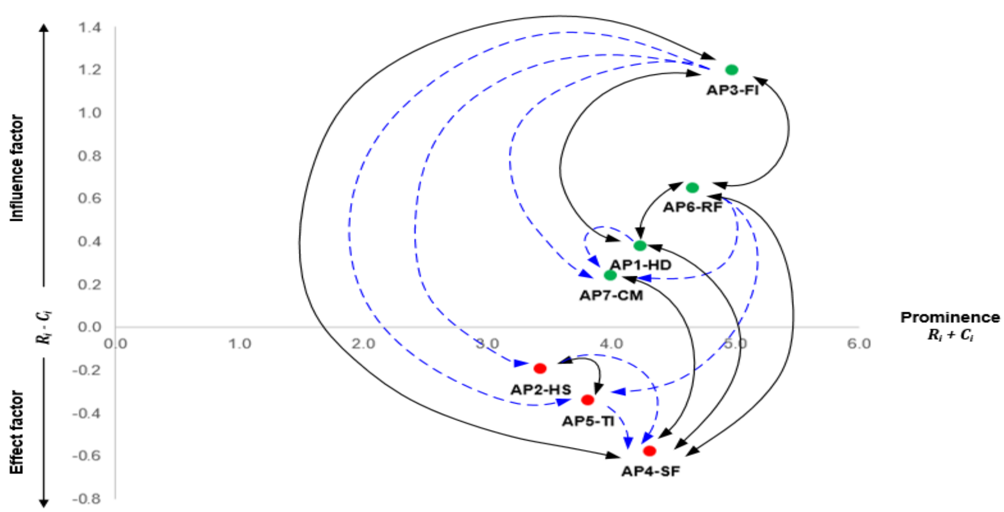


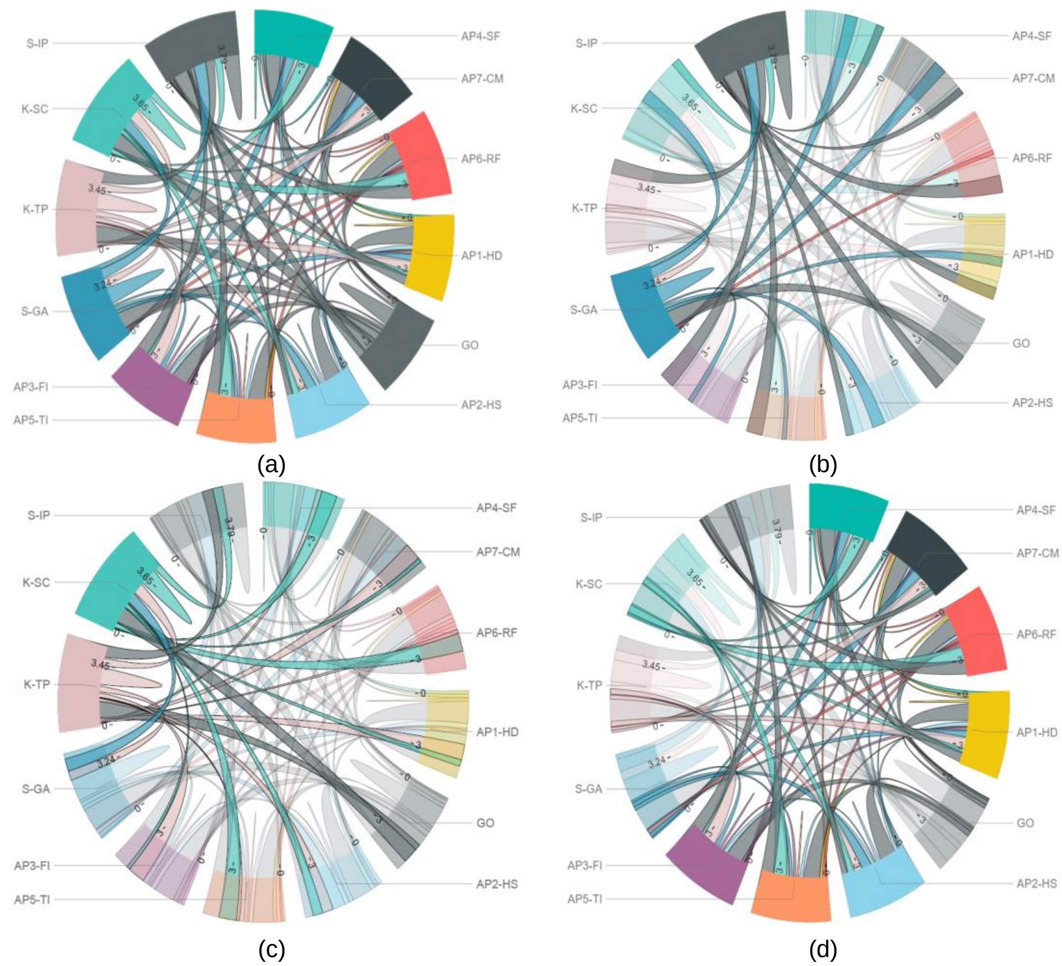
Figure 8-4 Dematel prominence-causal relationship diagram

Table 8-7 Distribution for each action plan for sensitivity analysis

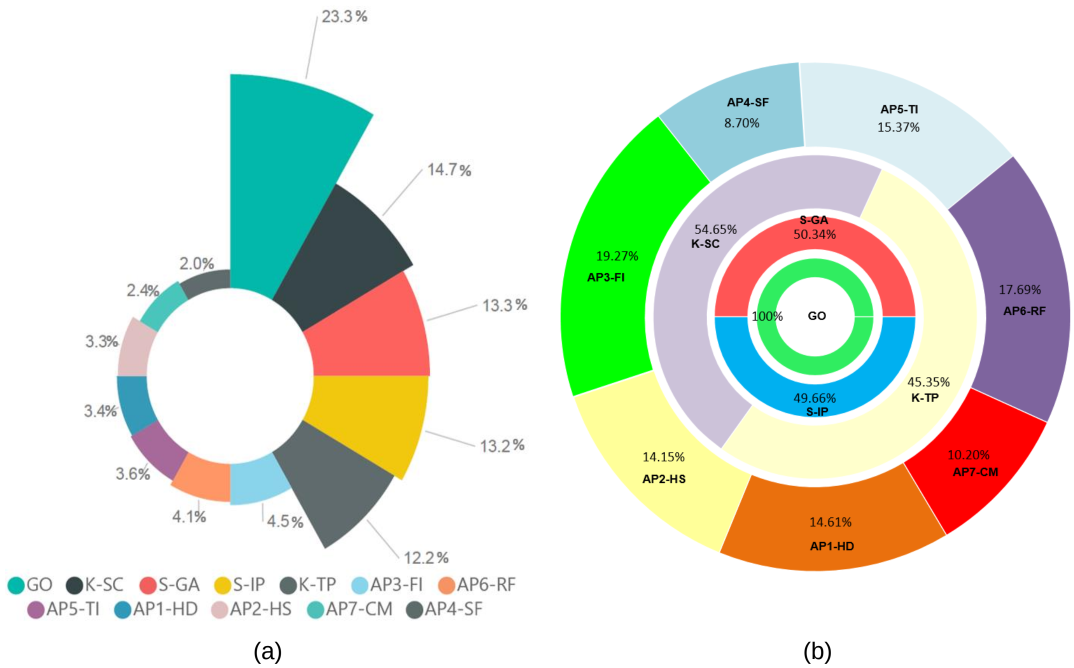
Action Plan	Remark	Distribution	Variation and range	Unit
AP1-HD		Triangular	Minimum: 1200 Median:1700 Maximum: 2200	tonne/year
AP2-HS		Triangular	Minimum: 10,000 Median: 20,000 Maximum: 30,000	tonne/year
AP3-FI		Triangular	Minimum: 5 Median: 6 Maximum: 10	%/annum
AP4-SF	Minimum – Fossil fuel; Maximum – biodiesel; Correlated with CO2 emission with correlation coefficient of -1	Discrete uniform	Minimum: 1.80 Maximum: 2.80	MYR/L
AP5-TI	For the first 5 years	Triangular	Minimum: 20 Median:80 Maximum: 100	% reduction /year
AP6-RF	Median = $C^{FIT} x$ 1.1 (10% increase)	Triangular	Minimum: 0.44 Median:0.52 Maximum: 0.58	MYR/kWh
AP7-CM	CAPEX is assumed 60% more expensive [260] OPEX = 0.1505 MYR/kg CO_2 removed [261]	Triangular	Minimum: 30 Median:80 Maximum: 90	CO^2 Removal efficiency (%)

8.3 Results and Discussion

The outcomes generated from the DEFANP model are presented in Figures 8-5 and 8-6. Figure 8-5 is the relational nexus illustrating the relationship of elements in the network problem.



Figures 8-5 DEFANP relationship nexus highlighted for: (a) Overall elements; (b)Stakeholder cluster; (c) Key elements cluster; (d) Action plan cluster.



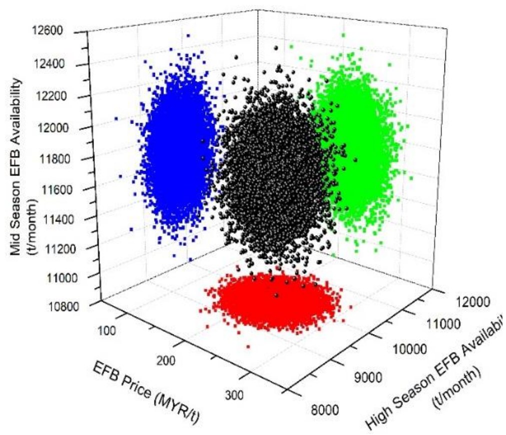
Figures 8-6 Importance weights of elements: (a) Relative to full project; (b) Relative to goal in cluster.

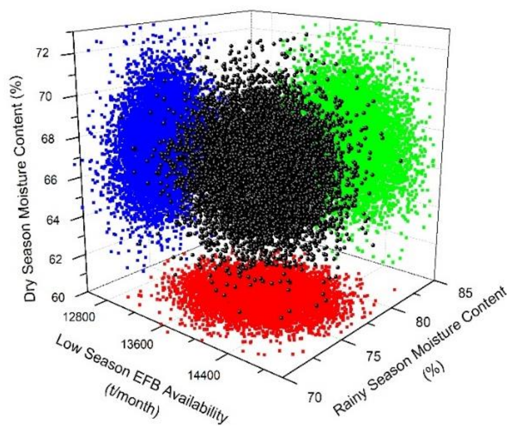
The value of each element signifies the structural and causal dependency of the elements with respect to other elements in the network model. For instances, the goal element (i.e., GO = 23.3 %) is interpreted as the importance of GO with respect to KE, SH, and APs, vice versa. Traditionally, the results of FANP can be interpreted in two dimensions, based on clusters' weight and elements' weight. In term of the cluster, KE appeared to be the most important cluster, followed by SH, and finally, GO cluster and AP cluster. It is because KE (i.e., supply chain and technology/process) and SH are the underlying assets and the executor of the project. Thus, KE and SH serve as the core elements prior prioritising the action plans (i.e., APs cluster) to improve NPV for the biomass polygeneration project (i.e., GO).

To improve understanding of the dominance relationship of the elements in the whole system, the result has been normalized based on clusters. It is observed that the enhancement on the supply chain (54.65 %) is slightly more effective compared to the process and technology chosen/implemented (45.35 %) in improving the NPV of the biomass polygeneration projects. This outcome is supported by Kurian et al. [77], in which supply chain (i.e., logistics, consistent feedstock supply, demand) can contribute up to 70 % of the total operating cost for a biomass project. The remote location of biomass sources has further aggravated the supply chain issue for the biomass polygeneration project in Malaysia. In general, the palm oil biomass (i.e., EFB. PKS, DC) are high in moisture content at its original form (i.e., from palm oil mill). This results in higher degradability and shorter shelf life for the biomass. Supply chain management comes in to play a key role in reducing the overall logistics time and to prevent any disruption of materials as well as information to prevent a halt in operation. In term of technology and process selection for the biomass polygeneration process, Malaysia is still highly dependent on the foreign technology, which might involve higher cost and uncertainty performance due to the nature of biomass characteristics [159]. Even though there has been active on-going research and development project working on different technologies for different biomass conversion pathway, the outcomes largely remain in a laboratory setting or a pilot scale. More resources need to be devoted to solving the scalability and commerciality issues of locally manufactured technology and to help driving down the high CAPEX due to the implementation of technology.

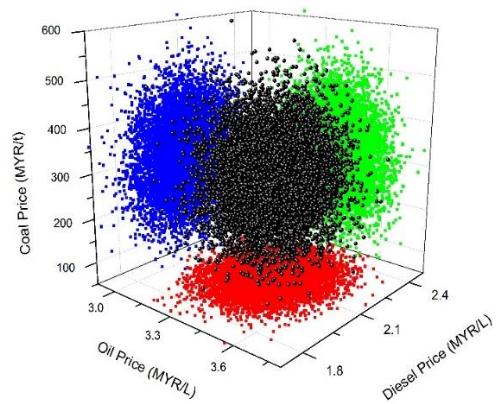
In term of industry stakeholders, both government agency (i.e., 50.34 %) and industry players (i.e., 49.66 %) appeared to be equally important in improving the NPV of the project. Meanwhile, the dependency of the effectiveness of action plans with respects to industry stakeholders as illustrated in the Figure 8-3 (i.e., w_{43}: column 4-5, row 6-12) shows that the government agency is more suitable to execute AP3–FI, AP5-TI, AP6-RF and AP1-HD while industry players have stronger capability to implement AP5-TI, AP6-RF, AP7-CM, AP2-HS. It is worth to note that both stakeholder groups are capable to execute all the action plans at different cost according to their role. Nonetheless, the higher priority weights of the action plan with respect to the stakeholders signifies greater impact can be achieved. For instance, government agency has more influence on the AP3 – FI compared to industry players (i.e., 27.18 % vs 11.29 %). This is because government agency plays a pivotal role in providing a macro-environment which is heuristics and friendly for the development of green growth. Government agency can encourage the industry players to participate in this initiative to best utilise the abundancy of oil palm biomass and convert it into wealth through introducing policy, rules and regulations. Nonetheless, without the input from the industry stakeholders, the development of the industry will remain stagnant. Some of the action plans exert similar level of dependency on both stakeholders as AP5 – TI and AP6 – RF. This indicates a close collaboration is required between government agency and industry players to successfully execute the action plans and to spur the development of biomass industry together [30]. Industry players should proactively communicate to and associate with their respective government agency on expressing the issue and problems faced in the industry. Government agency should understand the needs of the industry players to aptly offer incentives and supports for them to venture into the industry, and such move can eventually contribute to the overall economic growth. Government agency should also make sure that a clear policy signal is sent out to the investors to encourage the funding and investment for the biomass-related project. Furthermore, it is crucial for the information of the industry, inclusive of the support mechanisms and benefits offered made available to the public. This is to ensure clear guidelines are provided to ease the administrative and apply process of the stakeholders to shorten the time in acquiring such benefits.

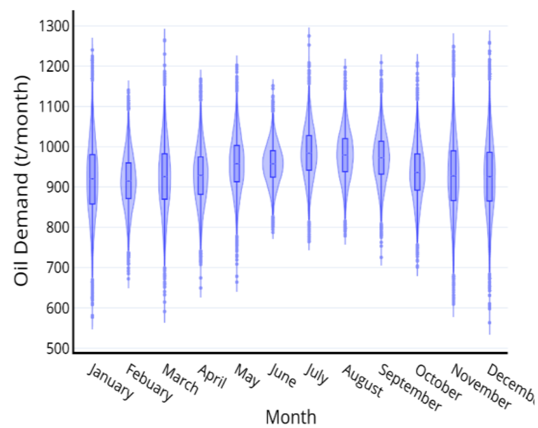
To test the robustness and reliability of action plans generated from the proposed DEFANP model as shown in Figures 8-5 and 8-6, Monte Carlo simulations are carried out with random disturbances factors such as availability, moisture content and fluctuations in prices as a verification for the DEFANP output. For each batch of simulations, the 10,000 number of individual cases were carried out. The randomised points for Monte Carlo simulation are shown in Figures 8-7.





(a) (b)





(c) (d)

Figures 8-7 Monte Carlo generated input for: (a) Mid and high season EFB availability, EFB price; (b) Dry and rainy season moisture content, low season EFB availability; (c) Coal price, oil price and diesel price; (d) Oil demand.

For this work, a total of seven action plan has been proposed to be implemented to improve the NPV of biomass polygeneration project. As mentioned above, Monte-Carlo simulation is performed to simulate the financial performance of 20-years project life, EFB based polygeneration plant to verify the outcomes from DEFANP with actual cost benefits of the respective action plan. According to the outcomes from DEFANP model as illustrated in Figure 8-6(b), AP3 –FI appeared to be the top one action to be implemented to improve the NPV of the biomass polygeneration plant. Failure to attain financing and funding for sustainable projects, including biomass project is often cited as the main reason for the slow growth of the industry in Malaysia [66,262,263]. Thus, it is important for the government to step in to offer financing incentives in aiding the industry players to start-up the project. Financing incentives can be in the form of interest rate reduction, credit guarantee, policy signal for financial institutions and investors (i.e., local, international). The currently available financing incentives offered by the government related to the development of renewable energy is the Green Technology Financing Scheme (GTFS) 2.0. Under the term of GTFS, the producers, users of the green technology and energy services companies (ESCO) can apply for up to MYR 100 million, MYR 50 million and MYR 25 million respectively from participating financial institution for the project [6]. Successful applicants for the GTFS will get a 2 % reduction in interest rate per annum based on the loan rates charged by the financial institution. Besides, Credit Guarantee Corporation (CGC) will also provide 60% of the guarantee of total financing amount, to increase the likelihood of loan approval. The first round of GTFS is completely utilised by the end of 2017, benefits up 319 green tech-related projects. Recently announced National budget 2019 continue to allocate additional MYR 2 billion for the GTFS to further accelerate the growth of green technology industry [264]. This further affirms the initiative of the government to move towards green growth.

Based on simulation results as illustrated in Figure 8-8, it is observed that there is a 58.51 % increase in the mean of NPV by introducing new financing incentive, with an additional 2 % interest rate reduction. The payback period as shown in Figure 8-9 also improved by 12.22 %, which indicates the project will achieve breakeven seven months earlier than the base case.

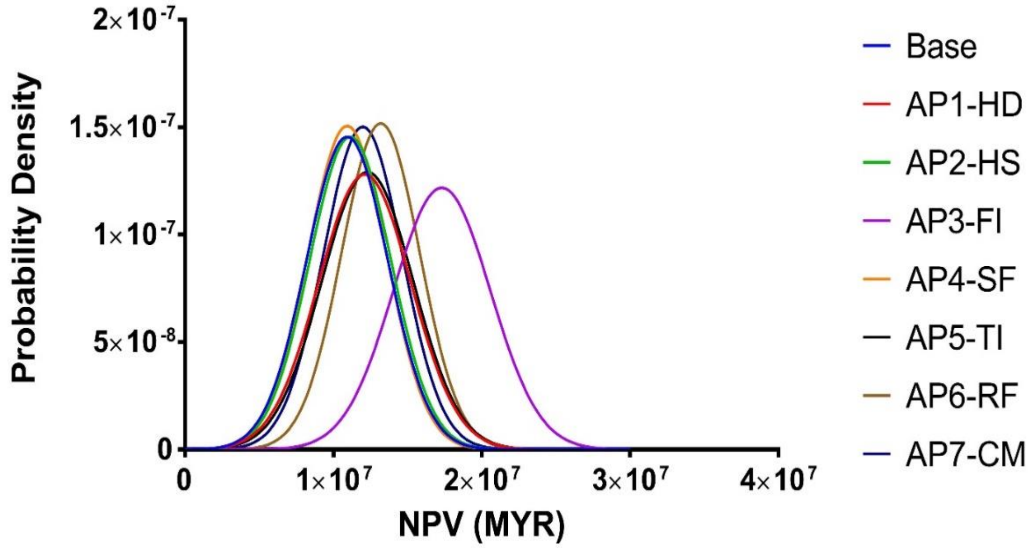


Figure 8-8 The effect of the respective action plans on NPV from 10,000 Monte Carlo simulations.

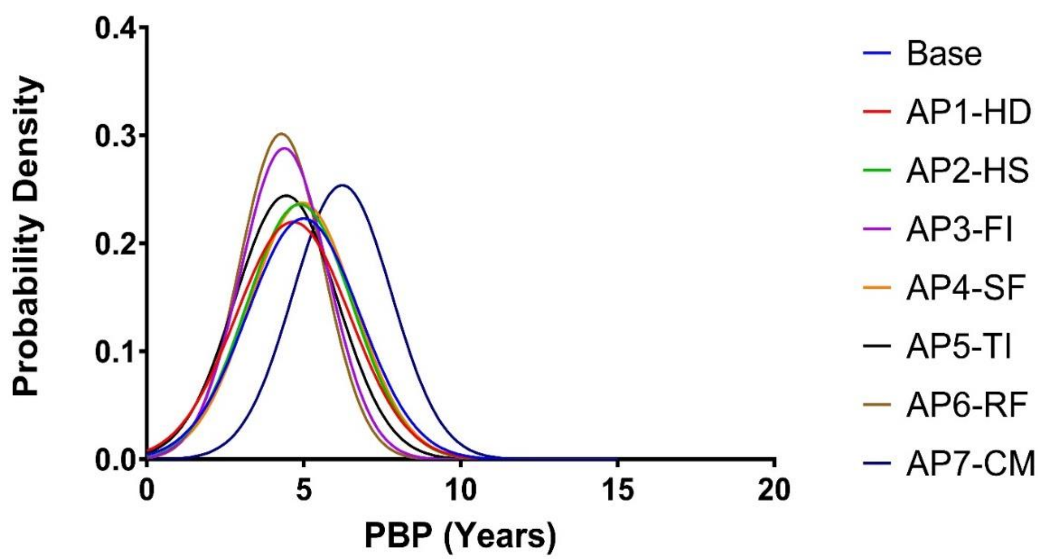


Figure 8-9 The effect of the respective action plans on the PBP from 10,000 Monte Carlo simulations.

Furthermore, the sensitivity of each action plan on the NPV and PBP as illustrated in the Figure 8-10 and 8-11 further affirmed outcomes generated by the DEFANP model. "AP3 = FI" that reduce the interest rate has the highest influence in the NPV, as high as 76.3% in term of NPV and ranked second in term on PBP (i.e., 34.5%). This further affirm that the reduction of interest rate, which directly decreases the debt obligations through lowering amount of loan repayment across the project life-cycle (i.e., 20 years) can significantly increase mean NPV and shorten the breakeven year. As minimal as it may seem, the 2% reduction of the interest rate per annum reduced the amortisation future value of loan tremendously.

"AP6 - RF" is ranked second from the proposed DEFANP model method. FiT mechanism is amongst the most widely used support systems across the world to accelerate the development of renewable energy. FiT is the premium paid to the generation of electricity based on renewable energy sources for a fixed duration, depending on the type of renewable energy sources [117]. The primary energy generation for Malaysia based on renewable sources is merely recorded as 2 % as of 2018, which is falling behind the initial target of the Renewable Energy Policy and Action Plan (2009) to reach at 5.5 % by end of 2015 [5]. In the recent announcement by the Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC), the Minister is committed to increase the generation of electricity of renewable sources to 20 % by end of 2030 [265]. The FiT rates were introduced in 2011 to promote the utilisation of renewable energy sources (i.e., solar, biomass, biogas, geothermal and hydro) in electricity generation. However, the growth of renewable energy in Malaysia remains relatively slow, as reflected by the statistics. Based on the feedback from the focus group discussion, the experts claimed that current FiT rates offered by the government are less attractive, particularly when such renewable energy plant is associated with high upfront investment. Furthermore, the quota to attain FiT rates is very limited and the application process is taking a long time as well. Nonetheless, multiple countries have achieved successful growth in renewable energy sectors through the implementation of FiT. For instance, the high rate of FiT in Thailand has successfully increased the power generation capacity by renewable sources from 8 % in 2015 to 17 % by the end of 2017 [266]. The simulation results show that the overall NPV will increase by 20.72 % with a 14.04 % reduction in the payback period by adopting AP6 to increase FiT rates. The outcomes also in line with its sensitivity analysis on NPV (i.e., 13.9 %) and PBP (i.e., 34.9 %).

The action plan that ranked 3rd, 4th and 5th are “AP5 - TI”, “AP1 - HD” and “AP2 - HS”. Identical to financing incentive, the tax incentive is another type of financial instrument that is widely used by the government to spur the growth of an industry. Some of the examples of tax incentives are tax returns, tax exemption, tax reduction and so forth. Similar with the GTFS introduced in 2013 to drive investment into the green technology industry, Malaysia government has offered multiple tax incentives for renewable energy and energy efficiency projects. For instance, green technology projects inclusive biomass polygeneration project are entitled to 70 % statutory income tax allowance (ITA) on the qualifying capital expenditure, until all the allowances are fully absorbed. Besides, the import duty and sales tax for green technology (i.e., equipment, materials, spare parts, machinery) are fully exempted as well [267]. As Malaysia has shown its clear intent in the transition towards to green growth, it is necessary to make this information known publicly to reduce the high barrier of entry to this industry [77]. The introduction of tax incentives in a specific industry is also claimed to positively affect the credit decision of investors to fund the relevant project [268]. In line with the outcome of the DEFANP, the simulation result for implementing “AP5 - TI” is also ranked 3, in which it increases the mean of the NPV by 12.62 %, and reduce the payback period by 11.04 %.

As mentioned in the above, the supply chain of the biomass polygeneration project plays a significant role in securing the long-term performance of the plant. Even though Malaysia has abundant availability of oil palm biomass, it is still an issue for the oil palm biomass production plant to experience non-disruption or non-distortion of supply across the project life cycle. One of the main factors in this issue is the scattered ownership of the oil palm plantation. About 40 % of the oil palm plantation owner are categorized as small-shareholders, who are unwilling to commit into a long-term supply contract with the potential business partner but to sell with a higher price in the short future [16]. Furthermore, the hikes in demanding for biomass is built up in Asia country such as Japan, South Korea, and China (i.e., >100% increase). This has caused a lot of the local suppliers to bound under long-term obligation to supply biomass to meet their demand, prior fulfilling the needs of local market [269]. The availability of oil palm biomass is also highly sensitive to the weather across different seasons in Malaysia. Thus, proper planning of supply chain is necessary to avoid the disruption of supply to meet the demand of market. It is a common practice in industry for production plant to engage into a long-term supply or/and demand contract to supply or purchase a fixed quantity of the product at a fixed price, for a fixed duration. This idea is similar to future contract in stock market, wherein the buyer enters into a contract at t = 0, to purchase X amount of share with Z price, at T = 1. In return, the contract owner will need to provide some premiums for the suppliers or purchasers to be bound under the obligation of demand and supply contract. For common industry practices, if party A initiates to enter into a supply contract with party B to buy 1000 EFB per month for two years, the fixed price of the EFB across the duration is required to be higher than the current market price (i.e., t = 0) by at least 10 %. As the demand curve is more sensitive than the supply curve, the premium for demand contract is usually lower than supply contract (i.e., 3 %). The simulation results based on demand contract, supply contract and a combination of both contracts shows that all three scenarios achieve better performance in NPV and payback period compared to the base case. The increase of mean of NPV for AP1 - HD, AP2 – HS and combination of AP1 - HD and AP2 - HS is 10.84 %, 1.95 %, and 15.31 % respectively. Meanwhile, the improvement of the payback period for each scenario is 6.68 %, 2.49 % and 9.46 %. It is worth to note that the impact of the combination of both supply and demand contract is higher than the "AP5 - Introduce new tax incentives".

"AP7 - CM" and "AP4 - SF" are ranked 6th and 7th in the action plan to improve the NPV for the biomass polygeneration project by the DEFANP model. The results can be interpreted as these two action plans has a lack of causal and influential power on other elements in the model to meet the goal of this work. The increment of NPV for AP7 - CM (i.e., 9.69 %) is higher than the "AP2-HS" (i.e., 1.95 %). However, the payback period of AP7 - CM is 24.75 % longer than the base case, which means it required an additional 2 years for the project to reach the breakeven point. This is because carbon capture and sequestration (CCS) is still an emerging technology which is extremely costly at the moment. The performance of CCS technology also remains largely unproven on a large scale [270]. Thus, the uptake of CCS at this stage is categorized as a high-risk decision and is less favourable compared to other action plans which could achieve a similar improvement in NPV, without incurring a higher upfront cost. This is reflected as negative correlation in the sensitivity analysis for NPV and positive influence on PBP. "AP4 - SF" has very minimal impact on both the NPV as well as the payback period. It is the most passive action plan evaluated by DEFANP and easily influenced by the changes of other action plans. The initial rationale for selecting this action plan is to increase the demand of bio-oil with the substitution. However, it is observed that it is still highly depending on the substitution cost resulting from the implementation of another action plan. Solaymani and Kari [262] also pointed out that the transportation sector is one of the most sensitive sectors that affected by energy subsidy reform such as introduction and of FiT, financing incentives, and tax incentives.

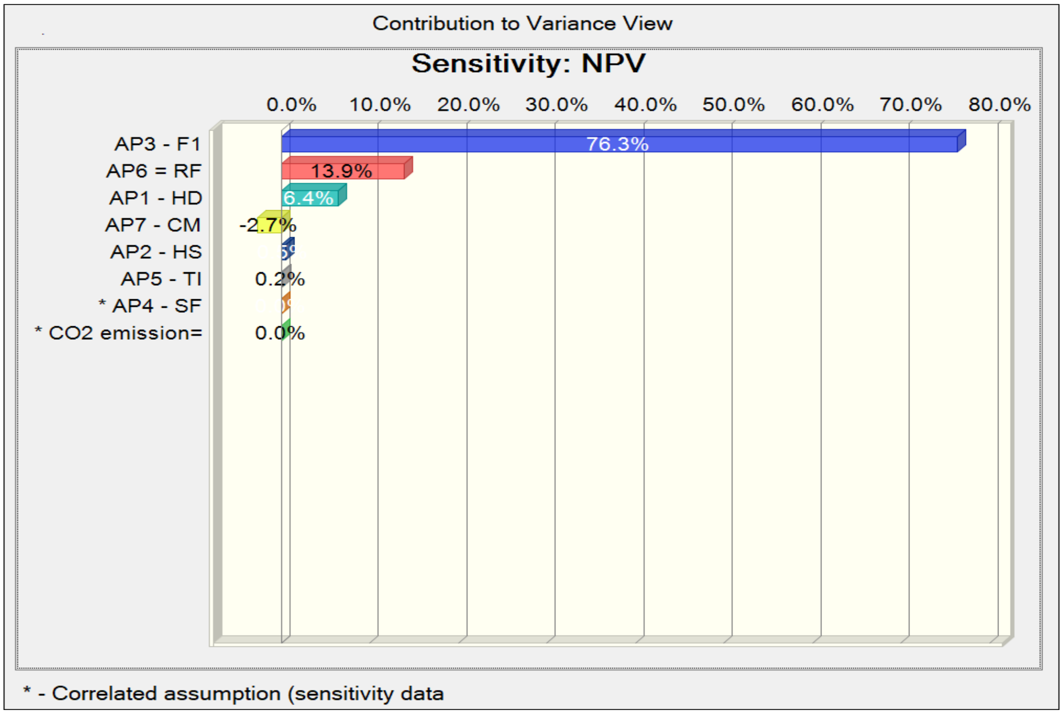


Figure 8-10 Contribution of the implementation of risk mitigation action plans to NPV.

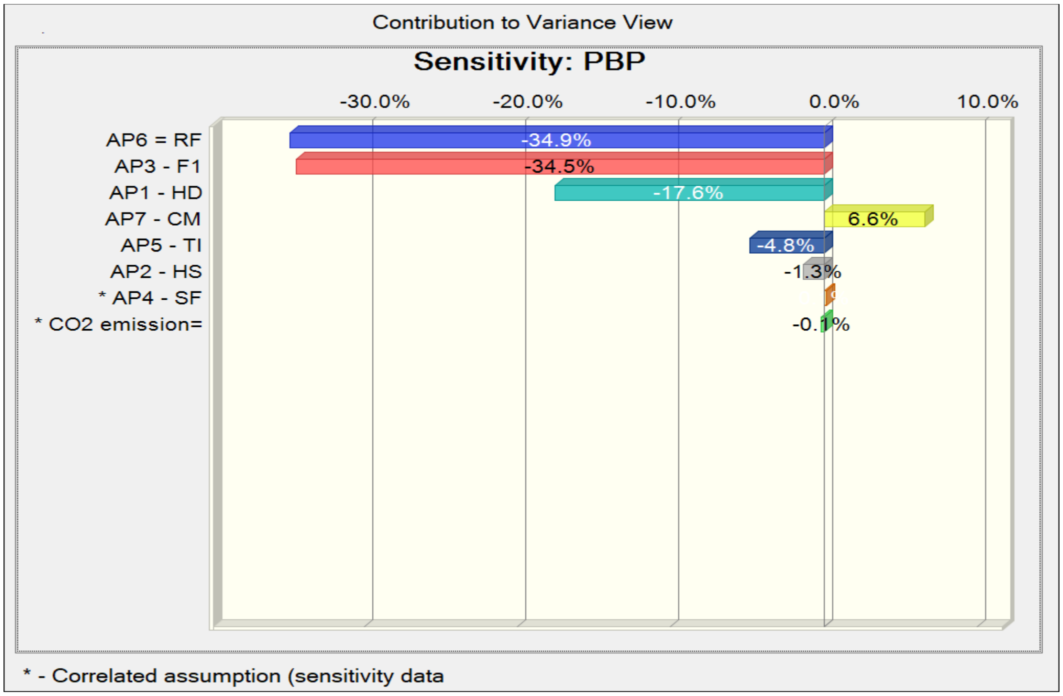


Figure 8-11 Contribution of the implementation of risk mitigation action plans to PBP.

8.4 Conclusions and Future works

The results of the combined DEFANP decision-making framework has been validated by using rigorous Monte Carlo simulations. The DEFANP method has ranked financial incentives action plan (AP3 - FI) as rank 1, indicating that the action plan would be most impactful in terms of outer and interdependence. Monte Carlo simulation has also validated that by providing financial incentives (AP3 - FI) to biomass polygeneration companies, it would give the highest expected 20-years net present value (mean NPV is MYR 17.3 million) and relatively short payback period (mean payback period is 4.38 years). The rank 2 action plan that was determined by the DEFANP method is "revise feed-in-tariff rate" action plan (AP6 - RF). The action plan gives a 20-years mean NPV of MYR 13.2 million and has the fastest mean payback period of 4.29 years amongst all action plans. The DEFANP method has also shown that the supply chain (rank weight is 14.66 %) would be slightly more important than the technologies (rank weight is 12.17 %) in a biomass polygeneration project. This suggests that the difficulties within the biomass supply chain in Malaysia is more complex than the processing system itself. For stakeholders, the impact of government and industry players are equally important with the rank weight of 13.33 % and 13.15 % respectively. This indicates that a successful biomass polygeneration project would require both government and industry player to provide an equal contribution. Meanwhile, the priority weights on the influences of respective stakeholders on each action plan enable industry stakeholders to select mitigation strategies that best suits their role and resource. The outcomes provide references for the government agency to design policy in providing financial support in the form of financial incentives, tax incentives, as well as procurement plan to encourage the demand of products from biomass polygeneration system. Besides, the information also enables industry players to be more vigilant on the viability and cost of different risk mitigation mechanism to enhance the overall decision making in risk management.

In this work, the simulation of the biomass polygeneration system is based on a first-order input-output model. This approach would give satisfactory operational estimations with the detailed resolution of the processing system has been omitted. Our future work would consider the rigorous simulation of the processing system to study the micro-behaviours of the biomass systems. In this method, a detailed analysis of factors (such as product composition and quality, conversion variations etc.) can be carried out to improve the research findings. Moreover, the developed framework is a generic decision-making framework that can be applied into other case studies (e.g., energy source planning, petrochemical allocation, biogas supply chain etc.), which will be demonstrated in future work.

Chapter 9. Conclusions and Future Plans

9.1 Conclusions

Despite the sustainability of oil palm industry remains controversial, with both European countries and major palm oil producers (i.e., Indonesia, Malaysia) each claiming the pros and cons of the industry, complete substitution of palm oil is infeasible and irrational. With the international organization working together with domestic authorities to ensure the sustainability of the industry for green growth, the utilisation of the oil palm biomass for waste-to-wealth concepts should be forged ahead. Failure to attain financing and sufficient capital to venture into the industry or sustain its operation is one of the main factors that hindering the overall development of the industry. Even though the innovation of the synthesis and design of processes and technologies in converting biomass into value added products (i.e., bio-chemical, energy) are well-developed and have reached stage for industrial implementation, the risks and uncertainties associated with the industry value chain often hindering the investment and financing for the related projects. The thesis presents a comprehensive framework to utilise MCDA tools in assessing risks for financing green growth, demonstrated by the oil palm biomass industry in Malaysia. The risk assessment framework comprised of four main stages: i. Risk identification with industry life-cycle analysis; ii. Risk evaluation and estimation with ANP; iii. Quantification of stakeholders' preferences towards sustainability with FANP; iv. Evaluation and selection of risk mitigation strategies with DEFANP. The suggested framework integrates the non-quantitative factors such as experience, expertise to assess the risks associated within the industry and proposed risk mitigation and management strategies that achieve maximum economic performances with minimum costs (i.e., CAPEX, operation cost). The case study performed also illustrated significant improvement in reduction of risks, as reflected through higher overall project NPV and lower PBP with lower variance as compare to base case.

This work offers a systematic and transparent approach for different industry stakeholders to identify, assess, evaluate risks that are associated with the whole biomass project risks. The risk events include but not limited to attaining investment or financing to start-up the project, procurement of feedstocks, selection of technology and process, logistics, and the deliverance of end product to customers. It allows industry stakeholders to integrate their role and resources to maximise the strengths in customising the risk mitigation and management mechanisms to secure economic performance of the project, without neglecting social and environmental welfare. The comprehensive framework also served as a reference for the policy makers to design, underwrite and modify new and currently available regulations and policies to spur the growth of the biomass oil palm industry for green growth. Furthermore, it also provides a new insight for the financial institution and investors on the needs to include non-quantitative benefits particularly on environmental and social aspects on financing and investment decision assessment. Last but not least, industry players (i.e., biomass suppliers, plant owners, logistics coordinators, technology providers etc.) can utilise the information to enhance decision making process to achieve their own goal and preferences.

9.2 Limitation and recommendations

A limitation of the proposed risk assessment framework is that the integration of qualitative factors into risk measurement requires expert input. Therefore, it would give less satisfactory results when implemented or replicated without having a group of relevant topic experts. For example, if the selected experts to represent the industry only concentrated on R&D stages but no other industry players from different stages of the industry life cycle are included, the outcomes will be highly skewed toward R&D stages. Thus, it is important to ensure that selection of the experts should be conducted in a fair manner to include experts that can well-represent the subject matter.

Another limitation that associated with the framework is that the number of questions required response from the expert in data collection. For the multiple MCDAs employed in this framework, data is collected based on pairwise comparison method -- to compare two elements in pair to determine the relative dominance relationship. Pairwise comparison is indeed one of the powerful methods to convert non-measurable parameter such as reputation, perspective, preference etc. into quantitative value through the concept of relativity. However, the process required high concentration and patience from the expert to evaluate the dominance of relationship of all the elements in pair by pair. The large amount of pairwise comparison questions may affect the accuracy of the responses from the expert. Hence, a proper sectioning should be included in the questionnaires to allow experts to have a break time in the process of responding. With a proper setup, such as the usage of linguistic terms, laymen language in the questionnaires and clear instruction and sectioning, it can avoid mislead the experts in giving wrong judgement and affect the reliability of the result. Consistency analysis is a must prior to data analysis and interpretation to ensure that the inputs from the experts are consistent across all the responses without self-contracting.

Furthermore, the proposed framework that is highly flexible and customisable based on case-by-case basis can become a limitation as well when the selection of the criteria and elements of the model is not done in a systematic and organized manner. The model is capable to analyse structural and causal dependency between different cluster and elements included in the model. Nonetheless, to apply the framework in generic problem which associate with vast amount of information, a step-by-step data filtering and cleaning is necessary to avoid the inclusion of the non-necessary element or criteria in the model. The inclusion of non-necessary element in the model can complicate the data collection and analysis stages, resulting in wastage of effort and resources throughout the process. Thus, it is necessary to ensure the development of the network model is done in an organized way to include both structural dependency and causal dependency of the selected criteria and elements to enhance the clarity of the decision-making process to achieve the goal. Sensitivity analysis or simulation is recommended to be conducted to verify the outcomes to increase its reliability.

9.3 Future works

As illustrated in the limitation, the framework often constructed to achieve a specific goal based on the interest of the study. Nonetheless, different countries also exert different historical and cultural background that affect the perspectives of risks. Thus, future work can be focused on expanding the model to produce a generic risk index for the overall biomass industry, inclusive of different biomass type (i.e., wood-based biomass, municipal solid waste, risk husk etc.) as well as the level of development across nation (i.e., developed country, developing country). The biomass type can be reflected through the characteristics of biomass such as density, moisture contents, calorific value etc. while the level of development can be represented through economic growth indicators (i.e., GDP, CPI). The inclusion of the resources and strengths based on the level of development of the country can provides policy recommendations for domestic authority to design appropriate development blueprint to manage risk while spur green growth. Furthermore, it also serves as an initial guideline for the interest industry players that interested to venture into the industry in managing risk, and ultimately, reducing the possibility of occurrences and consequences of the risk events.

With the innovation of artificial intelligence and data technology that widely accepted across the world nowadays, the risk assessment framework model can also be enhanced by incorporating artificial intelligence into the framework. Artificial neural network approach is capable to constantly learn and analyse the trend of data to identify potential future risk events. ANN can be incorporated to analyse available data particularly macroeconomic indicators such as fluctuation of stock market, GDP, foreign exchange rate to predict future cost and prices of the supply and demand across the biomass value chain creation. The output of the ANN can significantly increase the accuracy of the cost information while filter out unnecessary parameter to populate into the DEFANP for selection and evaluation of risk mitigation evaluation. The integration of ANN into the framework can increase the accuracy of the output of the risk framework and reduce the redundancy information that hindering the decision-making process.

References

[1] Department of Statistics Malaysia (DOSM). Malaysia Economic Performance Fourth Quarter 2018 2018. dosm.gov.my (accessed September 13, 2019).

[2] AIM. National Biomass Strategy 2020: New wealth creation for Malaysia's palm oil industry. Agensi Inovasi, Malaysia, Kuala Lumpur 2013:1–32.

[3] Mekhilef S, Saidur R, Safari A, Mustaffa WESB. Biomass energy in Malaysia: Current state and prospects. Renew Sustain Energy Rev 2011;15:3360–70.

[4] Ng WPQ, Lam HL, Ng FY, Kamal M, Lim JHE. Waste-to-wealth: Green potential from palm biomass in Malaysia. J Clean Prod 2012;34:57–65.

[5] Mekhilef S, Barimani M, Safari A, Salam Z. Malaysia's renewable energy policies and programs with green aspects. Renew Sustain Energy Rev 2014;40:497–504.

[6] Greentech Malaysia (Malaysian Green Technology Corporation). Green Technology Financing Scheme (GTFS) 2018. https://www.gtfs.my/ (accessed December 24, 2018).

[7] Masini A, Menichetti E. The impact of behavioural factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. Energy Policy 2012;40:28–38.

[8] Tongsopit S, Moungchareon S, Aksornkij A, Potisat T. Business models and financing options for a rapid scale-up of rooftop solar power systems in Thailand. Energy Policy 2016;95:447–57.

[9] MPOC (Malaysian Palm Oil Council). Annual Report 2017: Innovation in Extraordinary Times. Kelana Jaya,Malaysia: 2017.

[10] Iskandar MJ, Baharum A, Anuar FH, Othaman R. Palm oil industry in South East Asia and the effluent treatment technology—A review. Environ Technol Innov 2018;9:169–85.

[11] IndexMundi. Palm Oil Production by Country in 1000MT 2018. https://www.indexmundi.com/agriculture/?commodity=palm-oil (accessed December 17, 2018).

[12] Rosner H. Palm oil is unavoidable. Can it be sustainable? Natl Geogr Mag 2018. https://www.nationalgeographic.com/magazine/2018/12/palm-oil-products-borneo-africa-environment-impact/ (accessed March 3, 2019).

[13] Tang K. Towards Environmental & Economic Sustainability in Malaysia via Biomass Industry. Malaysia: 2014.

[14] Tang KM. Best Practices & Success Stories of Biomass Industry in Malaysia. J Sustain Energy Environ 2015:7–12.

[15] Yatim P, Mamat MN, Mohamad-Zailani SH, Ramlee S. Energy policy shifts towards sustainable energy future for Malaysia. Clean Technol Environ Policy 2016;18:1685–95.

[16] Ahmad S, Kadir MZAA, Shafie S. Current perspective of the renewable energy development in Malaysia. Renew Sustain Energy Rev 2011;15:897–904.

[17] Malaysian Industry-Government Group for High Technology (MiGHT).

Malaysian biomass industry action plan 2020: Driving SMEs towards sustainable future. Selangor, Malaysia: 2013.
[18] MBIC (Malaysia Biomass Industries Confedetation). MBIC PROFILE 2018.
[19] United Nation, UNFCCC. Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nations Framew Conv Clim Chang 1998;2011:795–811.
[20] United Nations General Assembly. Report of the world commission on environment and development: Our common future. Oslo, Norway: 1987.
[21] United Nations (UN). Sustainable Development Goals n.d. https://sustainabledevelopment.un.org/sdgs (accessed November 10, 2018).
[22] United Nations Environment Programme (UNEP). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. 2011.
[23] Gasparatos A, Doll CNH, Esteban M, Ahmed A, Olang TA. Renewable energy and biodiversity: Implications for transitioning to a Green Economy. Renew Sustain Energy Rev 2017;70:161–84.
[24] Loiseau E, Saikku L, Antikainen R, Droste N, Leskinen P, Kuikman P, et al. Green economy and related concepts : An overview. J Clean Prod 2016;139:361–71.
[25] Bracking S. Performativity in the Green Economy: how far does climate finance create a fictive economy? Third World Q 2015;36:2337–57.
[26] Pitkanen K, Antikainen R, Droste N, Loiseau E, Saikku L, Aissani L, et al. What can be learned from practical cases of green economy ? -studies from five European countries. J Clean Prod 2016;139:666–76.
[27] Steiner A. Global Green New Deal. NEW Solut A J Environ Occup Heal Policy 2009;19:185–93.
[28] United Nations Environment Programme (UNEP). Global Green New Deal: An Update for the G20 Pittsburgh Summit. 2009.
[29] D'Amato D, Droste N, Allen B, Kettunen M, Lähtinen K, Korhonen J, et al. Green, circular, bio economy: A comparative analysis of sustainability avenues. J Clean Prod 2017;168:32042–5.
[30] Yatim P, Ngan SL, Lam HL. Financing green growth in Malaysia: Enabling conditions and challenges. Chem Eng Trans 2017;61:1579–84.
[31] Montefrio MJF, Dressler WH. The Green Economy and Constructions of the "Idle" and "Unproductive" Uplands in the Philippines. World Dev 2016;79:114–26.
[32] Boulding K. The Economy of the Coming Spaceship Earth. Environ. Qual. a Grow. Econ., Baltimore, MD: Johns Hopkins University; 1966.
[33] Daly HE. Beyond Growth: The Economics of Sustainable Development. reprint. Boston: Beacon Press; 1996.
[34] Domenech T, Bleischwitz R, Doranova A, Panayotopoulos D, Roman L. Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy. Resour Conserv Recycl 2019;141:76–98.
[35] McDonough, W.; Braungart M. Remaking the way we make things: Cradle

to cradle. New York: North Point Press; 2002.
[36] Kirchherr J, Reike D, Hekkert M. Conceptualizing the circular economy : An analysis of 114 definitions. Resour , Conserv Recycl 2017;127:221–32.
[37] Korhonen J, Honkasalo A, Seppälä J. Circular Economy: The Concept and its Limitations. Ecol Econ 2018;143:37–46.
[38] Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ. The Circular Economym- A new sustainability paradigm? J Clean Prod 2017;143:757–68.
[39] Costa I, Massard G, Agarwal A. Waste management policies for industrial symbiosis development: case studies in European countries. J Clean Prod 2010;18:815–22.
[40] Winans K, Kendall A, Deng H. The history and current applications of the circular economy concept. Renew Sustain Energy Rev 2017;68:825–33.
[41] Geng Y, Fu J, Sarkis J, Xue B. Towards a national circular economy indicator system in China: An evaluation and critical analysis. J Clean Prod 2012;23:216–24.
[42] Charonis G-K. Degrowth, steady state economics and the circular economy: three distinct yet increasingly converging alternative discourses to economic growth for achieving environmental sustainability and social equity. World Econ. Assoc. Conf., 2012.
[43] Geissdoerfer M, Morioka SN, Carvalho MM de, Evans S. Business models and supply chains for the circular economy. J Clean Prod 2018;190:712–21.
[44] Ellen MacArthur Foundation (EMF). Towards a Circular Economy - Economic and Business Rationale for an Accelerated Transition. 2015.
[45] Diaz LF. Waste management in developing countries and the circular economy. Waste Manag Res 2017;35:1–2.
[46] Ellen MacArthur Foundation (EMF). Towards the circular economy: opportunities for the consumer goods sector. 2013.
[47] Murray A, Skene K, Haynes K. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. J Bus Ethics 2017;140:369–80.
[48] European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Innovating for Sustainable Grow, A Bioeconomy for Europe. Brussels: 2012.
[49] Schmid O, Padel S, Levidow L. The Bio-Economy Concept and Knowledge Base in a Public Goods and Farmer Perspective. Bio-Based Appl Econ 2012;1:47–63.
[50] Scarlat N, Dallemand J-F, Monforti-Ferrario F, Nita V. The role of biomass and bioenergy in a future bioeconomy: Policies and facts. Environ Dev 2015;15:3–34.
[51] Bugge MM, Hansen T, Klitkou A. What is the bioeconomy? A review of the literature. Sustainability 2016;8:1–22.
[52] Hasenheit M, Gerdes H, Kiresiewa Z, Beekman V. Summary report on the social, economic and environmental impacts of the bioeconomy. 2016.

[53] Kleinschmit D, Lindstad BH, Thorsen BJ, Toppinen A, Roos A, Baardsen S. Shades of green: A social scientific view on bioeconomy in the forest sector. Scand J For Res 2014;29:402–10.
[54] Della Croce R, Kaminker C, Stewart F. The role of pension funds in financing green growth intiatives 2011:70.
[55] Ferdous Alam ASA, Er AC, Begum H. Malaysian oil palm industry: Prospect and problem. J Food, Agric Environ 2015;13:143–8.
[56] Pye O. Commodifying sustainability: Development, nature and politics in the palm oil industry. World Dev 2018;In press. doi:10.1016/j.worlddev.2018.02.014.
[57] Goh CS. Can We Get Rid of Palm Oil? Trends Biotechnol 2016;34:948–50.
[58] RSPO (Roundtable on Sustainable Palm Oil). About Us 2018. https://rspo.org/about (accessed December 11, 2018).
[59] RSPO (Roundtable on Sustainable Palm Oil). Principles and Criteria: For the Production of Sustainable Palm Oil 2018 2018:1–91. http://www.rspo.org/file/RSPO Statutes.pdf (accessed August 9, 2018).
[60] MPOB (Malaysian Palm Oil Board). Malaysian Sustainable Palm Oil (MSPO) Scheme 2013. mspo.mpob.gov.my/wp-content/uploads/2016/02/Requirements-for-Palm-Based-Products-to-Fulfil-EU-RED.pdf (accessed November 18, 2018).
[61] Care Certificate International. MSPO for Sustainable Palm Oil. 2018 n.d. http://www.cciglobe.com/mspo.htm (accessed December 10, 2018).
[62] Hutabarat S. ISPO Certification and Indonesian Oil Palm Competitiveness in Global Market Smallholder Challenges Toward ISPO Certification. Agro Ekon 2017;28:170–88.
[63] Rogelio ZA, Soon HY. Malaysia: Biomass-based power generation and cogeneration in the palm oil industry (BioGen) Project-Phase I. Selangor, Malaysia: 2010.
[64] Lee CW, Zhong J. Financing and risk management of renewable energy projects with a hybrid bond. Renew Energy 2015;75:779–87.
[65] Dinica V. Support systems for the diffusion of renewable energy technologies - An investor perspective. Energy Policy 2006;34:461–80.
[66] Tang A, Chiara N, Taylor JE. Financing renewable energy infrastructure: Formulation, pricing and impact of a carbon revenue bond. Energy Policy 2012;45:691–703.
[67] Ortas E, Burritt RL, Moneva JM. Socially responsible investment and cleaner production in the Asia pacific: Does it pay to be good? J Clean Prod 2013;52:272–80.
[68] Sarkar A, Singh J. Financing energy efficiency in developing countries-lessons learned and remaining challenges. Energy Policy 2010;38:5560–71.
[69] Cook D, Hall R. Financing renewable energy projects in difficult economic times. Energy Eng J Assoc Energy Eng 2012;109:41–52.
[70] Yildiz Ö. Financing renewable energy infrastructures via financial citizen participation - The case of Germany. Renew Energy 2014;68:677–85.
[71] NEPCon. Supply Chain Mapping of Malaysian Timber and Wood-based

Industries of Malaysian Timber and Wood-based Industries 2016:1–81.
[72] Pelly R, Krämer-Eis H. Creating a Better Business Environment for Financing Business , Innovation and Green Growth. OECD J Financ Mark Trends 2011;2011:129–41.
[73] Knight L, Pfeiffer A, Scott J. Supply market uncertainty: Exploring consequences and responses within sustainability transitions. J Purch Supply Manag 2015;21:167–77.
[74] Platon V, Frone S, Constantinescu A. Financial and Economic Risks to Public Projects. Procedia Econ Financ 2014;8:204–10.
[75] Johari A, Nyakuma BB, Mohd Nor SH, Mat R, Hashim H, Ahmad A, et al. The challenges and prospects of palm oil based biodiesel in Malaysia. Energy 2015;81:255–61.
[76] Feedstock Logistics Interagency Working Group. Biofuel Feedstock Logistics: Recommendations for Research and Commercialization. California, United States: 2010.
[77] Kurian JK, Nair GR, Hussain A, Raghavan GS V. Feedstocks, logistics and pre-treatment processes for sustainable lignocellulosic biorefineries: A comprehensive review. Renew Sustain Energy Rev 2013;25:205–19.
[78] Criscuolo C, Menon C. Environmental policies and risk finance in the green sector: Cross-country evidence. Energy Policy 2015;83:38–56.
[79] Creedy GD. Quantitative risk assessment: How realistic are those frequency assumptions? J Loss Prev Process Ind 2011;24:203–7.
[80] Balin BJ. Basel I , Basel II , and Emerging Markets: A Nontechnical Analysis. Johns Hopkins Univ Sch Adv Int Stud 2008:1–17.
[81] Zadek S. Establishing China’s Green Financial System - Report of the Green Finance Task Force. Geneva, Switzerland: 2015.
[82] Beck F, Martinot E. Renewable Energy Policies and Barriers. Encycl Energy 2004;34:365–83.
[83] Lee MK, Park H, Noh J, Painuly JP. Promoting energy efficiency financing and ESCOs in developing countries: Experiences from Korean ESCO business. J Clean Prod 2003;11:651–7.
[84] Zheng J, He J. Risk assessment on agricultural products logistics financial based on FAHP. Proc - 2012 Int Conf Manag e-Commerce e-Government, ICMeCG 2012 2012:388–93.
[85] Bai Y, Faure M, Liu J. The role of China’s banking sector in providing green finance. Duke Environ Law & Policy Forum 2013;24:125–41.
[86] Wambeke B, Liu M, Hsiang S. Using Last Planner and a Risk Assessment Matrix to Reduce Variation in Mechanical Related Construction Tasks. J Constr Eng Manag 2012;138:491–8.
[87] Markowski AS, Mannan MS. Fuzzy risk matrix. J Hazard Mater 2008;159:152–7.
[88] McCoy SA, Wakeman SJ, Larkin FD, Jefferson ML, Chung PWH, Rushton AG, et al. HAZID, A Computer Aid for Hazard Identification: 1. The Stophaz Package and the Hazid Code: An Overview, the Issues and the Structure. Process Saf Environ Prot 1999;77:317–27.
[89] Kletz TA. Hazop and Hazan: Identifying and assessing process industry

hazards. 4th Editio. Boca Raton: CRC Press; 1999.
[90] Faber MH, Stewart MG. Risk assessment for civil engineering facilities: critical overview and discussion. Reliab Eng Syst Saf 2003;80:173–84.
[91] Webster LR. Risk mitigation strategies. In: Staats PS, Silverman SM, editors. Control. Subst. Manag. Chronic Pain A Balanc. Approach, Switzerland: Springer International Publishing; 2016, p. 163–80.
[92] Mustafa MA, Al-Bahar JF. Project risk assessment using the analytic hierarchy process. IEEE Trans Eng Manag 1991;38:46–52.
[93] Gandhi S, Mangla SK, Kumar P, Kumar D. Evaluating factors in implementation of successful green supply chain management using DEMATEL: A case study. Int Strateg Manag Rev 2015;3:96–109.
[94] Dedasht G, Zin RM, Ferwati MS, Abdullahi MMMM, Keyvanfar A, McCaffer R, et al. DEMATEL-ANP Risk Assessment in Oil and Gas Construction Projects. Sustainability 2017;9:1–24.
[95] Rauch P. Developing and evaluating strategies to overcome biomass supply risks. Renew Energy 2017;103:561–9.
[96] Rostamzadeh R, Ghorabaee MK, Govindan K, Esmaeili A, Nobar HBK. Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS- CRITIC approach. J Clean Prod 2018;175:651–69.
[97] Saaty TL. Decision Making with Dependence and Feedback: The Analytic Network Process. RWS Publ. 1996, ISBN 0-9620317-9-8, 1996, p. 370.
[98] Sipahi S, Timor M. The analytic hierarchy process and analytic network process : an overview of applications. Manag Decis 2010;48:775–808.
[99] Saaty TL. Decision making — the Analytic Hierarchy and Network Processes (AHP/ANP). J Syst Sci Syst Eng 2004;13:1–35.
[100] Saaty TL, Vargas LG. Decision Making with the Analytic Network Process: Economic, Political, Social and Technological Applications with Benefits, Opportunities , Cost and Risks. 2006.
[101] Saaty TL. Rank from comparisons and from ratings in the analytic hierarchy/network processes. Eur. J. Oper. Res., vol. 168, 2006, p. 557–70.
[102] Promentilla MAB, Furuichi T, Ishii K, Tanikawa N. A fuzzy analytic network process for multi-criteria evaluation of contaminated site remedial countermeasures. J Environ Manage 2008;88:479–95.
[103] Zadeh LA. Fuzzy Sets. Inf Control 1965.
[104] Tan RR, Aviso KB, Huelgas AP, Promentilla MAB. Fuzzy AHP approach to selection problems in process engineering involving quantitative and qualitative aspects. Process Saf Environ Prot 2014;92:467–75.
[105] Gabus A, Fontela E. World problems, an invitation to further thought within the framework of DEMATEL. Geneva, Switzerland: 1972.
[106] Si S-L, You X-Y, Liu H-C, Zhang P. DEMATEL Technique: A Systematic Review of the State-of-the-Art Literature on Methodologies and Applications. Math Probl Eng 2018:1–33.
[107] SEDA (Sustainable Energy Development Authority Malaysia). FiT Rates for Biomass (Solid Waste) 2018. https://www.seda.gov.my (accessed October 15, 2018).

[108] Abernathy WJ, Utterback JM. Patterns of industrial revolution. Technol Rev 1978;80:40–7.
[109] Gort M, Klepper S. Time Paths in the Diffusion of Product Innovations. Econ J 1982;92:630–53.
[110] Porter ME. Competitive Advantage: Creating and sustaining superior performance. New York: Free Press; 1980.
[111] Adner R, Levinthal D. Demand Heterogeneity and Technology Evolution: Implications for Product and Process Innovation. Manage Sci 2001;47:611–28.
[112] Adner R, Zemsky P. A demand-based perspective on sustainable competitive advantage. Strateg Manag J 2006;27:215–39.
[113] Malerba F. Innovation and the evolution of industries. Innov. Ind. Dyn. Struct. Transform. Schumpeterian Legacies, 2007, p. 7–27.
[114] Wing LC, Jin Z. Risk management methods applied to renewable and sustainable energy : A review. J Electr Electron Eng 2015;3:1–12.
[115] Chopra S, Sodhi MS. Managing risk to avoid supply-chain breakdown. MIT Sloan Manag Rev 2004;46:53–61.
[116] SEDA (Sustainable Energy Development Authority). FiT Dashboard 2017. www.seda.gov.my (accessed January 10, 2017).
[117] Piper DLA. Renewable Energy in the Asia Pacific: : A legal overview 2015:112. www.dlapiper.com (accessed November 10, 2018).
[118] Yusoff NY bte M, Bekhet HA. The Effect of Energy Subsidy Removal on Energy Demand and Potential Energy Savings in Malaysia. Procedia Econ Financ 2016;35:189–97.
[119] Ming Z, Ximei L, Yulong L, Lilin P. Review of renewable energy investment and financing in China: Status, mode, issues and countermeasures. Renew Sustain Energy Rev 2014;31:23–37.
[120] Chin MJ, Poh PE, Tey BT, Chan ES, Chin KL. Biogas from palm oil mill effluent (POME): Opportunities and challenges from Malaysia's perspective. Renew Sustain Energy Rev 2013;26:717–26.
[121] Holburn GLF. Assessing and managing regulatory risk in renewable energy: Contrasts between Canada and the United States. Energy Policy 2012;45:654–65.
[122] Olmos L, Ruester S, Liong SJ. On the selection of financing instruments to push the development of new technologies: Application to clean energy technologies. Energy Policy 2012;43:252–66.
[123] Grubb M. Technology Innovation and Climate Change Policy: an overview of issues and options. Keio Econ Stud 2004;41:103–32.
[124] Arnold U, Yildiz Ö. Economic risk analysis of decentralized renewable energy infrastructures - A Monte Carlo Simulation approach. Renew Energy 2015;77:227–39.
[125] Buerer MJ, Wuestenhagen R. Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors. Energy Policy 2009;37:4997–5006.
[126] Damerow BF, Kidney S, Clenaghan S. How Covered Bond markets can be adapted for Renewable Energy Finance and how this could Catalyse

Innovation in Low- Carbon Capital Markets Unlocking bank lending in an era of capital constraint and limited public budgets 2012:1–13.
[127] Hofmann M, Khatun K. Facilitating the financing of bioenergy projects in sub-Saharan Africa. Energy Policy 2013;52:373–84.
[128] Brealey RA, Cooper IA, Habib MA. Using Project Finance to Fund Infrastructure Investments. J Appl Corp Financ 1996;9:25–39.
[129] Alkemade F, Suurs RAA. Patterns of expectations for emerging sustainable technologies. Technol Forecast Soc Change 2012;79:448–56.
[130] Kemp R, Volpi M. The diffusion of clean technologies: a review with suggestions for future diffusion analysis. J Clean Prod 2008;16:14–21.
[131] Hansen UE, Ockwell D. Learning and technological capability building in emerging economies: The case of the biomass power equipment industry in Malaysia. Technovation 2014;34:617–30.
[132] Peck H. Reconciling supply chain vulnerability, risk and supply chain management. Int J Logist Res Appl 2006;9:127–42.
[133] MPOB. Malaysia: Oil Palm Planted Area by Category, 2018. Malaysian Palm Oil Board 2018. http://bepi.mpob.gov.my/images/area/2018/Area_summary.pdf (accessed April 9, 2019).
[134] Kenney KL, Smith WA, Gresham GL, Westover TL. Understanding biomass feedstock variability. Biofuels 2013;4:111–27.
[135] Awudu I, Zhang J. Uncertainties and sustainability concepts in biofuel supply chain management: A review. Renew Sustain Energy Rev 2012;16:1359–68.
[136] Altman IJ, Sanders DR, Boessen CR. Applying transaction cost economics: A note on biomass supply chains. J Agribus 2007;25:107–14.
[137] McCormick K, Kåberger T. Key barriers for bioenergy in Europe: Economic conditions, know-how and institutional capacity, and supply chain co-ordination. Biomass and Bioenergy 2007;31:443–52.
[138] Lamers P, Roni MS, Tumuluru JS, Jacobson JJ, Cafferty KG, Hansen JK, et al. Techno-economic analysis of decentralized biomass processing depots. Bioresour Technol 2015;194:205–13.
[139] Mulyati H, Geldermann J. Managing risks in the Indonesian seaweed supply chain. Clean Technol Environ Policy 2017;19:175–89.
[140] Hall DO, Scrase JI. Will biomass be the environmentally friendly fuel of the future? Biomass and Bioenergy, vol. 15, 1998, p. 357–67.
[141] Naylor RL, Liska AJ, Burke MB, Falcon WP, Gaskell JC, Rozelle SD, et al. The Ripple Effect: Biofuels, Food Security, and The Environment. Environment 2007;49:30–43.
[142] Wicke B, Sikkema R, Dornburg V, Faaij A. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy 2011;28:193–206.
[143] Mukherjee I, Sovacool BK. Palm oil-based biofuels and sustainability in southeast Asia: A review of Indonesia, Malaysia, and Thailand. Renew Sustain Energy Rev 2014;37:1–12.
[144] Wilcove DS, Koh LP. Addressing the threats to biodiversity from oil-palm

agriculture. Biodivers Conserv 2010;19:999–1007.
[145] Nesadurai HES. Food security, the palm oil–land conflict nexus, and sustainability: a governance role for a private multi-stakeholder regime like the RSPO? Pacific Rev 2013;26:505–29.
[146] Maidin AJ. Challenges in implementing and enforcing environmental protection measures in Malaysia. Malaysian Bar 2005.
[147] Llera E, Scarpellini S, Aranda A, Zabalza I. Forecasting job creation from renewable energy deployment through a value-chain approach. Renew Sustain Energy Rev 2013;21:262–71.
[148] Ferroukhi R, Lucas H, Renner M, Lehr U, Breitschopf B, Lallement D, et al. Renewable Energy and Jobs. 2013.
[149] Zyadin A, Halder P, Kähkönen T, Puhakka A. Challenges to renewable energy: A bulletin of perceptions from international academic arena. Renew Energy 2014;69:82–8.
[150] Rösch C, Kaltschmitt M. Energy from biomass - Do non-technical barriers prevent an increased use? Biomass and Bioenergy 1999;16:347–56.
[151] Ramayah T, Lee JWC, Mohamad O. Green product purchase intention: Some insights from a developing country. Resour Conserv Recycl 2010;54:1419–27.
[152] Zainul Abidin N. Investigating the awareness and application of sustainable construction concept by Malaysian developers. Habitat Int 2010;34:421–6.
[153] Wüstenhagen R, Menichetti E. Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. Energy Policy 2012;40:1–10.
[154] Montalvo C. General wisdom concerning the factors affecting the adoption of cleaner technologies: a survey 1990–2007. J Clean Prod 2008;16:S7–13.
[155] Scott JA, Ho W, Dey PK. Strategic sourcing in the UK bioenergy industry. Int J Prod Econ 2013;146:478–90.
[156] Promentilla MAB, Furuichi T, Ishii K, Tanikawa N. A Prioritization Method using Multi-criteria evaluation of Remedial Countermeasures 2006;62:308–24.
[157] Saaty TL. The Analytic Hierarchy Process. McGraw-Hill Inc 1980:17–34.
[158] Andiappan V, Ng DKS, Bandyopadhyay S. Synthesis of Biomass-based Trigeneration Systems with Uncertainties. Ind Eng Chem Res 2014;53:18016–28.
[159] Bufoni AL, Oliveira LB, Rosa LP. The declared barriers of the large developing countries waste management projects: The STAR model. Waste Manag 2016;52:326–38.
[160] Foo DCY, Tan RR, Lam HL, Abdul Aziz MK, Klemeš JJ. Robust models for the synthesis of flexible palm oil-based regional bioenergy supply chain. Energy 2013;55:68–73.
[161] Yatim P, Ngan SL, Lam HL. Sustainable Supply Chain: Feedstock Logistics Issues of Palm Oil Biomass Industry in Malaysia. In: Sayigh A, editor. Transit. Towar. 100% Renew. Energy, Cham, Switzerland: Springer,; 2018, p. 467–79.
[162] Karltorp K. Environmental Innovation and Societal Transitions Challenges

in mobilising financial resources for renewable energy — The cases of biomass gasification and offshore wind power. Environ Innov Soc Transitions 2016;19:96–110.
[163] Zabed H, Sahu JNN, Boyce ANN, Faruq G. Fuel ethanol production from lignocellulosic biomass: An overview on feedstocks and technological approaches. Renew Sustain Energy Rev 2016;66:751–74.
[164] Nambippan B, Ismail A, Hashim N, Ismail N, Shahari DN, Nik Idris NA, et al. Malaysia: 100 years of Resilient Palm Oil Economic Performance. J Oil Palm Res 2018;30:13–35.
[165] Chow E, Ananthalakshmi A, Hogue T. European move to ban palm oil from biofuels is "crop apartheid" - Malaysia. Reuters 2018. reuters.com/article/malaysia-palmoil-eu/european-move-to-ban-palm-oil-from-biofuels-is-crop-apartheid-malaysia-idUSL3N1PD1NJ (accessed August 20, 2018).
[166] Heidrich O, Reckien D, Olazabal M, Foley A, Salvia M, de Gregorio Hurtado S, et al. National climate policies across Europe and their impacts on cities strategies. J Environ Manage 2016;168:36–45.
[167] Covin JG, Slevin DP. New venture strategic posture, structure, and performance: An industry life cycle analysis. J Bus Ventur 1990;5:123–35.
[168] Antikainen M, Valkokari K. A Framework for Sustainable Circular Business Model Innovation. Technol Innov Manag Rev 2016;6:5–12.
[169] Zhu Q, Geng Y, Lai K. Circular economy practices among Chinese manufacturers varying in environmental-oriented supply chain cooperation and the performance implications. J Environ Manage 2010;91:1324–31.
[170] Oliver Wyman. Supporting the Circular Economy Transition: The role of the financial sector in the Netherlands. 2017.
[171] Cyberjaya Malaysia. Guide to Setting Up Business 2018. http://www.cyberjayamalaysia.com.my/business/setting-up-business (accessed December 24, 2018).
[172] Kaminker C, Stewart F. The role of institutional investors in financing clean energy. 2012.
[173] Park G, Kang J. Entry Conditions, Firm Strategies, and its Relationships on Innovation Performance in Emerging Green Industry. Asian J Technol Innov 2010;18:211–42.
[174] Bressanelli G, Perona M, Saccani N. Reshaping the Washing Machine Industry through Circular Economy and Product-Service System Business Models. Procedia CIRP 2017;64:43–8.
[175] Máša V, Bobák P, Vondra M. Potential of gas microturbines for integration in commercial laundries. Oper Res 2016;17:849–66.
[176] Sabol A, Sander M, Fuckan D. The concept of industry life cycle and development of business strategies. Manag. Knowl. Learn. Int. Conf. 2013, Zadar, Croatia: 2013, p. 635–42.
[177] McDougall PP, Covin JG, Robinson Jr RB, Herron L. The Effects of Industry Growth and Strategic Breadth on New Venture Growth and Strategy Content. Strateg Manag J 1994;15:537–54.
[178] Yuan Z, Bi J, Moriguchi Y. The Circular Economy: A New Development

Strategy in China. J Ind Ecol 2008;10:4–8.
[179] Roseland M. Dimensions of the eco-city. Cities 1997;14:197–202.
[180] Chen X, Geng Y, Fujita T. An overview of municipal solid waste management in China. Waste Manag 2010;30:716–24.
[181] Rada E, Ragazzi M, Torretta V, Castagna G, Adami L, Cioca L-I. Circular economy and waste to energy. AIP Conf. Proc., vol. 1968, 2008, p. 1–6.
[182] Stehlik P. Up-to-Date Waste-to-Energy Approach: From Idea to Industrial Application. 1st ed. Springer International Publishing; 2016.
[183] Touš M, Bébar L, Houdková L, Pavlas M, Stehlík P. Waste-to-Energy (W2E) software–a support tool for decision making process. Chem Eng Trans 2009;18:971–6.
[184] Lausselet C, Cherubini F, Oreggioni GD, del Alamo Serrano G, Becidan M, Hu X, et al. Norwegian Waste-to-Energy: Climate change, circular economy and carbon capture and storage. Resour Conserv Recycl 2017;126:50–61.
[185] Uerdingen E. Retrofit design of continuous chemical processes for the improvement of production cost-efficiency. Swiss Federal Institute of Technology Zurich, 2002.
[186] Audretsch DB, Feldman MP. Innovative clusters and the industry life cycle. Rev Ind Organ 1996;11:253–73.
[187] Florida R. Lean And Green: The Move To Environmentally Conscious Manufacturing. Calif Manage Rev 1996;39:80–105.
[188] Leong WD, Lam HL, Tan CP, Ponnambalan SG. Development of Multivariate Framework for Lean and Green Process. Chem Eng Trans 2018;70:2191–6.
[189] Liew PY, Lim JS, Wan Alwi SR, Abdul Manan Z, Varbanov PS, Klemeš JJ. A retrofit framework for Total Site heat recovery systems. Appl Energy 2014;135:778–90.
[190] Ren X-Y, Jia X-X, Varbanov PS, Klemeš JJ, Liu Z-Y. Targeting the cogeneration potential for Total Site utility systems. J Clean Prod 2018;170:625–35.
[191] Lakhal SY, Khan MI, Islam MR. An “Olympic” framework for a green decommissioning of an offshore oil platform. Ocean Coast Manag 2009;52:113–23.
[192] Zhao Y, Zang L, Li Z, Qin J. Discussion on the Model of Mining Circular Economy. Energy Procedia 2012;16:438–43.
[193] Saaty TL, Takizawa M. Dependence and independence: From linear hierarchies to nonlinear networks. Eur J Oper Res 1986;26:229–37.
[194] Vaidya OS, Kumar S. Analytic hierarchy process : An overview of applications. Eur J Oper Res 2006;169:1–29.
[195] Zimmermann HJ. Fuzzy set theory. 2010 John Wiley Sons, Inc 2010;2:317–32.
[196] Promentilla MAB, Antonio MR, Chuaunsu RM, De Serra AJ. A Calibrated Fuzzy AHP Approach to Derive Priorities in a Decision Model for Low Carbon Technologies. DLSU Res. Congr. 2016, 2016, p. 1–6.
[197] Promentilla MAB, Aviso KB, Tan RR. A Fuzzy Analytic Hierarchy

Process (FAHP) Approach for Optimal Selection of Low-carbon Energy Technologies. Chem Eng Trans 2015;45:1141–6.
[198] Abazue CM, Er AC, Ferdous Alam ASA, Begum H. Oil Palm Smallholders and Its Sustainability Practices in Malaysia. Mediterr J Soc Sci 2015;6:482–8.
[199] Jelsma I, Schoneveld GC, Zoomers A, van Westen ACM. Unpacking Indonesia's independent oil palm smallholders: An actor-disaggregated approach to identifying environmental and social performance challenges. Land Use Policy 2017;69:281–97.
[200] Hill CWL, Jones GR. Strategic management: An integrated approach. Boston: Houghton Mifflin; 2008.
[201] Yatim P, Lin NS, Lam HL, Choy EA. Overview of the key risks in the pioneering stage of the Malaysian biomass industry. Clean Technol Environ Policy 2017;19:1825–39.
[202] Karniouchina E V., Carson SJ, Short JC, Ketchen Jr DJ. Extending the Firm VS. Industry Debate: Does Industry Life Cycle Stage Matter? Strateg Manag J 2013;34:1010–8.
[203] Malerba F, Nelson RR, Orsenigo L, Winter SG. Innovation and the Evolution of Industries: History-Friendly Models. Cambridge: Combridge University Press; 2016.
[204] Kalmykova Y, Sadagopan M, Rosado L. Circular economy - From review of theories and practices to development of implementation tools. Resour Conserv Recycl 2018;135:190–201.
[205] Adnan H. Buyers cite price of sustainable palm oil among deterrents when sourcing for CSPO. Star Online 2017. https://www.thestar.com.my/business/business-news/2017/09/22/buyers-cite-price-of-sustainable-palm-oil-among-deterrents-when-sourcing-for-cspo/ (accessed December 12, 2018).
[206] Pischke EC, Rouleau MD, Halvorsen KE. Biomass and Bioenergy Public perceptions towards oil palm cultivation in Tabasco , Mexico. Biomass and Bioenergy 2018;112:1–10.
[207] Salm S, Hille SL, Wüstenhagen R. What are retail investors' risk-return preferences towards renewable energy projects? A choice experiment in Germany. Energy Policy 2016;97:310–20.
[208] Winzer F, Kraska T, Elsenberger C, Kötter T, Pude R. Biomass from fruit trees for combined energy and food production. Biomass and Bioenergy 2017;107:279–86.
[209] Nguyen TLT, Gheewala SH, Sagisaka M. Greenhouse gas savings potential of sugar cane bio-energy systems. J Clean Prod 2010;18:412–8.
[210] Parraga J, Khalilpour KR, Vassallo A. Polygeneration with biomass-integrated gasification combined cycle process: Review and prospective. Renew Sustain Energy Rev 2018;92:219–34.
[211] Gan DKW, Loy ACM, Chin BLF, Yusup S, Unrean P, Rianawati E, et al. Kinetics and thermodynamic analysis in one-pot pyrolysis of rice hull using renewable calcium oxide based catalysts. Bioresour Technol 2018;265:180–90.

[212] Enerdata. World Energy Consumption Statistics 2010. https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html (accessed December 14, 2018).
[213] Huang C-Y, Shyu JZ, Tzeng G-H. Reconfiguring the innovation policy portfolios for Taiwan's SIP Mall industry. Technovation 2007;27:744–65.
[214] Dağdeviren M, Yüksel İ, Kurt M. A fuzzy analytic network process (ANP) model to identify faulty behavior risk (FBR) in work system. Saf Sci 2008;46:771–83.
[215] Naghadehi MZ, Mikaeil R, Ataei M. The application of fuzzy analytic hierarchy process (FAHP) approach to selection of optimum underground mining method for Jajarm Bauxite Mine, Iran. Expert Syst Appl 2009;36:8218–26.
[216] Promentilla MAB, Janairo JIB, Yu DEC, Pausta CMJ, Beltran AB, Huelgas-Orbecido AP, et al. A stochastic fuzzy multi-criteria decision-making model for optimal selection of clean technologies. J Clean Prod 2018;183:1289–99.
[217] Büyüközkan G, Güleryüz S. An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey. Int J Prod Econ 2016;182:435–48.
[218] Fazli S, Mavi RK, Vosooghidizaji M. Crude oil supply chain risk management with DEMATEL–ANP. Oper Res 2015;15:453–80.
[219] Rezaeisaray M, Ebrahimnejad S, Khalili-Damghani K. A novel hybrid MCDM approach for outsourcing supplier selection: A case study in pipe and fittings manufacturing. J Model Manag 2016;11:536–59.
[220] Hu JW-S, Hu Y-C, Yang T-P. DEMATEL and Analytic Network Process for Evaluating Stock Trade Strategies Using Livermore's Key Price Logic. Univers J Account Financ 2017;5:18–35.
[221] Ngan SL, How BS, Promentilla MAB, Yatim P, Lam HL. Integrating stakeholder's role in mitigating risks for future cleaner production. Chem Eng Trans 2018;70:1327–32.
[222] Talluri S (Sri), Kull TJ, Yildiz H, Yoon J. Assessing the Efficiency of Risk Mitigation Strategies in Supply Chains. J Bus Logist 2013;34:253–69.
[223] Mangla S, Kumar P, Barua M. A Flexible Decision Framework for Building Risk Mitigation Strategies in Green Supply Chain Using SAP–LAP and IRP Approaches. Glob J Flex Syst Manag 2014;15:203–218.
[224] Christopher M, Peck H. Building the Resilient Supply Chain. Int J Logist Manag 2004;15:1–13.
[225] Allen J, Browne M, Hunter A, Boyd J, Palmer H. Logistics management and costs of biomass fuel supply. Int J Phys Distrib Logist Manag 1998;28:463–77.
[226] Kim J, Realff MJ, Lee JH. Optimal design and global sensitivity analysis of biomass supply chain networks for biofuels under uncertainty. Comput Chem Eng 2011;35:1738–51.
[227] Gebreslassie BH, Yao Y, You F. Design under uncertainty of hydrocarbon biorefinery supply chains: Multiobjective stochastic programming models, decomposition algorithm, and a Comparison between CVaR and downside

risk. AIChE J 2012;58:2155–79.
[228] Sy CL, Aviso KB, Ubando AT, Tan RR. Target-oriented robust optimization of polygeneration systems under uncertainty. Energy 2016;116:1334–47.
[229] Benjamin MFD, Tan RR, Razon LF. A methodology for criticality analysis in integrated energy systems. Clean Technol Environ Policy 2015;17:935–46.
[230] Wang Z, Xu G, Ren J, Li Z, Zhang B, Ren X. Polygeneration system and sustainability: Multi-attribute decision-support framework for comprehensive assessment under uncertainties. J Clean Prod 2017;167:1122–37.
[231] Sy CL, Ubando AT, Aviso KB, Tan RR. Multi-objective target oriented robust optimization for the design of an integrated biorefinery. J Clean Prod 2018;170:496–509.
[232] LHDN (Lembaga Hasil Dalam Negeri Malaysia). Investment Tax Allowance 2018. https://www.hasil.gov.my/ (accessed November 3, 2018).
[233] GE (General Electric). Jenbacher gas engines n.d. http://kts-eng.com/assets/files/J208.pdf (accessed November 16, 2018).
[234] How BS, Tan KY, Lam HL. Transportation decision tool for optimisation of integrated biomass flow with vehicle capacity constraints. J Clean Prod 2016;136:197–223.
[235] Zhou H, Qian Y, Yang S. Energetic/economic penalty of CO2 emissions and application to coal-to-olefins projects in China. Appl Energy 2015;156:344–53.
[236] Atsonios K, Kougioumtzis M-A, Grammelis P, Kakaras E. Process Integration of a Polygeneration Plant with Biomass/Coal Co-pyrolysis. Energy & Fuels 2017;31:14408–14422.
[237] Chen D, Chen X, Sun J, Zheng Z, Fu K. Pyrolysis polygeneration of pine nut shell: Quality of pyrolysis products and study on the preparation of activated carbon from biochar. Bioresour Technol 2016;216:629–36.
[238] Michailos S, Parker D, Webb C. A techno-economic comparison of Fischer–Tropsch and fast pyrolysis as ways of utilizing sugar cane bagasse in transportation fuels production. Chem Eng Res Des 2017;118:206–14.
[239] Chen Y, Yang H, Wang X, Zhang S, Chen H. Biomass-based pyrolytic polygeneration system on cotton stalk pyrolysis: Influence of temperature. Bioresour Technol 2012;107:411–8.
[240] Wan Alwi SR, Klemeš JJ, Varbanov PS. Cleaner energy planning, management and technologies: Perspectives of supply-demand side and end-of-pipe management. J Clean Prod 2016;136:1–13.
[241] Liu P, N. Pistikopoulos E, Li Z. A Multi-Objective Optimization Approach to Polygeneration Energy Systems Design. AIChE J 2010;56:1218–34.
[242] Hossein Sahraei M, McCalden D, Hughes R, Ricardez-Sandoval LA. A survey on current advanced IGCC power plant technologies, sensors and control systems. Fuel 2014;137:245–59.
[243] Shoko E, McLellan B, Dicks AL, da Costa JCD. Hydrogen from coal: Production and utilisation technologies. Int J Coal Geol 2006;65:213–22.

[244] Toka A, Iakovou E, Vlachos D. Biomass Supply Chain Management for Energy Polygeneration Systems. Ist Int. Conf. Supply Chain., 2010, p. 1–17.
[245] Jana K, De S. Environmental impact of biomass based polygeneration - A case study through life cycle assessment. Bioresour Technol 2016;227:256–65.
[246] MPOB (Malaysian Palm Oil Board). Production of crude palm oil for the month of December 2017. Malaysian Palm Oil Board 2018. http://bepi.mpob.gov.my/index.php/en/statistics/production/177-production-2017/792-production-of-crude-oil-palm-2017.html (accessed October 10, 2018).
[247] Trading Economics. Commodity Crude Oil 2018. https://tradingeconomics.com/commodity/crude-oil (accessed December 14, 2018).
[248] Index Mundi. Coal, Australian thermal coal Monthly Price – Malaysian Ringgit per Metric Ton n.d. www.indexmundi.com (accessed October 15, 2018).
[249] RinggitPlus. Petro Price Malaysia Live Updates (RON95, RON97 & Diesel) 2018. https://ringgitplus.com/en/blog/Petrol-Credit-Cards/Petrol-Price-Malaysia-Live-Updates-RON95-RON97-Diesel.html (accessed October 3, 2018).
[250] IFC (International Finance Corporation). Converting Biomass to Energy. Washington: 2017.
[251] Noor Afiqah B. Conventional and Microwave Pyrolysis of Empty Fruit Bunch and Rice Husk Pellets. The University of Sheffield, Sheffield, U.K., 2017.
[252] Gu H, Bergman R. Life-cycle GHG emissions of electricity from syngas produced by pyrolyzing woody biomass. 58th Int. Conv. Soc. Wood Sci. Technol., 2015, p. 376–89.
[253] PNAS. SI APPENDIX GENERAL INFORMATION AND ASSUMPTION 2018. http://www.pnas.org/content/pnas/suppl/2007/03/08/0609921104.DC1/09921SuppAppendix.pdf (accessed November 16, 2018).
[254] Tan K. Personal communication. 2018.
[255] Othman NF, Boosroh MH, Hassan H, Mohan C, Aziz WALWA. Gasification of Triple Fuel Blends Using Pilot-Scale Fluidised-Bed Gasification Plant. Int. Conf. Sci. Technol. Soc. Sci. 2012, 2014, p. 471–7.
[256] Sukiran MA, Kheang LS, Abu Bakar N, Choo YM. Production and Characterization of Bio-Char from the Pyrolysis of Empty Fruit Bunche. Am J Appl Sci 2011;8:984–8.
[257] Rogers JG, Brammer JG. Estimation of the production cost of fast pyrolysis bio-oil. Biomass and Bioenergy 2012;36:208–17.
[258] Kovařík P. Drying of Biomass with High Water Content. Czech Technical University, 2017.
[259] Wright MM, Daugaard DE, Satrio JA, Brown RC. Techno-economic analysis of biomass fast pyrolysis to transportation fuels. Fuel 2010;89.

[260] ETSAP (Energy Technology Systems Analysis Programme). Combined Heat and Power 2010. http://www.etsap.org (accessed November 4, 2018).
[261] How BS, Lam HL. Sustainability evaluation for biomass supply chain synthesis: Novel principal component analysis (PCA) aided optimisation approach. J Clean Prod 2018;189:941–61.
[262] Solaymani S, Kari F. Impacts of energy subsidy reform on the Malaysian economy and transportation sector. Energy Policy 2014;70:115–25.
[263] Li Y, Shi X, Su B. Economic, social and environmental impacts of fuel subsidies: A revisit of Malaysia. Energy Policy 2017;110:51–61.
[264] MOF (Ministry of Finance Malaysia). Budget 2019 2018. http://www.treasury.gov.my (accessed October 21, 2018).
[265] Eusoff N. Malaysia sets new goal of 20% clean energy generation by 2030. Edge Mark 2017. http://www.theedgemarkets.com (accessed October 21, 2018).
[266] IRENA (International Renewable Energy Agency). Renewable Energy Outlook: Thailand. Abu Dhabi: 2017.
[267] MIDA (Malaysian Investment Development Authority). Tax Incentives for Green Industry 2018. http://www.mida.gov.my/home/tax-incentives-for-green-industry/posts/ (accessed December 13, 2018).
[268] Cansino JM, Pablo-Romero M del P, Román R, Yñiguez R. Tax incentives to promote green electricity: An overview of EU-27 countries. Energy Policy 2010;38:6000–8.
[269] Obayashi Y. Japan fires up biomass energy, but fuel shortage looms. Reuters 2017. https://www.reuters.com (accessed October 11, 2018).
[270] Arnette AN. Renewable energy and carbon capture and sequestration for a reduced carbon energy plan: An optimization model. Renew Sustain Energy Rev 2017;70:254–65.

Appendices

A-1: Acknowledgement

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- Malaysia Debt Ventures Berhad
- Malaysian Palm Oil Board
- RMF Gemilang Sdn Bhd
- Salmaq Greentech Sdn Bhd
- Sime Darby Research Sdn Bhd
- The Associated Chinese Chambers of Commerce and Industry of Malaysia
- Top Biomass Resources
- Treehouz Asia Sdn Bhd
- Trunk Busters Sdn Bhd
- University of Nottingham Malaysia Campus
- Universiti Kebangsaan Malaysia
- Universiti Sains Malaysia
- Universiti Taknologi PETRONAS
- Universiti Teknologi Malaysia

A-2: Sample Pairwise Comparison Questionnaires for ANP

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Survey Participation Consent Form

Assessing Risk for Financing Biomass in Malaysia with Analytic Network Process Approach

Dear participant,

I am a PhD student, under the supervision of Associate Professor DDr. Lam Hon Loong in the Department of Chemical and Environmental Engineering, Faculty of Engineering, University of Nottingham Malaysia Campus. I am conducting a research study to quantify the risk associated with the green financing in Malaysia.

I am requesting your participation, which will involve filling questionnaires that will take approximately 20 minutes in total. Your participation in this study is completely voluntary and you may withdraw at any time. We want to assure you that all responses to this survey will be kept completely anonymous and confidential. The results of the survey will be reported only in the aggregate.

If you have questions or want a copy or summary of the study results, please contact me at *017-2030873* or *kebx6nsl@nottingham.edu.my*.

Thank you in advance for your contributions to this important study. Return of the questionnaire will be considered your consent to participate.

Thank you.

Sincerely,

Ngan Sue Lin
kebx6nsl@nottingham.edu.my

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Instruction-Part A

Please compare the pair of variable in the same row, and indicate the level of importance based on the scale of 1,3,5,7,9 with a tick sign "√". The description of the scale level is as below:

1 – equally ***3 – moderately*** ***5 – strongly*** ***7 – very strongly*** ***9 – extremely***

For example, if A is ***very strongly*** more important than B, please insert the tick sign on the "7" column closer to A, vice versa.

A is more important than B ◄ ► B is more important than A

	9	7	5	3	1	3	5	7	9	
A		√								B

Based on your expertise and experience, please make the pairwise comparison judgement by comparing the two variables in the same row.

Part I: Risk group vs risk group

- To determine the importance of the risk groups in financing biomass project in Malaysia

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
1 Technology										2 Financing
1 Technology										3 Supply chain
1 Technology										4 Regulatory
1 Technology										5 Environmental and Social
2 Financing										3 Supply chain
2 Financing										4 Regulatory
2 Financing										5 Environmental and Social
3 Supply chain										4 Regulatory
3 Supply chain										5 Environmental and Social
4 Regulatory										5 Environmental and Social

Part II: Risk factor vs risk factor

Part II-A Technology risk group

- To rank the importance of **technology** risk factors in financing biomass project in Malaysia

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
T1: Lack of information about the performance of the technologies										T2: Lack of resources and capability to scale up to industrial level
T1: Lack of information about the performance of the technologies										T3: Slow pace of technology development, deployment and application
T1: Lack of information about the performance of the technologies										T4: Poor techno-economic attractiveness
T1: Lack of information about the performance of the technologies										T5: Lack of clarity on the availability and duration of policies, incentives and subsidies for green technology
T1: Lack of information about the performance of the technologies										T6: High research and development cost
T2: Lack of resources and capability to scale up to industrial level										T3: Slow pace of technology development, deployment and application
T2: Lack of resources and capability to scale up to industrial level										T4: Poor techno-economic attractiveness
T2: Lack of resources and capability to scale up to industrial level										T5: Lack of clarity on the availability and duration of policies, incentives and subsidies for green technology
T2: Lack of resources and capability to scale up to industrial level										T6: High research and development cost
T3: Slow pace of technology development, deployment and application										T4: Poor techno-economic attractiveness
T3: Slow pace of technology development, deployment and application										T5: Lack of clarity on the availability and duration of policies, incentives and subsidies for green technology
T3: Slow pace of technology development, deployment and application										T6: High research and development cost
T4: Poor techno-economic attractiveness										T5: Lack of clarity on the availability and duration of policies, incentives and subsidies for green technology
T4: Poor techno-economic attractiveness										T6: High research and development cost
T5: Lack of clarity on the availability and duration of policies, incentives and subsidies for green technology										T6: High research and development cost

Part II-B Financing risk group

- To rank the importance of **financing** risk factors in financing biomass project in Malaysia

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
F1: High upfront capital										F2: Long pay back periods
F1: High upfront capital										F3: Uncertain return of investment
F1: High upfront capital										F4: Lack of timely, appropriate and truthful information regarding to longer-term stability of the biomass project
F1: High upfront capital										F5: Lack of appropriate risk assessment method and lending structure for financing decision
F1: High upfront capital										F6: Macroeconomic condition
F2: Long pay back periods										F3: Uncertain return of investment
F2: Long pay back periods										F4: Lack of timely, appropriate and truthful information regarding to longer-term stability of the biomass project
F2: Long pay back periods										F5: Lack of appropriate risk assessment method and lending structure for financing decision
F2: Long pay back periods										F6: Macroeconomic condition
F3: Uncertain return of investment										F4: Lack of timely, appropriate and truthful information regarding to longer-term stability of the biomass project
F3: Uncertain return of investment										F5: Lack of appropriate risk assessment method and lending structure for financing decision
F3: Uncertain return of investment										F6: Macroeconomic condition
F4: Lack of timely, appropriate and truthful information regarding to longer-term stability of the biomass project										F5: Lack of appropriate risk assessment method and lending structure for financing decision
F4: Lack of timely, appropriate and truthful information regarding to longer-term stability of the biomass project										F6: Macroeconomic condition
F5: Lack of appropriate risk assessment method and lending structure for financing decision										F6: Macroeconomic condition

Part II-C Supply chain risk group

- To rank the importance of **supply chain** risk factors in financing biomass project in Malaysia

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
S1: Underdeveloped supply chain and logistics infrastructure										S2: Reliability of long term supply of the feedstocks
S1: Underdeveloped supply chain and logistics infrastructure										S3: High logistics cost
S1: Underdeveloped supply chain and logistics infrastructure										S4: Complication in feedstock logistics
S1: Underdeveloped supply chain and logistics infrastructure										S5: Lack of clarity for sustainability requirements, regulatory regime for biomass industry
S2: Reliability of long term supply of the feedstocks										S3: High logistics cost
S2: Reliability of long term supply of the feedstocks										S4: Complication in feedstock logistics
S2: Reliability of long term supply of the feedstocks										S5: Lack of clarity for sustainability requirements, regulatory regime for biomass industry
S3: High logistics cost										S4: Complication in feedstock logistics
S3: High logistics cost										S5: Lack of clarity for sustainability requirements, regulatory regime for biomass industry
S4: Complication in feedstock logistics										S5: Lack of clarity for sustainability requirements, regulatory regime for biomass industry

Part II-D Regulatory risk group

➢ To rank the importance of **regulatory** risk factors in financing biomass project in Malaysia

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
R1: Unstable political environment										R2: Lack of clarity in regulations and policies related to the biomass industry
R1: Unstable political environment										R3: Lack of control and standard to governance the supply and pricing of biomass residues
R1: Unstable political environment										R4: Tightening of standard of CO2 emission
R1: Unstable political environment										R5: Poor governance, lack of coordination in biomass related institutions
R2: Lack of clarity in regulations and policies related to the biomass industry										R3: Lack of control and standard to governance the supply and pricing of biomass residues
R2: Lack of clarity in regulations and policies related to the biomass industry										R4: Tightening of standard of CO2 emission
R2: Lack of clarity in regulations and policies related to the biomass industry										R5: Poor governance, lack of coordination in biomass related institutions
R3: Lack of control and standard to governance the supply and pricing of biomass residues										R4: Tightening of standard of CO2 emission
R3: Lack of control and standard to governance the supply and pricing of biomass residues										R5: Poor governance, lack of coordination in biomass related institutions
R4: Tightening of standard of CO2 emission										R5: Poor governance, lack of coordination in biomass related institutions

Part II-E Environmental & social risk group

- To rank the importance of **environmental & social** risk factors in financing biomass project in Malaysia

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
E1: Potential impacts to the environment										E2: Threats for social well-being
E1: Potential impacts to the environment										E3: Lack of development of technical and safety standards
E1: Potential impacts to the environment										E4: Lack of awareness of the potential of biomass industry, incentives and supports available
E1: Potential impacts to the environment										E5: Low public acceptance on value-added bio-based products
E2: Threats for social well-being										E3: Lack of development of technical and safety standards
E2: Threats for social well-being										E4: Lack of awareness of the potential of biomass industry, incentives and supports available
E2: Threats for social well-being										E5: Low public acceptance on value-added bio-based products
E3: Lack of development of technical and safety standards										E4: Lack of awareness of the potential of biomass industry, incentives and supports available
E3: Lack of development of technical and safety standards										E5: Low public acceptance on value-added bio-based products
E4: Lack of awareness of the potential of biomass industry, incentives and supports available										E5: Low public acceptance on value-added bio-based products

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Instruction-Part B

Please indicate the level of **influence** of **named** risk on the pair of variable in the same row, based on the scale of 1,3,5,7,9 with a tick sign "√". The description of the scale level is as below:

1 – equal ***3 – moderate*** ***5 – strong*** ***7 – very strong*** ***9 – extreme strong***

For example, if **technology** risk has **stronger** influence on A as compare to B, please insert the tick sign on the "7" column closer to A, vice versa.

A is more important than B ◄ 9 7 5 3 1 3 5 7 9 ► B is more important than A

A		√								B

Part 1: To determine the influence power of **technology risk** on other risk groups.

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
2 Financing										3 Supply chain
2 Financing										4 Regulatory
2 Financing										5 Environmental and Social
3 Supply chain										4 Regulatory
3 Supply chain										5 Environmental and Social
4 Regulatory										5 Environmental and Social

Part 2: To determine the influence power of **financing risk** on other risk groups.

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
1 Technology										3 Supply chain
1 Technology										4 Regulatory
1 Technology										5 Environmental and Social
3 Supply chain										4 Regulatory
3 Supply chain										5 Environmental and Social
4 Regulatory										5 Environmental and Social

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Part 3: To determine the influence power of **supply chain risk** on other risk groups.

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
1 Technology										2 Financing
1 Technology										4 Regulatory
1 Technology										5 Environmental and Social
2 Financing										4 Regulatory
2 Financing										5 Environmental and Social
4 Regulatory										5 Environmental and Social

Part 4: To determine the influence power of **regulatory risk** on other risk groups.

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
1 Technology										2 Financing
1 Technology										3 Supply chain
1 Technology										5 Environmental and Social
2 Financing										3 Supply chain
2 Financing										5 Environmental and Social
3 Supply chain										5 Environmental and Social

Part 5: To determine the influence power of **environmental & social risk** on other risk groups.

Risk factor	9	7	5	3	1	3	5	7	9	Risk factor
1 Technology										2 Financing
1 Technology										3 Supply chain
1 Technology										4 Regulatory
2 Financing										3 Supply chain
2 Financing										4 Regulatory
3 Supply chain										4 Regulatory

A-3: Sample Pairwise Comparison Questionnaires for FANP

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Survey Participation Consent Form

Prioritization sustainability indicators for promoting sustainable development: the case of developing country

Dear participant,

I invite you to participate in a research study entitled ***Prioritization sustainability indicators for promoting sustainable development: the case of developing country***. I am currently enrolled in the PhD Program at University of Nottingham Malaysia Campus, and am in the process of writing my PhD thesis. The doctoral thesis is co-supervised by Professor DDr. Lam Hon Loong from University of Nottingham Malaysia Campus and Associate Professor Dr. Puan Yatim from Universiti Kebangsaan Malaysia.

Sustainability indicators and composite index are increasingly recognized as a powerful tool for policy making and corporate communication in providing information on sustainability performance in areas such as environment, economic, and social. The purpose of the research is to quantify and prioritize the sustainability indicators for promoting sustainable development in developing country, with the focus on palm oil industry.

Your participation in this research project is completely voluntary. You may decline altogether or leave blank any questions you don't wish to answer. There are no known risks to participation beyond those encountered in everyday life. Your responses will remain confidential and anonymous. No one other than the researchers will know your individual answers to this questionnaire. The results of the survey will be reported only in the aggregate format.

If you agree to participate in this research, please answer the questions on the questionnaire as best you can. It should take approximately 15 minutes in total to complete. Please return the questionnaire as soon as possible by replying the email.

If you have any questions about this research project or want a copy or summary of the study results, feel free to contact me at *017-2030873* or *kebx6nsl@nottingham.edu.my*. Your decision to complete and return this questionnaire will be interpreted as an indication of your consent to participate.

Thank you for your assistance in this important endeavour. I highly appreciate your contributions to this research project.

Thank you.

Sincerely,

Ngan Sue Lin
kebx6nsl@nottingham.edu.my

This questionnaire consists of 3 parts as the following:

Part I – To determine the preference of the stage in industry life cycle to initiate sustainability practices for sustainable development.

Part II – To determine the importance of different sustainability indicators at different stage of industry life-cycle.

Part III – To determine the interdependency of the sustainable indicator in affecting other indicators in the transition toward sustainable development.

Linguistics term associated with triangular fuzzy numbers is adopted in this study and illustrated in the following table:

Linguistic scale	Lower bound (l_{ij})	Modal value (m_{ij})	Upper bound (u_{ij})
Equally	1.0	1.0	1.0
Slightly more	1.2	2.0	3.2
Moderately more	1.5	3.0	5.6
Strongly more	3.0	5.0	7.9
Very strongly more	6.0	8.0	9.5

General instruction

Please compare the pair of variables in the same row and indicate the level of dominance relationship (i.e. importance, likelihood, preference, influence, dependency) based on the scale of *equal, moderate, strong, very strong, and extreme*.

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Part I – To determine the preference of the stage in industry life cycle to initiate sustainability practices for sustainable development.

Based on the general palm oil industry life cycle, which stage of the project/business is **more preferred** to initiate sustainability practices in its operation for sustainable development? (i.e. *equally important, moderately more important, strongly more important, very strongly more important, extremely more important)*

Stage			Level of preference			Stage
Pioneering/Emerging	Equally	Moderately	Strongly	Very strongly	Extremely	Rapid growth
Pioneering/Emerging	Equally	Moderately	Strongly	Very strongly	Extremely	Maturity and stable growth
Pioneering/Emerging	Equally	Moderately	Strongly	Very strongly	Extremely	Deceleration of growth
Rapid growth	Equally	Moderately	Strongly	Very strongly	Extremely	Maturity and stable growth
Rapid growth	Equally	Moderately	Strongly	Very strongly	Extremely	Deceleration of growth
Maturity and stable growth	Equally	Moderately	Strongly	Very strongly	Extremely	Deceleration of growth

Part II – To determine the importance of different sustainability indicators at different stage of industry life-cycle

For firm/business in PIONEERING/EMERGING stage, which sustainability indicators play a **more important** role to encourage the transition toward sustainable development? (i.e. *equally important, moderately more important, strongly more important, very strongly more important, extremely more important)*

Indicator	Level of importance					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

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For firm/business in **RAPID GROWTH** stage, which sustainability indicators play a **more important** role to encourage the transition toward sustainable development? (i.e. ***equally important, moderately more important, strongly more important, very strongly more important, extremely more important)***

Indicator	Level of importance					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

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For firm/business in **MATURITY and STABLE GROWTH** stage, which sustainability indicators play a **more important** role to encourage the transition toward sustainable development? (i.e. *equally important, moderately more important, strongly more important, very strongly more important, extremely more important)*

Indicator	Level of importance					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

For firm/business in **DECELERATION of GROWTH** stage, which sustainability indicators play a **more important** role to encourage the transition toward sustainable development? (i.e. *equally important, moderately more important, strongly more important, very strongly more important, extremely more important)*

Indicator	Level of importance					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

Part III – To determine the interdependency of the sustainable indicator in affecting other indicators in the transition toward CE.

What is the influence power of COST on other sustainability indicators in the transition toward sustainable development? (i.e. *equally, moderately more, strongly more, very strongly, extremely more)*

Indicator	Level of influence					Indicator
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

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What is the influence power of **PROFIT** on other sustainability indicators in the transition toward sustainable development? (i.e. *equally, moderately more, strongly more, very strongly, extremely more)*

Indicator	Level of influence					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

What is the influence power of **CARBON FOOTPRINT** on other sustainability indicators in the transition toward sustainable development? (i.e. ***equally, moderately more, strongly more, very strongly, extremely more)***

Indicator	Level of influence					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

What is the influence power of WATER FOOTPRINT on other sustainability indicators in the transition toward sustainable development? (i.e. *equally, moderately more, strongly more, very strongly, extremely more)*

Indicator	Level of influence					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

What is the influence power of ECOLOGY on other sustainability indicators in the transition toward sustainable development? (i.e. *equally, moderately more, strongly more, very strongly, extremely more)*

Indicator	Level of influence					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

What is the influence power of **HEALTH & SAFETY** on other sustainability indicators in the transition toward sustainable development? (i.e. *equally, moderately more, strongly more, very strongly, extremely more)*

Indicator	Level of influence					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Education & Training	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

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What is the influence power of EDUCATION & TRAINING on other sustainability indicators in the transition toward sustainable development? (i.e. *equally, moderately more, strongly more, very strongly, extremely more)*

Indicator	Level of influence					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Public acceptance

What is the influence power of PUBLIC ACCEPTANCE on other sustainability indicators in the transition toward sustainable development? (i.e. *equally, moderately more, strongly more, very strongly, extremely more)*

Indicator	Level of influence					Indicator
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Profit margin
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Cost	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Carbon footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Profit margin	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Water footprint
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Carbon footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Ecology
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Water footprint	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Health & Safety
Ecology	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training
Health & Safety	Equally	Moderately	Strongly	Very strongly	Extremely	Education & Training

--- END ---

A-4: Sample of FANP coding (4*4 matrix size) – LINGO 16.0

Lingo 16.0 - Lingo Model - 4x4 go

File Edit Solver Window Help

Lingo Model - 4x4 go

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model:
!fuzzy number triangular distribution (Lij, Mij, Uij) of judgement,
!upper right;
!Ratio Scale Estimation;
L12 = 0.89   ; M12 = 1.65 ; U12 = 2.97 ;
L13 = 0.41   ; M13 = 0.69 ; U13 = 1.21 ;
L14 = 2.08   ; M14 = 2.92 ; U14 = 3.97 ;

L23 = 0.34   ; M23 = 0.46 ; U23 = 0.65 ;
L24 = 2.21   ; M24 = 3.68 ; U24 = 5.85 ;

L34 = 2.78   ; M34 = 4.31 ; U34 = 6.22 ;

!lower left;

L21 = 1/U12 ; M21 = 1/M12     ; U21 = 1/L12     ;
L31 = 1/U13 ; M31 = 1/M13     ; U31 = 1/L13     ;
L41 = 1/U14 ; M41 = 1/M14     ; U41 = 1/L14     ;

L32 = 1/U23 ; M32 = 1/M23     ; U32 = 1/L23     ;
L42 = 1/U24 ; M42 = 1/M24     ; U42 = 1/L24    ;

L43 = 1/U34 ; M43 = 1/M34     ; U43 = 1/L34     ;

@free(lambda); !lambda for criteria;

max = lambda; !objective function
      !lambda greater than 0 means consistent judgement, otherwise, inconsistent;

w1 + w2 + w3 + w4 = 1;
w1 >= 0;
w2 >= 0;
w3 >= 0;
w4 >= 0;
```

Lingo 16.0 - Lingo Model - 4x4 go

File Edit Solver Window Help

Lingo Model - 4x4 go

```
!upper right;
! 1-9;
(lambda)*(M12 - L12)*w2 - w1 + L12*w2 <= 0;
(lambda)*(U12 - M12)*w2 + w1 - U12*w2 <= 0;

(lambda)*(M13 - L13)*w3 - w1 + L13*w3 <= 0;
(lambda)*(U13 - M13)*w3 + w1 - U13*w3 <= 0;

(lambda)*(M14 - L14)*w4 - w1 + L14*w4 <= 0;
(lambda)*(U14 - M14)*w4 + w1 - U14*w4 <= 0;


!2-9;
(lambda)*(M23 - L23)*w3 - w2 + L23*w3 <= 0;
(lambda)*(U23 - M23)*w3 + w2 - U23*w3 <= 0;

(lambda)*(M24 - L24)*w4 - w2 + L24*w4 <= 0;
(lambda)*(U24 - M24)*w4 + w2 - U24*w4 <= 0;

!3-9;
(lambda)*(M34 - L34)*w4 - w3 + L34*w4 <= 0;
(lambda)*(U34 - M34)*w4 + w3 - U34*w4 <= 0;


!lower left;
!9-1;
(lambda)*(M21 - L21)*w1 - w2 + L21*w1 <= 0;
(lambda)*(U21 - M21)*w1 + w2 - U21*w1 <= 0;

(lambda)*(M31 - L31)*w1 - w3 + L31*w1 <= 0;
(lambda)*(U31 - M31)*w1 + w3 - U31*w1 <= 0;

(lambda)*(M41 - L41)*w1 - w4 + L41*w1 <= 0;
(lambda)*(U41 - M41)*w1 + w4 - U41*w1 <= 0;

!9-2;
(lambda)*(M32 - L32)*w2 - w3 + L32*w2 <= 0;
(lambda)*(U32 - M32)*w2 + w3 - U32*w2 <= 0;

(lambda)*(M42 - L42)*w2 - w4 + L42*w2 <= 0;
(lambda)*(U42 - M42)*w2 + w4 - U42*w2 <= 0;

!9-3;
(lambda)*(M43 - L43)*w3 - w4 + L43*w3 <= 0;
(lambda)*(U43 - M43)*w3 + w4 - U43*w3 <= 0;


A12 = w1/w2;
A13 = w1/w3;
A14 = w1/w4;

A23 = w2/w3;
A24 = w2/w4;

A34 = w3/w4;

end
```

A-5: Sample DEFANP questionnaires

Part I – General instruction

Instruction

Linguistic scale	Fuzzy number	lower	modal	upper
Equally	1	1	1	1
Moderately more (MM)	2	1.2	2	3.2
Strongly more (ST)	3	1.5	3	5.6
Very strongly more (VS)	5	3	5	7.9
Extremely more (EM)	8	6	8	9.5

Example:

1. Which element is more important in improve the NPV of polygeneration project?

GOAL	SC	TP
SC	1.00	X
TP		1.00

IF X =

1 > it means both supply chain and technology/process are equally important in improving the NPV of polygeneration project

3 > it means supply chain(element in row) is strongly more important than technology/process (element in column) in improving the NPV of polygeneration project, as comparing to technology/process.

1/3 > it means technology/process (element in column) is strongly more important than supply chain (element in row) in improving the NPV of polygeneration project, as comparing to technology/process.

Part II – To determine the dependency of the key elements for biomass polygeneration project and role of stakeholders with respects to the goal

1. Which element is more important in improve the NPV of polygeneration project?

GOAL	SC	TP
SC	1.00	
TP		1.00

2. Which stakeholder is playing a more important role in improving the NPV of polygeneration project?

GOAL	GA	IP
GA	1.00	
IP		1.00

3. By implementing which action plan is more likely to improve the NPV of polygeneration project?

GOAL	AP1-RF	AP2-ES	AP3-F1	AP4-SF	AP5-HS	AP6-HD	AP7-CM
AP1-RF	1.00						
AP2-ES		1.00					
AP3-FI			1.00				
AP4-SF				1.00			
AP5-HS					1.00		
AP6-HD						1.00	
AP7-CM							1.00

1. Which stakeholders plays a more important role in enhancing the **supply chain** of the polygeneration project?

GOAL	GA	IP
GA	1.00	
IP		1.00

2. Which stakeholders plays a more important role in enhancing the **process and technology** of the polygeneration project?

GOAL	GA	IP
GA	1.00	
IP		1.00

3. Comparing the action plan in pairs, which action plan is **more effective** in enhance the **supply chain** of the polygeneration project? Effective by how much?

GOAL	AP1-RF	AP2-ES	AP3-F1	AP4-SF	AP5-HS	AP6-HD	AP7-CM
AP1-RF	1.00						
AP2-ES		1.00					
AP3-FI			1.00				
AP4-SF				1.00			
AP5-HS					1.00		
AP6-HD						1.00	
AP7-CM							1.00

4. Comparing the action plan in pairs, which action plan is **more effective** in enhance the **process and technology** of the polygeneration project? Effective by how much?

GOAL	AP1-RF	AP2-ES	AP3-F1	AP4-SF	AP5-HS	AP6-HD	AP7-CM
AP1-RF	1.00						
AP2-ES		1.00					
AP3-FI			1.00				
AP4-SF				1.00			
AP5-HS					1.00		
AP6-HD						1.00	
AP7-CM							1.00

1. The enhancement of which key elements of polygeneration project is more likely to improve the overall benefits for **industry players**?

GOAL	SC	TP
SC	1.00	
TP		1.00

2. The enhancement of which key elements of polygeneration project is more likely to **increase government's income** (i.e., through tax)?

GOAL	SC	TP
SC	1.00	
TP		1.00

3. Comparing the action plan in pairs, which action plan is **more likely to improve the overall benefits for industry players**? More likely by how much?

GOAL	AP1-RF	AP2-ES	AP3-F1	AP4-SF	AP5-HS	AP6-HD	AP7-CM
AP1-RF	1.00						
AP2-ES		1.00					
AP3-FI			1.00				
AP4-SF				1.00			
AP5-HS					1.00		
AP6-HD						1.00	
AP7-CM							1.00

4. Comparing the action plan in pairs, which action plan is **more likely to increase government's income (i.e., through tax)**? More likely by how much?

GOAL	AP1-RF	AP2-ES	AP3-F1	AP4-SF	AP5-HS	AP6-HD	AP7-CM
AP1-RF	1.00						
AP2-ES		1.00					
AP3-FI			1.00				
AP4-SF				1.00			
AP5-HS					1.00		
AP6-HD						1.00	
AP7-CM							1.00

1.By revising the FiT rates, which key elements of polygeneration project is more likely to be enhanced?

GOAL	SC	TP
SC	1.00	
TP		1.00

2.By eliminating the subsidy for electricity, which key elements of polygeneration project is more likely to be enhanced?

GOAL	SC	TP
SC	1.00	
TP		1.00

3. By introducing new financing incentives for polygeneration projects, which key elements of polygeneration project is more likely to be enhanced?

GOAL	SC	TP
SC	1.00	
TP		1.00

4. By subsituting fossil fuel with bio-oil in transportation, which key elements of polygeneration project is more likely to be enhanced?

GOAL	SC	TP
SC	1.00	
TP		1.00

5. By securing the long-term supply cost with hedging instruments, which key elements of polygeneration project is more likely to be enhanced?

GOAL	SC	TP
SC	1.00	
TP		1.00

6. By securing the long-term demand with hedging instruments, which key elements of polygeneration project is more likely to be enhanced?

GOAL	SC	TP
SC	1.00	
TP		1.00

7. By implementing carbon management strategy, which key elements of polygeneration project is more likely to be enhanced?

GOAL	SC	TP
SC	1.00	
TP		1.00

1.By revising the FiT rates, which stakeholders is more likely to be benefitted?

GOAL	GA	IP
GA	1.00	
IP		1.00

2.By eliminating the subsidy for electricity, which stakeholders is more likely to be benefitted?

GOAL	GA	IP
GA	1.00	
IP		1.00

3. By introducing new financing incentives for polygeneration projects, which stakeholders is more likely to be benefitted?

GOAL	GA	IP
GA	1.00	
IP		1.00

4. By subsituting fossil fuel with bio-oil in transportation, which stakeholders is more likely to be benefitted?

GOAL	GA	IP
GA	1.00	
IP		1.00

5. By securing the long-term supply cost with hedging instruments, which stakeholders is more likely to be benefitted?

GOAL	GA	IP
GA	1.00	
IP		1.00

6. By securing the long-term demand with hedging instruments, which stakeholders is more likely to be benefitted?

GOAL	GA	IP
GA	1.00	
IP		1.00

7. By implementing carbon management strategy, which stakeholders is more likely to be benefitted?

GOAL	GA	IP
GA	1.00	
IP		1.00

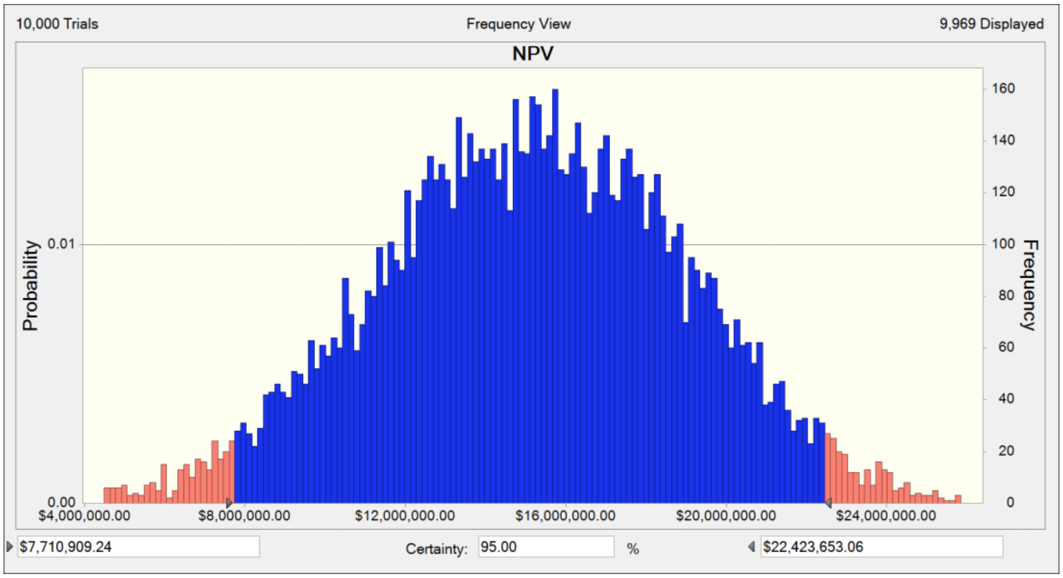
DEMATEL Questionnaires

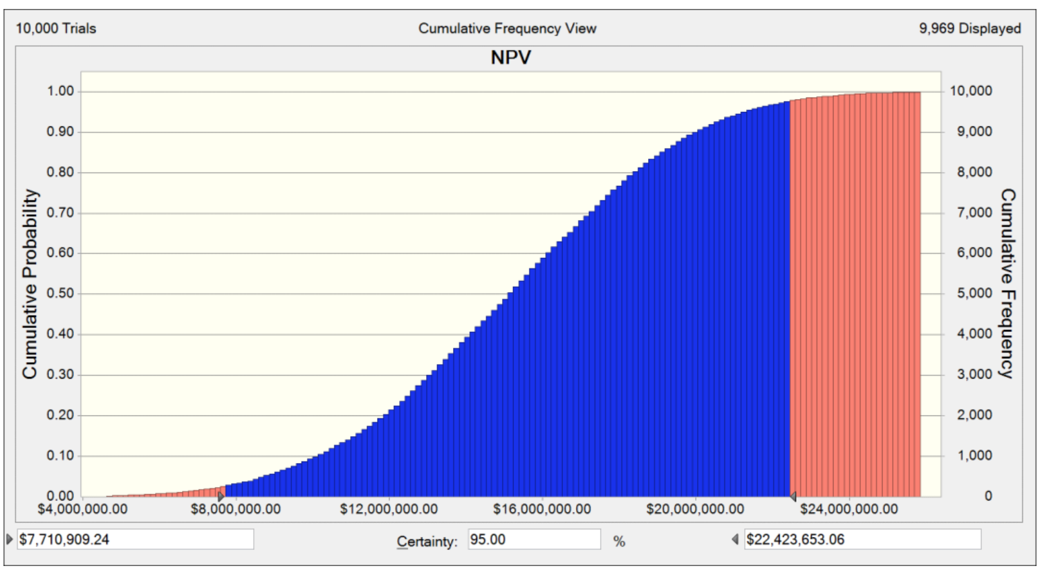
Linguistic scale	Value
No influence	0
Very low influence	1
Low influence	2
High influence	3
Very high influence	4

<table>
<tr><th>GOAL</th><th>AP1-RF</th><th>AP2-ES</th><th>AP3-F1</th><th>AP4-SF</th><th>AP5-HS</th><th>AP6-HD</th><th>AP7-CM</th></tr>
<tr><td>AP1-RF</td><td>0.00</td><td colspan="6">what is the influence of the implementation of AP1 to AP2,...,AP7</td></tr>
<tr><td>AP2-ES</td><td rowspan="6">Does the implementation of AP1 depending on AP2,...,AP7</td><td>0.00</td><td colspan="5">what is the influence of the implementation of AP2 to AP3,...,AP7</td></tr>
<tr><td>AP3-FI</td><td rowspan="5">Does the implementation of AP2 depending on AP2,...,AP7</td><td>0.00</td><td></td><td></td><td></td><td></td></tr>
<tr><td>AP4-SF</td><td></td><td>0.00</td><td></td><td></td><td></td></tr>
<tr><td>AP5-HS</td><td></td><td></td><td>0.00</td><td></td><td></td></tr>
<tr><td>AP6-HD</td><td></td><td></td><td></td><td>0.00</td><td></td></tr>
<tr><td>AP7-CM</td><td></td><td></td><td></td><td></td><td>0.00</td></tr>
</table>

A-6: Crsytal Ball outputs

The frequency distribution and cumulative frequency view of the NPV for 10,000 Monte Carlo simulation (Chapter 8 case study)





The frequency distribution and cumulative frequency view of the PBP for 10,000 Monte Carlo simulation (Chapter 8 case study)