OPTIMAL DESIGN FOR PRODUCTION OF GREEN DIESEL FROM INTEGRATED OIL PALM BIOMASS DERIVED ALCOHOLS BIO-REFINERY

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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A report submitted
In fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I declare that this project report entitled “Optimal Design for Production of Green Diesel from Integrated Oil Palm Biomass derived Alcohols Bio-refinery” is the result of my own work except as cited in the references

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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ABSTRACT

Biomass has long been viewed as a future opportunity with the ever-increasing need for sustainable and affordable energy sources. Malaysia is one of the world's leading producers with the world's largest palm oil crop. Biomass from the palm oil sector, thus, seems to be a very interesting alternative source of raw materials in Malaysia, including renewable energy. There is a growing interest in biofuels nowadays. Thus, this study focuses on the model-based formulation and optimization of advanced biofuels from integrated oil palm biomass bio-refinery. A simulation approach based on superstructure offers alternatives to biomass production routes to minimize the total cost of the supply chain. Thus, this study aims to analyze the model that integrates comprehensive spatial modelling techniques with the strategic oil palm biomass supply chain network design. This study will also optimize supply chain using simulation software such as GAMS and ArcGIS. Based on the findings, there are 78 potential facilities for oil palm biomass in Johor. Next, the least cost and low GHG supply chain of biofuel was obtained based on various constraints that served as the upper and lower boundaries of the decision variables. With ArcGIS software, spatial data is presented then solved by mathematical optimization programming (Linear Programming) in GAMS software. Lastly, Analytical Hierarchy Process (AHP) are carried out to determine the most optimal supply chain system.

ABSTRAK

Biomas telah lama dilihat sebagai peluang masa depan dengan keperluan sumber tenaga yang mampan dan berpatutan yang semakin meningkat. Malaysia adalah antara pengeluar tanaman kelapa sawit terbesar di dunia. Oleh itu, biomas dari sektor kelapa sawit yang juga merupakan tenaga boleh diperbaharui adalah sumber bahan mentah alternatif yang terbaik di Malaysia. Terdapat permintaan yang semakin meningkat terhadap bahan api bio pada masa kini. Oleh itu, kajian ini memfokuskan pada perumusan berdasarkan model dan pengoptimuman bahan api bio dari kilang bio biomas kelapa sawit. Penggunaan simulasi berdasarkan suprastruktur menawarkan alternatif kepada laluan pengeluaran biomas untuk meminimumkan jumlah kos rantaian bekalan. Oleh itu, kajian ini bertujuan untuk menganalisis model yang mengintegrasikan teknik pemodelan spasial yang komprehensif dengan reka bentuk rangkaian rantaian bekalan biomas kelapa sawit yang strategik. Kajian ini juga akan mengoptimumkan rantaian bekalan menggunakan perisian simulasi seperti GAMS dan ArcGIS. Berdasarkan penemuan dalam kajian ini, terdapat 78 tempat yang berpotensi sebagai kilang biorefineri di Johor. Seterusnya, rantai bekalan bahan api bio yang mempunyai kos dan pelepasan gas rumah hijau paling rendah diperoleh berdasarkan pelbagai kekangan yang berfungsi sebagai batas atas dan bawah pemboleh ubah keputusan. Dengan perisian ArcGIS, data spatial disajikan kemudian diselesaikan dengan pengaturcaraan pengoptimuman matematik (Linear Programming) dalam perisian GAMS. Terakhir, Proses Hierarki Analitik (AHP) dijalankan untuk menentukan sistem rantaian bekalan yang paling optimum.

ACKNOWLEDGMENT

I would like to express my gratitude to Almighty Allah who has given me the opportunity to go through the total process of final year project and also in writing this report. These years were very interesting and valuable enough, but sometimes it could also be challenging and difficult. I have learned a lot not only about my studies, but also a lot about myself, and eventually, it is fantastic to be able, to sum up, my work in this final year project. But without the help and support of many individuals, this would not have been feasible.

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Madam Nurul Hanim Binti Haji Razak from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for her essential supervision, support and encouragement towards the completion of this project report.

I am also grateful to those who help me complete this final year project and to any peers for their moral support and, above all, for their precious friendship. Special thanks to my beloved parent, siblings and friends for their moral support in completing this degree. Lastly, thank you to everyone who had been to the crucial parts for me to complete this project.

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ABBREVIATION

AHP	-	Analytic Hierarchy Process
AIMMS	-	Advanced Interactive Multidimensional Modelling System
BR	-	Biorefinery
CAPEX	-	Capital Expenditure
CFPP	-	Cold Filter Plugging Point
CH_4	-	Methane
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
EFB	-	Empty Fruit Bunch
GAMS	-	General Algebraic Modeling System
GHG	-	Green House Gas
GIS	-	Geographic Information System
GUI	-	Graphical User Interface
H_2	-	Hydrogen
LP	-	Linear Programming
MF	-	Mesocarp Fiber
MPOB	-	Malaysian Palm Oil Board
N_2	-	Nitrogen
NO	-	Nitrogen Oxide
NO_2	-	Nitrogen Dioxide
OPEX	-	Operational Expenditure
OPF	-	Oil Palm Frond
OPT	-	Oil Palm Trunk
OPP	-	Oil Palm Plantation
PKS	-	Palm Kernel Shell

POME	-	Palm Oil Mill Effluent
SCM	-	Supply Chain Management
SCOR	-	Supply Chain Operation Reference
SIRIM	-	Standard and Industrial Research Institute of Malaysia

CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter will be discussing on the structural sustainability study of integrated oil palm biomass bio-refinery to produce advanced biofuels in Malaysia. This research is motivated to assess the appropriateness of the modelling and optimization of oil palm biomass's supply chain to be implemented in Malaysia through the development of a new systematic modelling framework. The following sections will be covered in this chapter including the research background, problem statement, research objectives, research scopes and significant research.

1.1 Research Background

Currently, one of the most crucial energy sources in every region of the world is biomass (Thran *et al*., 2010). Biomass can be considered as one of the energies that can be replenished and has the potential to become one of the significant sources of energy in the future. So, it is essential to develop and utilize various renewable energy sources. One of the approach to utilize biomass as a major source of energy is through the utilization of the remaining agricultural products, plantations or waste of forest products, including oil palm biomass. Oil palm is one of the potential assets as a source of biofuel. The crude palm oil produced is the main raw material to produce biofuels in the form of biodiesel. However, the development and utilization of biomass as a source of biofuel often face various obstacles. For instance, oil palm biomass also faces several problems that arise within the supply chain context such as inaccessibility to forest land, resulting in a high cost of production and that keep the investors away, the government forbids the usage of biomass for food, materials and traditional bioenergy.

The attempts to fully exploit biofuel potential through agroindustry activities cannot be separated from supply chain management. Supply chain management can be considered as a network of organization employed in complex operations and including several processes. The globalized market causes an increase in demand for the supply chain. To overcome the complexities, the management of an organization needs coordination in order to improve the performance of the supply chain. In an endeavour to be able to compete in the global market and networked economy, an organization needs to rely on effective supply chains or effective networks.

One of the key concerns of supply chain management is both the coordinating producer and supplier. Typically, the supply chain for palm biomass begins from suppliers provide the raw material to be consumed in refinery process. Then, manufacturer will consume the raw material to convert into semi-finished or finished product. Next, the products will be delivered to the wholesaler in a large quantity for marketing. Wholesaler will sell the products to the retailer based on their demand for the item. Lastly, the product will reach the end consumer.

1.2 Problem Statement

The parameters that are considered within the general design of the biofuel supply chain of are listed below.

- A set of locations: oil palm biomass plantations, potential bio-refineries, and demand centre.
- Logistic options: The transportation modes.
- Capacity limitations: Availability of feedstock at oil palm plantations, capacity of bio-alcohol production at bio-refinery and demands of bio-alcohol at demand centre.
- Economics data: Feedstock costs, transportation costs, capital expenditures and operating expenditures.
- Environmental impact data (CO_2 Emission): Feedstock acquisition, transportation, conversion technology.

Important decision variables in designing the optimize supply chain of green diesel are listed as follows:

- The selection of feedstock suppliers.
- The selection of location to set up bio-refinery for the conversion process.
- The selection of transportation modes.

In this supply chain model, there are two objectives need to be achieved that are economic objective and environmental objective. The challenges faced in the biofuel supply chain planning network are how to achieve the two objectives. The economic objective is to obtain the least cost in the supply chain while the environmental objective is to obtain the least carbon dioxide emission in the supply chain. So, in order to obtain the most optimal biofuel supply chain system, the selection of decision variables that are stated above is important so that the two objectives for biofuel supply chain can be achieved.

1.3 Research Objectives

(i) To develop a GIS-AHP optimization framework of oil palm biomass to biofuel production via Linear Programming (LP)

(ii) To design a strategic optimal network design of oil palm biomass to biofuel including the resources availability assessment, optimal biorefinery localization, transportation network analysis and optimization (GAMS, AHP & ArcGIS)

1.4 Scope of Study

This study is mainly to focus on the network planning of the supply chain for production of green diesel from oil palm biomass in Malaysia. This study also will contributes towards supply chain optimization of green diesel planning operation by considering several of cost factors such as biomass cost, transportation cost, bio-refinery capital expenditure, and as well as bio-refinery operating expenditure. Apart from that, this particular study will develop green diesel platform planning and optimization for biodiesel production process and network design within the supply chain planning. The improvement in performance measurement will be identified by using simulation such as GAMS and ArcGIS which is a geographic information system (GIS) software. The use of simulation software is essential in designing the most optimize supply chain system.

1.5 Research Scopes

For Objective (i)

Developing an optimal supply chain optimization (SCO) for palm oil biomass (OPF) to biofuel.

For Objective (ii)

Adopting a computer-aided tool to build least logistic cost and low greenhouse gas (GHG) emission of an optimal SCO for OPF to biofuel.

1.6 Significance of Research

The results of this study will determine the level of transportation management to mobilize the biomass of palm oil throughout the supply chain, leading to increased productivity and cost reduction. The recommendations based on the results of this study can help to organize strategic planning for supply chain system in order to optimize the current logistic system. Thus, the significance of this study will contribute to uncovering about the supply chain processes and the appropriate strategies that can be implemented to optimize the performance of the operations. The planning is to minimize the cost of the entire supply chain of biofuel from bio-waste feedstock fields to end-users, simultaneously satisfying demand, resource, and technology constraints.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter presents the literature that was reviewed to come up with significant knowledge about the diesel fuel and the production of advanced biofuels from the integrated oil palm biomass. Section 2.1 explained about the background history of biofuels. In Section 2.2 the evolution of biofuels is discussed .In Section 2.3, the potential of oil palm biomass in Malaysia is discussed. The explanation of conversion technologies adopted to process solid oil palm biomass to liquid fuel is in Section 2.4. Section 2.5 provides the overview of the biofuel. Section 2.6 describes the introduction of green diesel and fuel additives used to increase the properties for green diesel are discussed. Section 2.7 discussed about supply chain optimization. Lastly, Section 2.8 provides the research gap for scientific literature.

2.1 Background of Biofuel

Secured supplies of energy are vital to ensure the technological developments for each country. Currently, the implementation of renewable energy usage is pursued in every state as it provides a safe and clean source of energy (Jiang Y & Swinton S, 2009). Biofuels must contain over 80 % of renewable resources, such as biomass, derived directly from the process of photosynthesis. Biofuels are used for basic energy needs and are used to blend or replace conventional fuel such as petroleum. In recent years, biofuels are becoming part of sustainable development all over the world as they are produced mainly from a feedstock of biomass**.** Biomass is a renewable source that contains very few sulphurs and carbon content. Thus, the utilization of biofuels can control greenhouse gas (GHG) emissions and can minimize adverse effects on the environment. For instance, bioethanol and biodiesel are the biofuels that are most commonly used nowadays. The percentage of biofuels in renewable energy utilization keeps increasing due to improving conversion technologies of biomass to biofuels. This has resulted in an increase of biofuel quality and minimize the cost of biofuel.

2.2 Evolution of Biofuel

Currently, biofuel can be classified into four generations. The first generation biofuel is mainly produced from food crops, and the commodities are derived from corn, sugar cane, and any sugar or starch. The production of the first-generation biofuel is through the technological method that is called enzymation. Enzymation is a process of enzyme digestion that releases sugars from starchy material in the food crops. Usually, the raw resources used have higher octane ratings that evaluate the fuel tends to burn in a way that suited the engine. However, a debate on food conflict as biomass and sustainability evaluation of such resources has limited the usage of the first-generation biofuel (Chakrabortty A, 2008).

This has reached the stage where the second and third generation of biofuel are introduced. The second generation refers to non-food type biomass that is called as lignocellulosic biomass. Lignocellulosic biomass is the raw materials that include waste biomass, wheat stalks, corn stalks, waste crops and others. The third-generation biofuel mainly refers to algae. Researchers are currently conducting experiments to identify mechanisms for the decomposition of cellulose into sugars, so, no marketing production has yet started. One of the advantages the second and the third generation is high content in lignin and cellulose that makes it ideal for higher carbon content, making it more effective and desirable to use in the development of bioenergy.

The fourth-generation biofuels are still ongoing and have not drawn attention as much as the first, second and third generations. Some organizations are starting to adopt the concept of biochemical and thermochemical processes that able to produce a better option for fuels such as green petrol and green diesel. The technologies that are used in developing the fourth generation include pyrolysis, gasification and organism genetic manipulation to secrete hydrocarbons. The generation biomass can be referred in Table 2.1.

Table 2. 1 Comparison of various types of biomass (Demirel, 2018)

Generation	Type	Source	Examples
First	Food crops	Starch crops	Corn, wheat
		Sugar crops	Sugarcane, sugar beet, sweet sorghum
		Feed	Grass
Second	Lignocellulosic crops	Woody	Short-rotation crops, willow poplar
		Herbaceous	Miscanthus, switchgrass
Third	Aquatic	Microalgae	Chlamydomonas rheinhardii, chlorella
		Macroalgae	Seaweed
		Water	Salt marshes, seagrass
		Water plants	
Wastes	Natural	Agricultural	Animal manure, crop residues
		Forest	Logging residues, tree wastes
	Human-made	Municipal	Solid waste, sewage sludge, waste oil Pulp
		Industrial	and paper industry, sludge

2.3 Potential of Oil Palm Biomass in Malaysia

Malaysia is among the important palm oil producers in the world. The oil palm tree is a beneficial crop that can help to improve the socio-cultural activities. The main problem is its substantial amount of biomass wastes after the oil palm trees are cultivated. Wastes such as empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fiber (MF), palm oil mill effluent (POME), oil palm trunks (OPT), and oil palm fronds (OPF) are produced following harvesting of oil palm fruits palm oil processing or during oil palm trees replantation (Mushtaq *et al*, 2015). Usually, these fronds and trunks and EFB are kept in the plantations and left to decompose naturally for nutrient replacement. The high potential value of these wastes is often ignored for more profitable purposes. The growing amount of waste of oil palm biomass every year urges the government to take further action. Then, the National Biomass Strategy 2020 is introduced in 2011. The strategy aims to ensure the biofuel and bio-based chemical industries are driven to the highest level (Ng *et al*, 2012). In addition, the priority is also on the production of biofuels of the second generation derived from lignocellulosic biomass from oil palm wastes. The oil palm tree can be regarded as a carbon-neutral element since the amount of carbon emitted is the same as they absorbed during their entire life during the combustion or decompose process. So, oil palm biomass can be considered as one of the most important renewable sources of material and energy. This is because this biomass produces less adverse impacts on the environmental. Thus, oil palm biomass is very sustainable for the environment (Panwar *et al*, 2011).

2.4 Conversion Technologies of Oil Palm Biomass

Currently, the most common conversion process applied to the biomass including biochemical, thermochemical and physical process. Thermochemical processes are considered as most of the biofuel production is produced through the process of pyrolysis and gasification. The conversion of solid biomass to liquid fuel is essential because the volumetric heat content can be increased and also minimize the logistic cost (Dhyani & Bhaskar, 2018). The conversion pathways are displayed in Figure 2.1

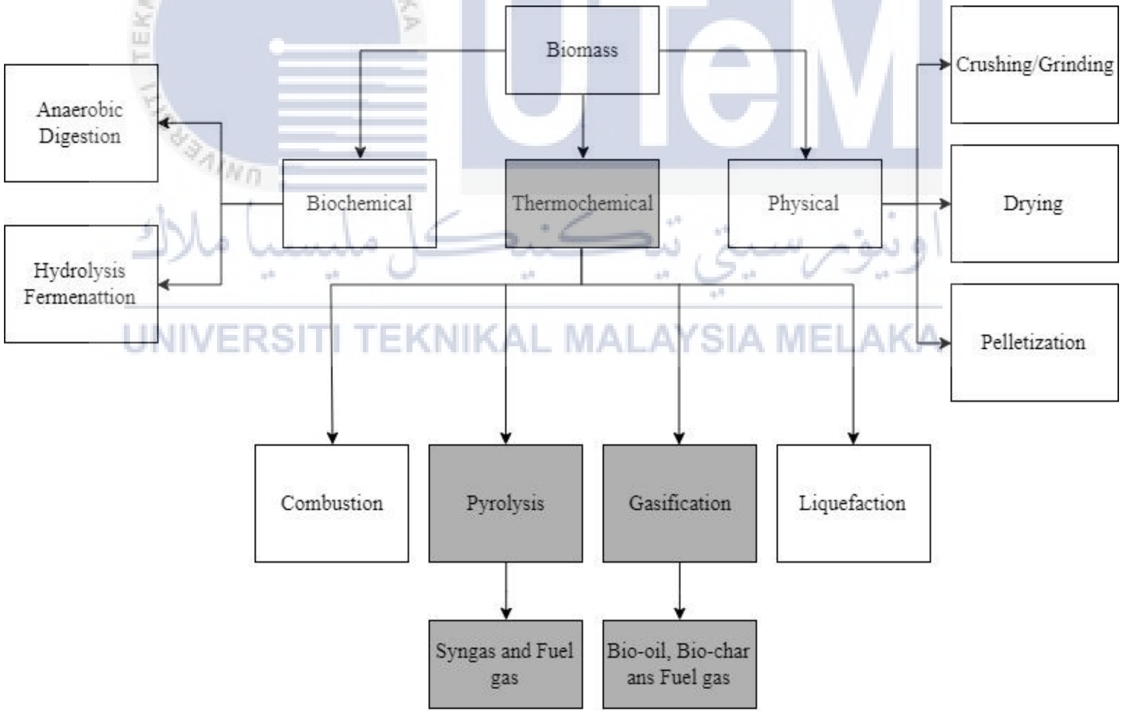

Figure 2. 1 Biomass to bioenergy conversion pathways. (Sharma et al., 2015)

2.4.1 Gasification

The mixture of combustible gas that is released from biomass is known as gasification process (Ingle & Lakade, 2016). During this conversion process, partial oxidation of carbonaceous material takes place, which is also known as indirect combustion. Gasification process requires a high temperature that ranges from 800 C up to 1800 C and under a relatively low amount of oxidant in order for the reaction to occur. Biomass is broken down into several elements throughout the process including hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2) and hydrocarbon molecules, like methane (CH_4) (Awalludin *et al*., 2015). This mixture of synthesis gases is called syngas. Syngas can be converted into bio-diesel fuel via the combination of biomass gasification and Fischer-Tropsch synthesis (Hu *et al*., 2012). Gasification process can be applied to all solid wastes from oil palm plantation such as EFB, MF, OPF, OPT and PKS. Gasification of OPT waste has been observed to produce more energy and hydrogen gas compared to other wastes with the same gasification conditions (Nipattummakul *et al*., 2012). Production of alcohol via biomass gasification is presented in Figure 2.2.

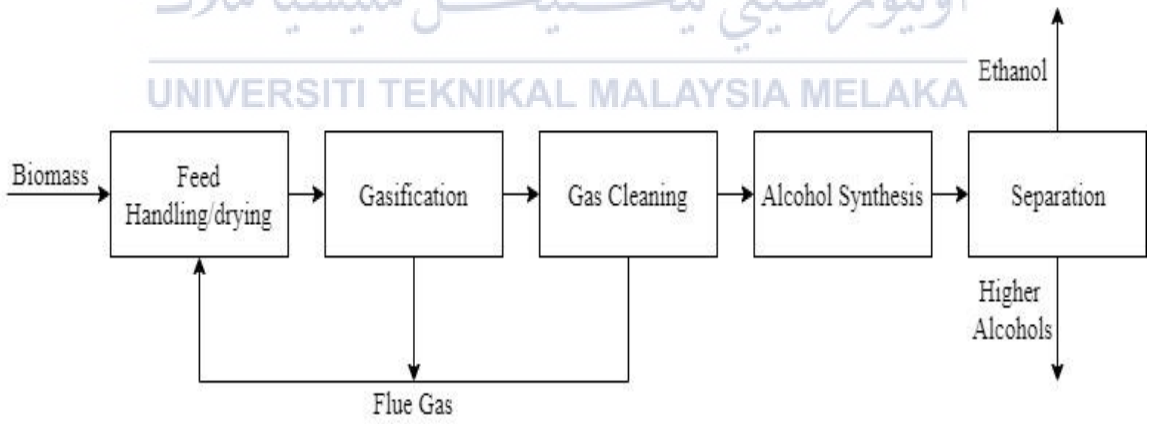

Figure 2. 2 Biomass gasification for alcohol production (Demirel, 2018)

2.4.2 Pyrolysis

Pyrolysis is a thermal degradation of organic matter that occurs in the range of (400–600) °C at atmospheric pressure. Pyrolysis process usually occurs without the presence of oxygen. The most common products that were obtained after the process including fuel gas, bio-oil and charcoal. These three types of pyrolysis which are slow pyrolysis, intermediate pyrolysis and fast pyrolysis. Generally, slow pyrolysis and fast pyrolysis are preferred to be used in the industry. The bio-oil product can be obtained when the vapour formed by the pyrolysis process undergoes rapid cooling (Awalludin *et al*., 2015). Considering the fact that the biomass has the potential to be converted to fuel, the pyrolysis process is widely used to convert from solid raw materials to liquid product.

2.5 Drawback of Biofuel (Diesel and Biodiesel)

2.5.1 Diesel

Diesel fuel is a mixture of hydrocarbons obtained by distillation of crude oil. The important properties which are used to describe diesel fuel include cetane number, fuel volatility, density, viscosity, cold behaviour, and sulphur content (Gad, 2014). Diesel fuel is among the contributing factors to pollution issues around the world. For example, the emissions of diesel fuel can cause adverse effects on respiratory health, pollution of air, and global climate change. The formation of particulate matter can be significantly reduced by minimize the sulphur content in the composition of diesel fuel.

2.5.2 Biodiesel

Biodiesel refers to animal or vegetable oil-based diesel fuel that is consisting of long-chain alkyl (methyl, ethyl, or propyl) esters. Biodiesel has more enormous advantages in terms of performance compared to the standard diesel fuel (Silitonga et al., 2013). The distinctive characteristic of biodiesel is that the fuel does not contain sulphur and aromatics compound in its composition (Özener *et al*., 2014). Hence, biodiesel can be utilized as an alternative fuel that can help to provide cleaner emission, especially when burnt in diesel engines. Although biodiesel has a lot of advantages, it still has a few drawbacks. For instance, the usage of biodiesel has caused an increase in nitrogen oxides (NO) emissions which can lead to the formation of acid rain and smog. Besides, a lower energy output was produced when compared the biodiesel to petrol-diesel (McCarthy *et al*, 2011). So, more biodiesel is needed to produce the same amount of energy to petrol-diesel.

2.6 Green Diesel

Green diesel is referred to as the second generation diesel that is obtained biologically from petroleum-like fuels. Green diesel and biodiesel have a definite chemical distinctive feature. Commonly, green diesel is produced through the reaction of hydrogenation in which the feedstock reacts with hydrogen (H_2). To hydrogenate triglycerides into high-cetane diesel fuel, a substantial amount of hydrogen and a catalyst are required to produce green diesel (Kalnes *et al*., 2009). The product yielded from the chemical reaction that is a liquid hydrocarbon fuel has the advantage of being fully compatible with petrol-diesel (Demirel, 2018). The blends of green diesel and petrol-diesel in a diesel engine have an effect which can reduce the emissions of unburned hydrocarbons and carbon monoxide.

2.6.1 Fuel Additives (Oxygenates)

In recent times, the reliance on petrol-diesel should be reduced to diminish the harmful emission in the air by considering a cleaner fuel option from renewable sources. Currently, to solve the energy and environment problems, researchers are using biodiesel in diesel engines with or without additives. Adding oxygenated fuels such as alcohols, esters and ethers can significantly help to improve the combustion efficiencies of diesel due to having complete combustion (Vijay Kumar *et al*., 2018). But, there was no massive change in the case of emission of carbon monoxide (CO).

Fuel additives which are alcohols including ethanol, methanol, pentanol, and butanol are suitable additive for diesel and biodiesel fuel in order to reduce exhaust emissions and improve engine combustion because of the high oxygen content (Yasin *et al*., 2013). The reason alcohols are being used as an oxygenate additive is because of low cost and have high oxygen content. Higher oxygen content could enhance the oxidation of soot and therefore, can significantly reduce the emission of the particulate matter (Graboski & McCormick, 1998; Tsolakis *et al*., 2007).

Butanol has the best fuel additive properties for internal combustion engine combustion compared to ethanol and methanol. This is because butanol offers higher cetane number, heating value, lower vaporization heat and better miscibility with biodiesel fuel than ethanol and methanol. Furthermore, butanol is a better choice to be used as an additive with biodiesel-diesel blend due to lower emission of carbon monoxide and soot compared to other alcohols.

2.6.2 Physiochemical Properties

Table 2.2 below depicts the different properties for different types of renewable diesel. There are nine different important characteristics are compared among the diesel such as density, sulphur content, cetane index, cetane number, flash point, net heating value, cold filter plugging point (CFPP), cloud point and pour point. In overall, Green Diesel has the best characteristics among the other renewable diesel.

Table 2. 2 Comparison between different types of renewable diesel

Analysis	Units	FT diesel	FAME biodiesel	Green diesel (HDO VO)	Fossil diesel	Reference
Density	g/ml	0.72 – 0.82	0.855 – 0.9	0.77 – 0.83	0.85	(Bezergianni & Dimitriadis, 2013)
Sulphur	mg/kg	<10	0 – 0.012	<10	12	
Cetane Index	-	70	58.3	50 – 105	54.57	
Cetane Number	-	55–99	45 – 72.7	80 – 99	50	
Flash point	°C	55–78	96 – 188	68 – 120	52 – 136	
Net heating value	MJ/kg	43–45	37.1 – 40.4	42 – 44	34.97	
CFPP	°C	(-22)-0	(-13)-15	>20	-6	
Cloud point	°C	(-25)-0	(-3)-17	(-25)-30	-5	
Pour point	°C	-	(-15)-16	(-3)-29	-21	

2.7 Supply Chain Optimization

Systematic supply chain management attempts to find the best supply chain configuration, including location setup, procurement, production, storage and distribution, to enable the efficient operation of the entire supply chain. Therefore, the biofuel system design problem considered here is within the general category of multi-location-layer supply chain management problems. The issues include both spatial and physical aspect. The spatial element mainly related to the geographic distributions of the raw material resources, the fuel demands, and the production and transportation infrastructures. Long term biofuel system planning lies within the physical aspect.

The production and distribution infrastructure system needs to be expanded to keep up with the growing demand from customers. The supply chain of biofuels consisting of a network of raw material sources (biomass), bio-refinery facilities, storage facilities, demand centre and end-users. Figure 2.3 shows the basic superstructure for the supply chain of green diesel. A reliable, efficient and sustainable supply chain of biofuels plays a crucial role to deliver a competitive end-product of the commodity to end-user markets (Redman G, 2008).

Management of the biofuels supply chain should consider three critical levels of decisions to ensure efficient and effective distribution of end products from the source to the intended location. In this study, simulation software such as GAMS and ArcGIS are adopted to have strategic planning on optimal production and distribution system for future biofuels supply chain systems.

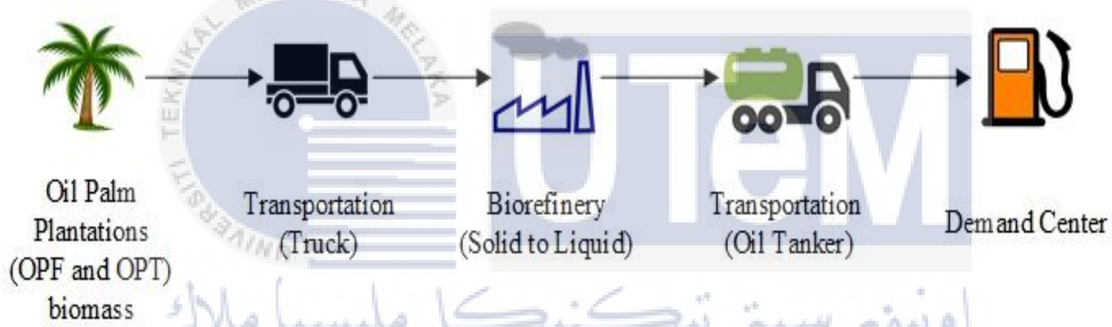

Figure 2. 3 Basic superstructure for the supply chain of green diesel

2.8 Research Gap

A research gap can be classified as a topic or field for which the ability to reach a conclusion on a problem that is restricted by a lack of or insufficient information. The research gap in Table 2.3 below will provide systematic reviews for supply chain management in order to generate ideas to obtain efficient supply chain of green diesel. There are five criteria included in the research gap such as year, author, methodology, research finding and what need to be done to improve the supply chain system.

Table 2. 3 Research Gap

Year	Author	Objectives	Methodology	Research Finding	What Need To Be Done?
2018	E. Permata, I. Kusumanto, Papilo	The major actors in the oil palm supply chain model such as biomass supply, treatment facility and demand centre are responsible to each other to increase the performance of the supply chain system.	Use two analysis methods which are Supply Chain Operation Reference (SCOR) Method and Added Value Analysis (Hayami Method)	The added value on each actor is not balanced. As a result, the performance of the three actors in the supply chain system is still below average.	New strategies need to be figured out in order to improve the current supply chain

2018	Lourenço, Helena Ramalhinho Ravetti, *et al*.	The supply chain system consists of integrated and collaborative processes within a clear business model that leads to a more cohesive and efficient performance of companies and better customer services.	Use metaheuristic and heuristics techniques to solve such significant problems in supply chain management.	Metaheuristics and heuristics are the most appropriate tools to solve decision problems in supply chain management.	system. This is important as supply chain management is one of important part in determining the performance of a business and company.
2014	S. Hidayat, Marimin	The development of several formula by implementing agent-based modelling to determine the ideal distribution in the supply chain to ensure supply chain sustainability.	The supply chain actors (or agents) behaviours are identified by utilizing agent-based modelling approach	All stakeholders in the palm oil supply chain (POSC) need to consider supply chain sustainability in negotiation to ensure the continuity of the supply chain system is not compromised.	
2012	F. Zhang, D. Johnson, M. Johnson	To implement the use of the simulation model in order to improve the biofuel supply chain	Use Quantitative method.	The simulation model is a useful tool for supply chain management, including the selection of the optimal biofuel facility location, logistics design, inventory management, and information exchange.	

2011	A.Agus	The importance of supply chain management programs in enhancing performances of Malaysian manufacturing companies	1)Quantitative (cross-sectional survey) 2)Pearson's Correlation and Structural Equation Modelling (SEM)	The business performance and supply chain stability depend on the efficiency the supply chain management.	

Based on the finding in the research gap, most of the supply chain is still not reached the expected level. Problems in supply chain management (SCM) are becoming more and more challenging. Globalization of the industry and growing demand from the consumer is the reason why efficient SCM is crucial in today's business. Thus, the implementation of optimal network design by adopting simulation-based model program can help to increase the performance of current SCM.

CHAPTER 3

STRUCTURAL METHODOLOGY

3.0 Introduction

This chapter presents the overall about the spatial modelling framework developed for the supply chain of advanced biofuels from integrated oil palm biomass bio-refinery. Since the most successful supply chain are based on the methodology, hence, this chapter is concluded with some ideas about the methodology to achieve efficient supply chain of green diesel.

3.1 K-Chart

Green diesel is a next-generation transportation fuel that emerges as alternatives for renewable diesel fuel for internal combustion engine fuel and also completely compatible with current powertrain systems. Green diesel is produced from the blending of biodiesel, diesel and fuel additives. Several properties can be enhanced through the utilization of green diesel such as engine performance, emission, lubrication and storage. In this context of studies, the aspects of engine performance and emission will be covered.

There are three types of fuel additives that have the potential to increase the properties of bio-diesel fuel which are alcohol, ester and ether. In terms of engine performance, it is important to consider the cetane number as higher cetane number ensured lower ignition delay (Lin *et al*., 2009). Hence, the blending between the diesel, bio-diesel and ether is the ideal in order to obtain higher cetane number. In case of emission, it is important to consider cleaner emission to the environment by significantly reduce the emission of the level of carbon monoxide (CO), carbon di-oxide (CO_2), and smoke. In order to achieve cleaner emission, higher oxygen content in biodiesel fuel blend is needed to ensure a complete combustion process. Then, network analysis is implemented by using ArcGIS to determine the resources of biomass.

The resources of biomass can be classified into two categories that are edible and non-edible. Non-edible biomass also known as lignocellulosic biomass, is selected as the resources of biomass rather than edible resources. This is because it is not appropriate to utilize edible resources as a bio-fuel in order to achieve sustainable development goals. The lignocellulosic biomass that is chosen to produce biofuel is based on palm oil wastes such as kernel shell, empty fruit bunch, oil palm fronds (OPF) and oil palm trunks (OPT). So, OPF is preferred as the resources as it has the best capability to produce biofuel among the other waste palm oil. To achieve an efficient supply chain system, some crucial factors need to be considered such as production yield, transportation cost, transportation distance, processing cost and resources capacity. The consideration of those factors in network optimization help to achieve least-cost supply chain of Green Diesel. Figure 3.1 visualizes the K-Chart for this study.

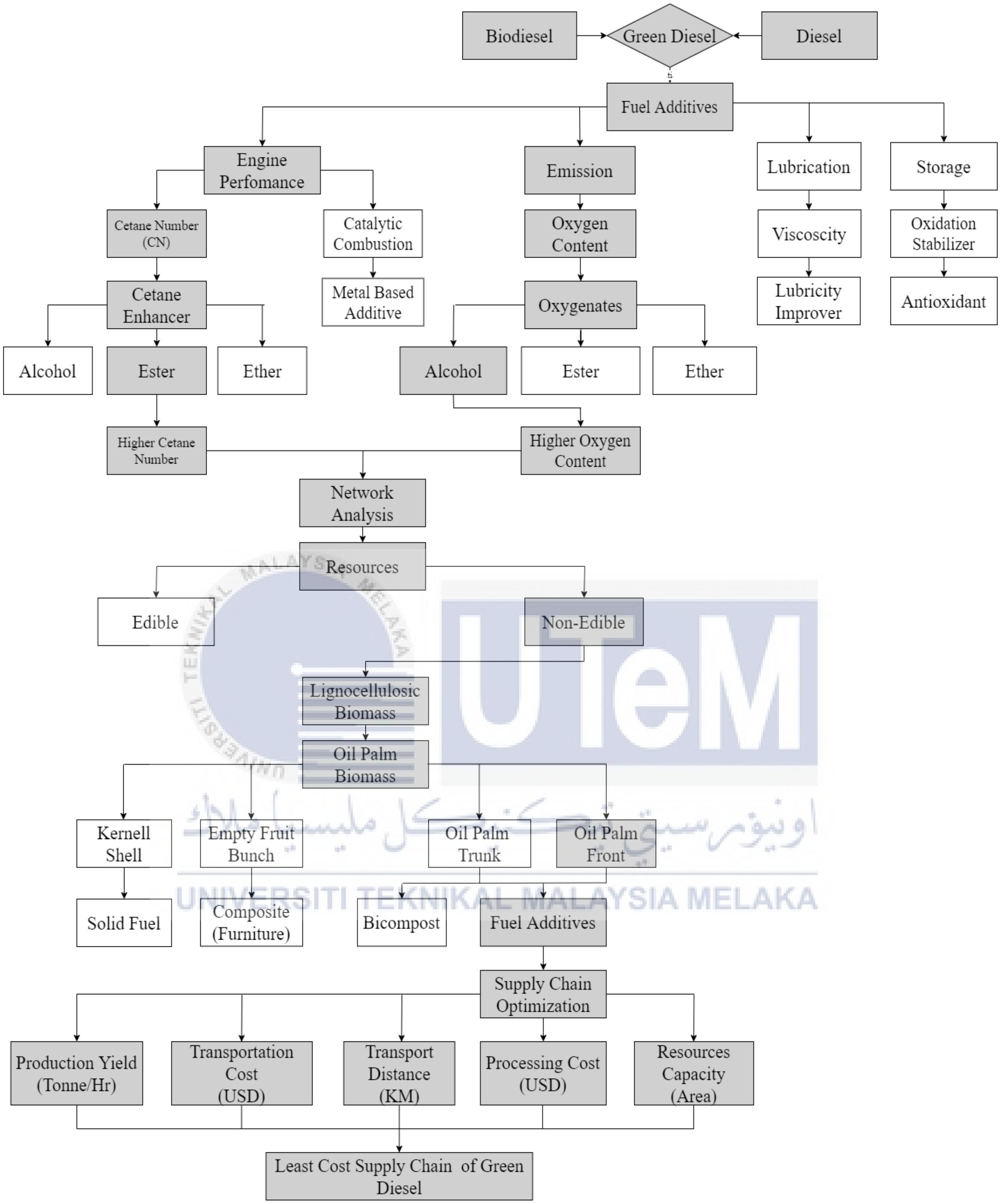

Figure 3. 1 K-Chart

3.2 Process Flow Chart

Process flowchart is essential as the critical and sequential steps are considered in modelling optimization of the biofuel supply chain. The flowchart can be segregated into two main objectives. The first objective is spatial analysis and the second is network optimization. First and foremost, the suitable feedstock of biomass which is oil palm fronds (OPF) identified, followed by identification of the desired product. Then, the range of biomass needs to be identified. Some of the target products can be produced by using the same feedstock through the different conversion pathways. Then, the appropriate set of conversion technologies are determined to convert the solid waste (OPF) to liquid. Spatial analysis by using ArcGIS is implemented in order to identify the oil palm biomass supplies, potential facilities for bio-refinery. Then, the superstructure is developed and the optimization model is formulated. The model's parameter estimation is performed. GAMS is implemented in order to execute the optimization model. Lastly, multi-criteria decision selection method based on the analytic hierarchy process (AHP) is performed in order to determine the most optimal supply chain of biofuel. The process flowchart of this study is visualized in Figure 3.2.

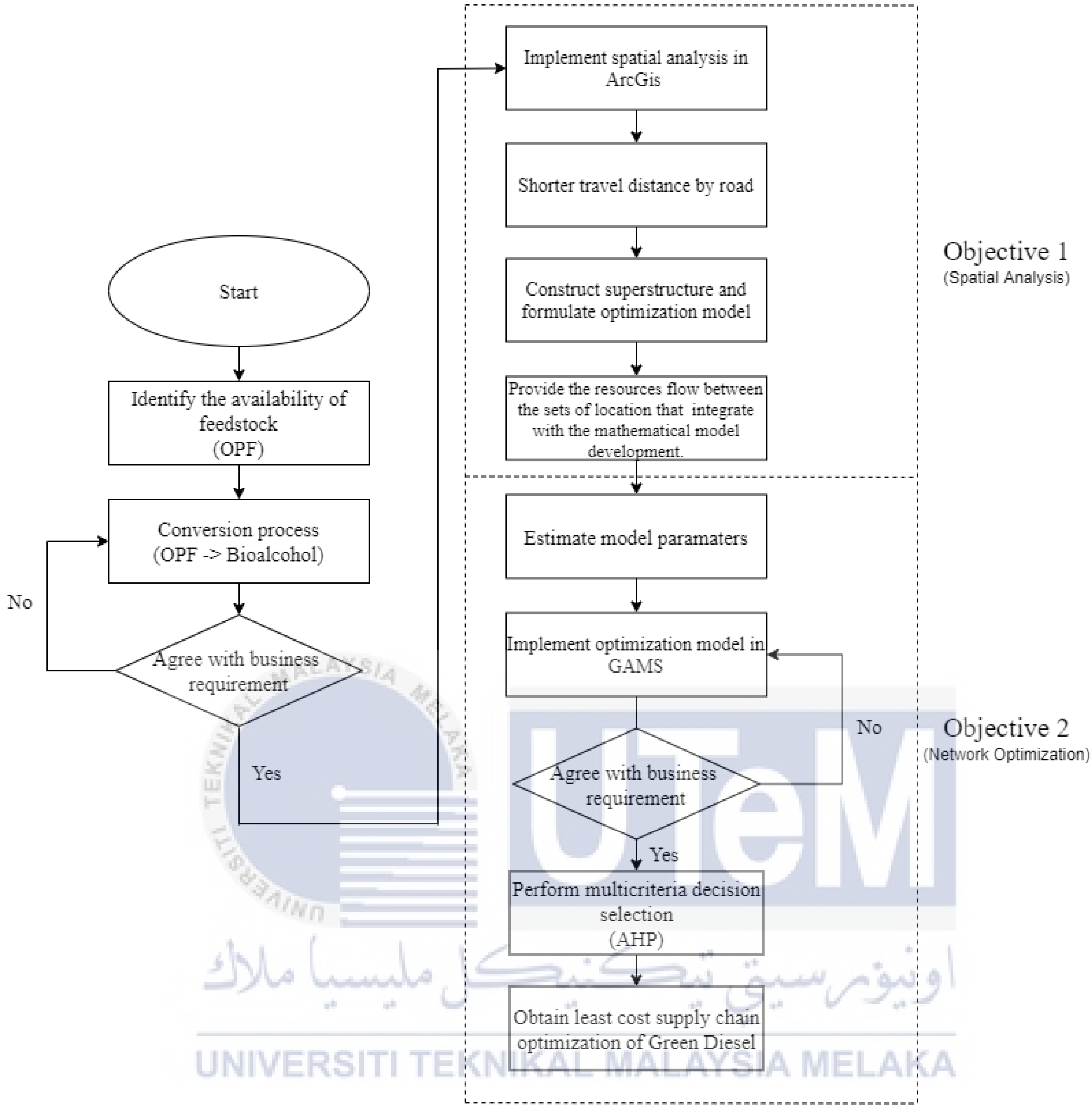

Figure 3. 2 Process Flow Chart of this study

3.3 Generic Methodologies

This sub-sections are focusing on the generic methodology utilized to solve a supply chain problem. There are five significant steps that include data collection and extraction, superstructure representation, mathematical modelling, GAMS programming and result analysis essential as shown in Figure 3.3.

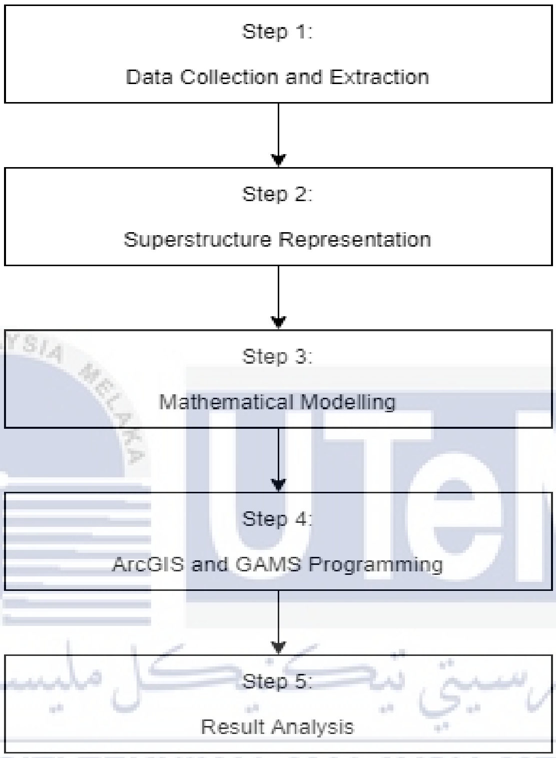

Figure 3. 3 Generic methodologies in solving the optimization problem

3.3.1 Data Collection and Extraction

In developing the optimization models, it is vital to establish a comprehensive database that consisted of an organised spatial database with economic, environment and technical inputs of the models. These data can be obtained from the following sources.

a) Industrial records

Every oil palm-based industries have records on input resources, process capacity, process yield and economic data for an existing process.

b) Literature review

There are a wide variety of reliable published source materials useful for the determination of economic, environmental and technical information.

c) Related organization

Standard and Industrial Research Institute of Malaysia (SIRIM) is a research organization owned by Malaysia Government. The data of oil palms such as plantation area or oil palm availability are obtained from this organization.

3.3.2 Superstructure Representation

The superstructure can be designated as the network diagram that includes all the possible network configurations between supply and demand of the supply chains system. The superstructure will illustrates the resources flow between the sets of locations that will be useful for the mathematical model development. The superstructure for this research is illustrated in Figure 3.4 based on the biomass supply chain network that includes the locations of biomass supply *i*, bio-refinery facilities *j*, and demand centre *k*. Oil palm biomass (OPF) will be supplied to the selected bio-refinery facility using a truck. The oil palm biomass will be converted into the liquid through certain conversion technologies in the bio-refinery facility. After the biomass had converted into bio-alcohol (liquid), it will be transported to the demand company by the oil tanker. The locations of biomass supply and the potential facilities of bio-refinery will be selected based on the optimization of GAMS simulation.

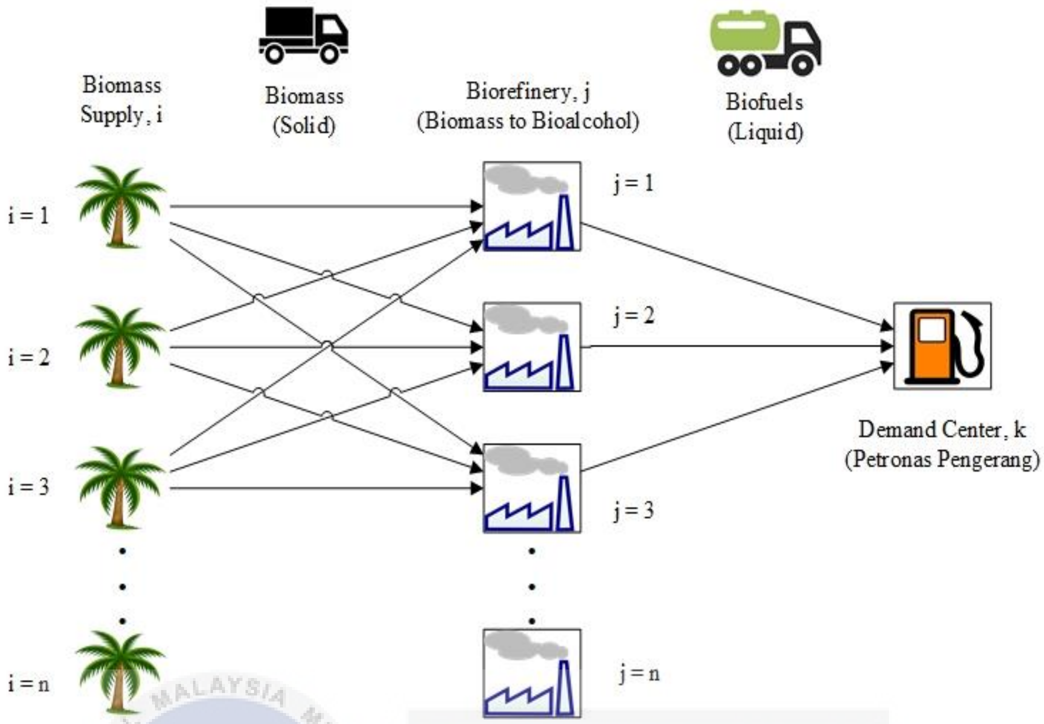

Figure 3. 4 Superstructure of the transportation network of biomass

3.3.3 Mathematical Modelling

This optimization model structure includes mathematical modelling that based on Linear Programming (LP), mainly used in planning and optimization. In an optimization model, there are several important elements such as objective function, decision variables, parameters and constraints which need to be considered. In this study, the objective function works by achieving the least cost supply chain of biofuel which is restricted by various constraints that served as the upper or lower conditions of the decision variables. The input parameter will be influencing the decision variables to configure the outputs of the models. To integrate the flow resources in the model, mass balance technique which is commonly used in the engineering system process.

3.3.4 ArcGIS and GAMS Programming

After the mathematical formulations are performed, ArcGIS which is a geographic information system (GIS) is used for spatial analysis. ArcGIS is a mapping and analytics platform that allows discovering geographic information, managing geographic information in a database and utilizing maps and geographic information in a range of applications. The software offers the technology to develop maps and geographical data accessible across the world. The implementation of ArcGIS in this study is crucial in order to estimate and determine the suitable locations for oil palm biomass supplies and the potential facilities of bio-refinery for the conversion process.

Next, GAMS software is used in this study to obtain the optimal result of network optimization. GAMS can be considered as one of the leading tool that can be used to efficiently describe and solve optimization problems. The function of GAMS is parallel to this study that is to achieve the optimal supply chain of green diesel. GAMS is the first software system that combine the conventional programming concepts and the language of mathematical algebra. In addition, GAMS is specifically developed for modelling linear, nonlinear and mixed integer optimization problems. So, the use of this software is essential in order to optimize the cost and emission of biofuel supply chain system.

3.3.5 Result Analysis

The result from the optimization problem will be analyzed based on achieving the intended research objectives and scopes of study. Then, the analytic hierarchy process (AHP) will be used to find the preference weight for each constraint. The decision-making method is an approach to determine the proportion scales from paired comparisons in order to obtain the most optimal supply chain system

3.4 Spatially Biofuel Supply Chain Framework

3.4.1 Framework Outline

The framework of biofuel supply chain consists of three major components:

(i) Spatial data generation:

Spatial data is generated.by using geo-information system software that is ArcGIS.

(ii) Potential bio-refinery location determination and distance:

The locations of potential bio-refinery are determined on the basis of selection criteria. The actual travel distances is calculated by using ArcGIS in order to develop an accurate optimization model of biofuel supply chain system.

(iii) Optimization:

Linear Programming (LP) model is developed to identify the most optimum supply chain network by considering economic and environmental parameters by using GAMS.

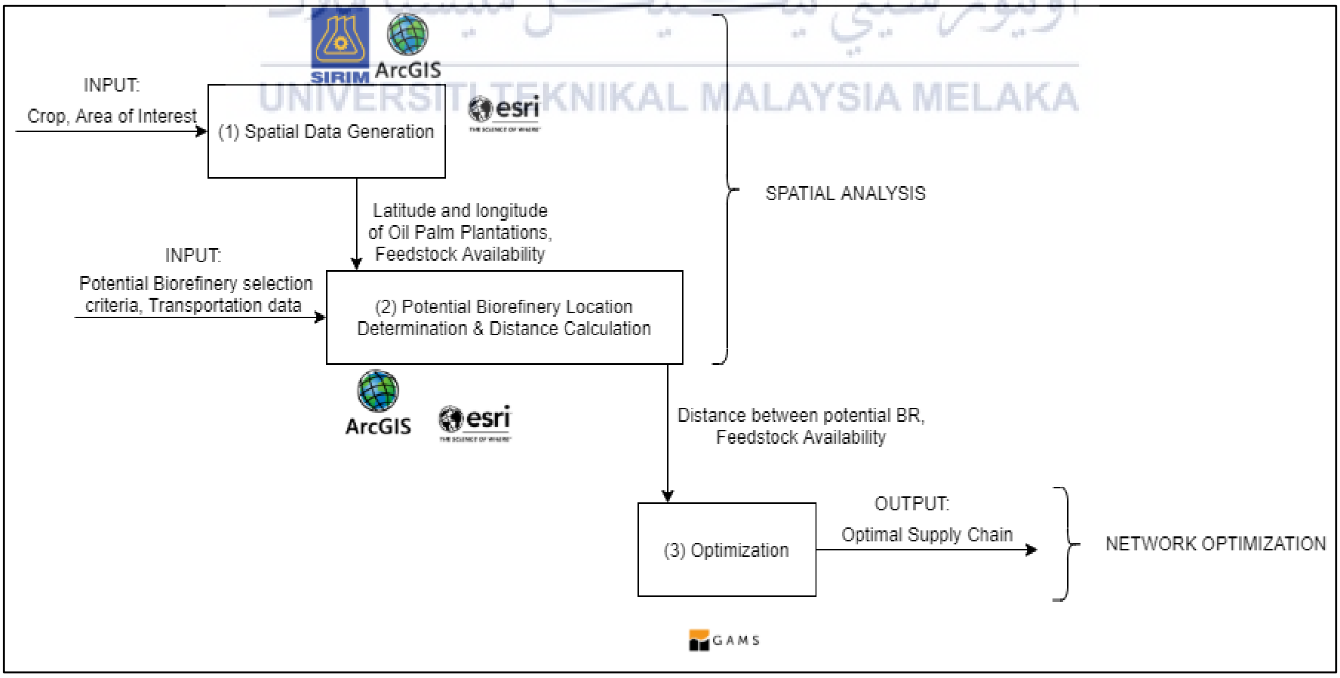

Figure 3. 5 Framework Outline of this study

3.4.2 Spatial Data Generation

First, the feedstock and geospatial data are collected. These data are obtained from the SIRIM so that the crop data at a spatial resolution in latitude and longitude able to be generated. The combination of crop type, representative pathway, and scenario are selected. Then, ArcGIS is used to synchronize the coordinate system by using the feedstock and geospatial data that had been collected earlier.

A map of Johor is digitalized to retrieve the oil palm plantation layer in vector format to be used in ArcGIS. The spatial analysis for locations of palm oil biomass distribution (OPF) and the potential facilities of bio-refinery in Johor were presented in Figure 3.6. The red colour region indicates that the amount OPF in the area is abundant while the green colour region has the least amount of OPF in that area. Next, the red triangular symbols represents the potential facilities of bio-refinery in Johor.

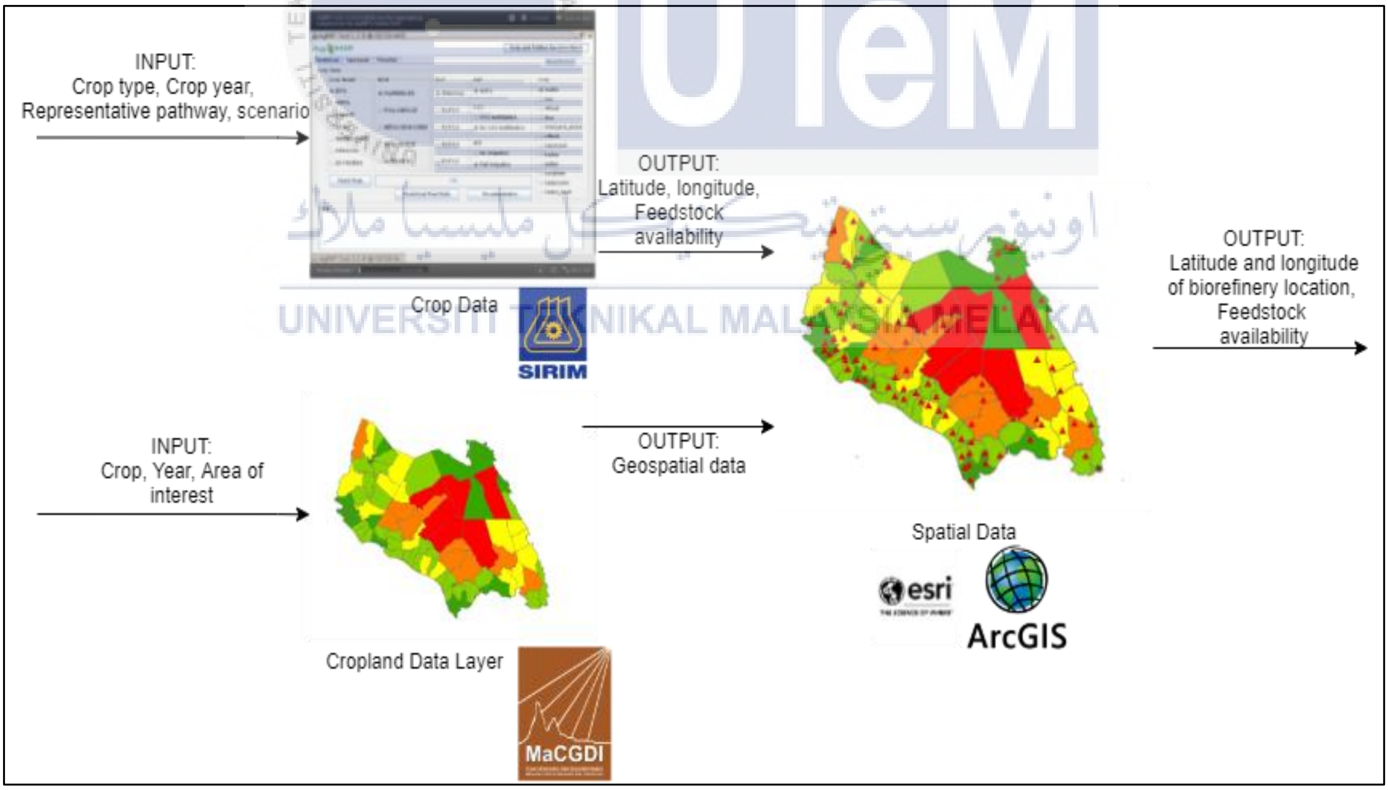

Figure 3. 6 The input and output of spatial data generation components

3.4.3 Spatial Analysis

Spatial analysis will be carried out by considering comprehensive road transport networks in order to identify the ideal transport routes from each location to the respective destinations. Network analysis can estimate the number of the linear networks such as roads, railways, rivers and utilities. In this case, only transportation by roads will be considered in the analysis of roadway transportation network. In this study, the distances from palm oil biomass supply (OPF) to the palm oil bio-refinery and finally to the demand centre will be identified through spatial analysis by the implementation of ArcGIS simulation. Then, the data obtained will be inputted into the optimization model for the calculation of transportation cost. Figure 3.7 illustrates input and output of spatial analysis.

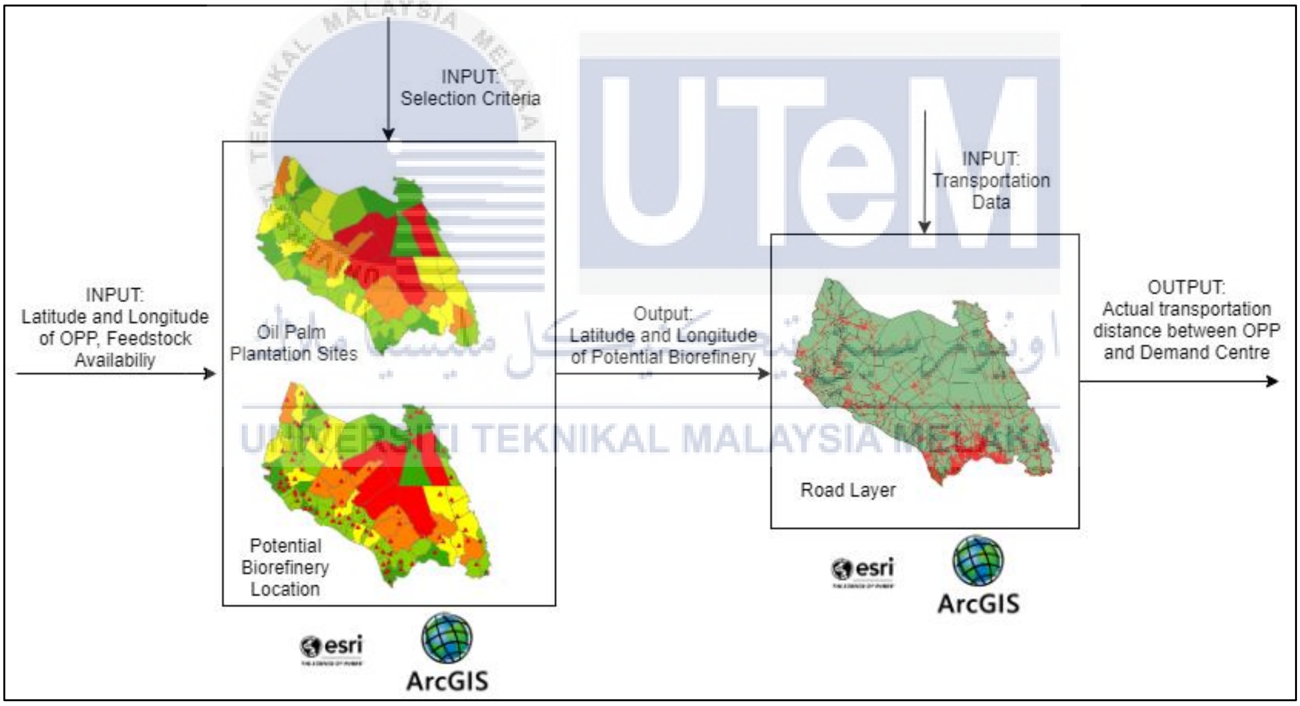

Figure 3. 7 The input and output to obtain actual transportation distance calculation

3.4.4 Network Optimization

The optimization models will be developed by integrating the spatial modelling approach with the biofuel supply chain network design for strategic and operational planning of least-cost supply chain of biofuel. The model will identify the optimal cost structure that includes different economic aspects such as feedstock cost, transportation cost, capital cost, operating cost and carbon cost (CO_2 emission). The minimization of these costs are influenced by various economic, environment and technical variables that are restricted by multiple constraints. In identifying the optimal cost-structure, the model will be selecting the most optimal way to achieve least cost and least emissions by considering the most feasible technologies, capacities and locations. Figure 3.8 below presents the input and output for network optimization in this study.

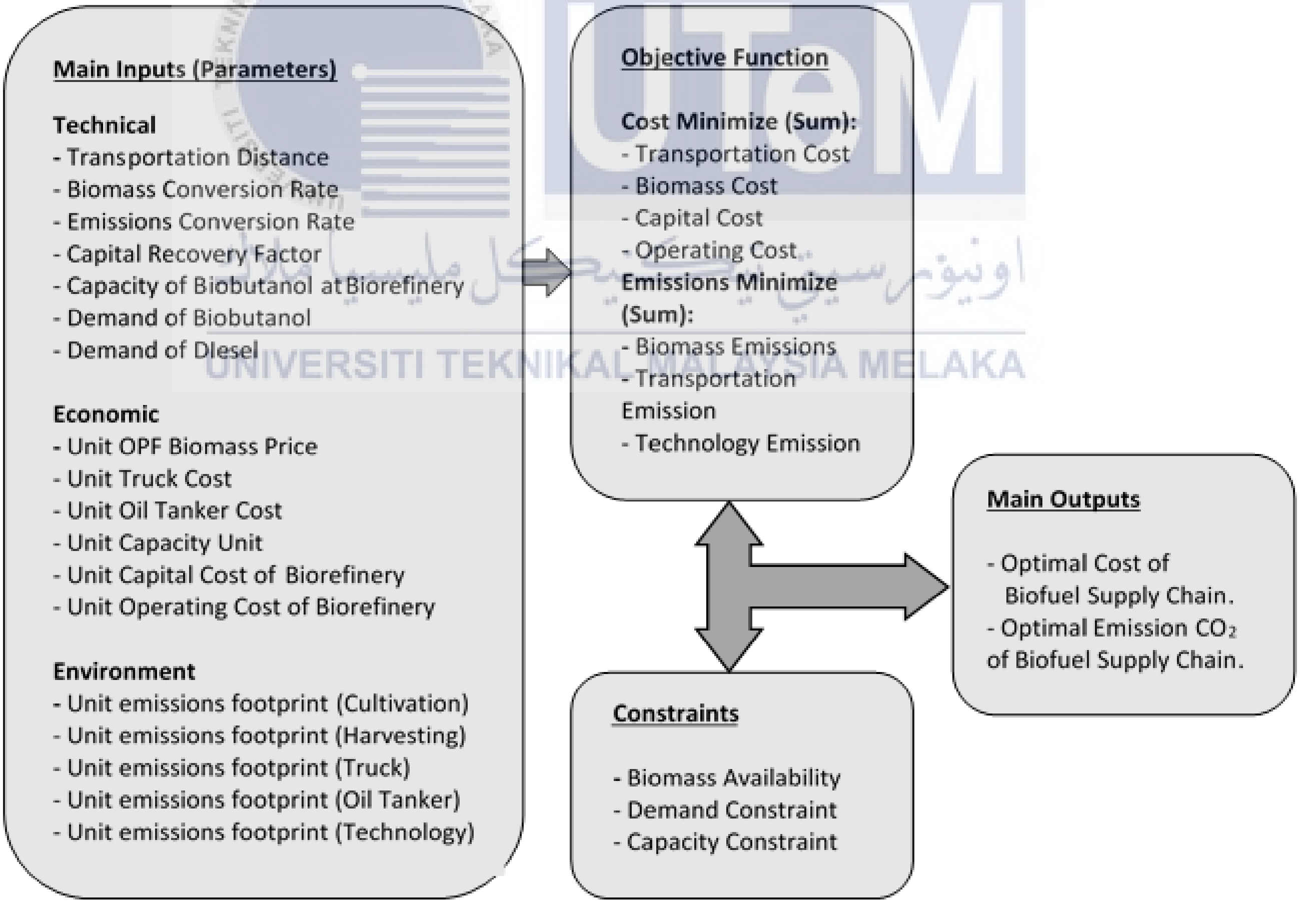

Figure 3. 8 Input and output for network optimization for this study

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents about the preliminary results that is focusing on the supply chain optimization of green diesel for cost and emission minimization. Johor, Malaysia is selected as the case study location for the preliminary analysis. Further discussions on the preliminary analysis are explained in the following section.

4.2 Preliminary Analysis

A conceptual biofuel supply chain with the implementation of simulation software, Geo-Information System (GIS) and GAMS are used. In GAMS, linear programming (LP) is use to execute the program. The suitability analysis is done based on the assessment of feedstock availability, the location of potential bio-refinery set up and the distance between plantation to potential bio-refinery and the potential bio-refinery to Pengerang Integrated Complex (Demand Center), social economy and emission. Several assumptions have been made in order to resolve the constraints of this study.

i) The emissions of CO_2 that are contributed from various of sources. The sources are from the biomass cultivations, biomass harvesting, the transportations by truck and oil tanker and lastly the technological emission.

ii) The capacity of bio-refinery is assume as ten percent of increment of butanol demand at Pengerang Integrated Complex.

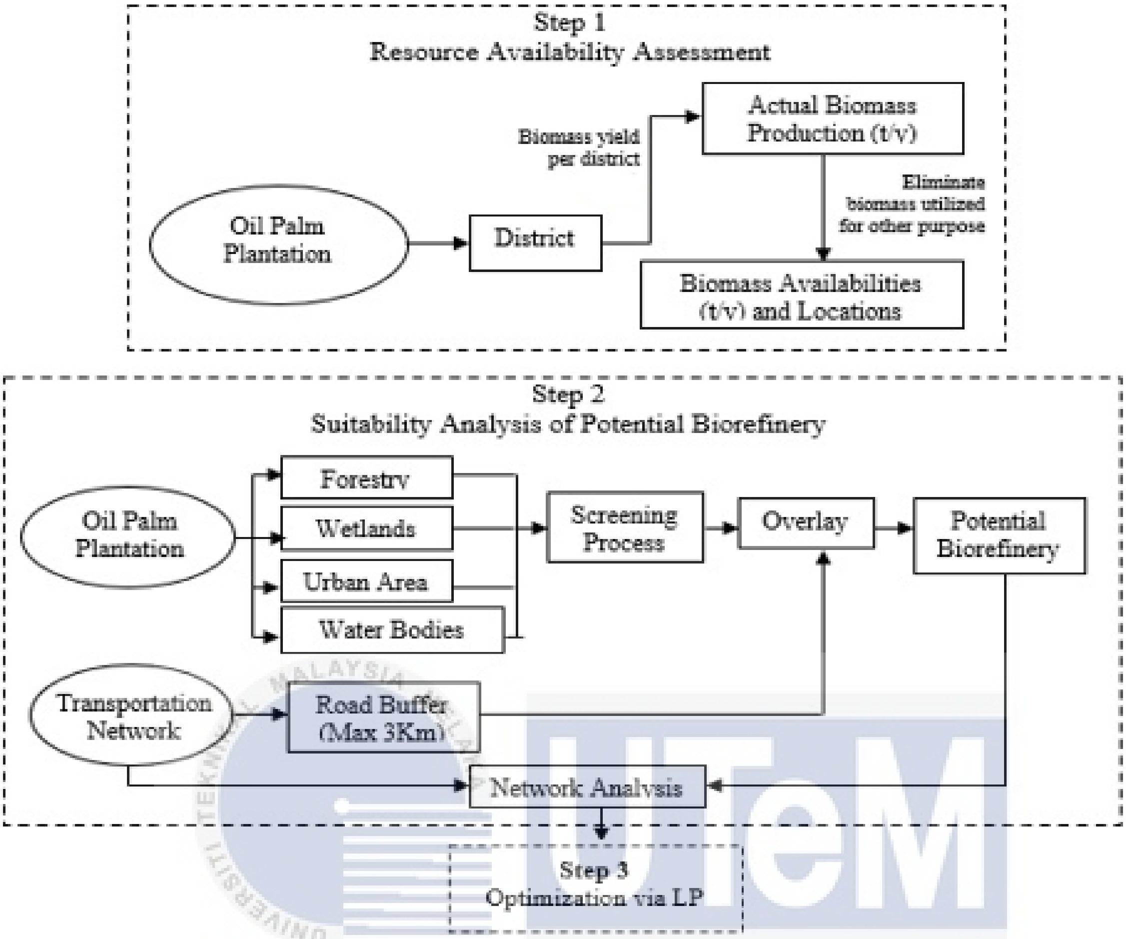

Figure 4. 1 GIS-based biomass resource assessment with spatial modelling approach

4.2.1 Resource Availability Estimations

Geo-information system (GIS) is essential in this study in order to determine the biomass availabilities and to identify the locations of oil palm plantation. This method is effective in assessing the resource potential locations of oil palm biomass supplier. Only OPF biomass is considered as the feedstock of biomass from the oil palm plantation in this study. The result from ArcGIS indicates that there are about 78 oil plantations in Johor Bahru. Each of the plantation can supply up to 7.5 t/ha of OPF.

4.2.2 Network analysis and transportation

In supply chain network, transportation always has been one of the important criteria in judging the economic performance of the system. Network analysis is carried out by considering comprehensive road transport networks in order to identify the ideal transport routes from each location to the respective destinations. Network analysis can estimate the number of the linear networks such as roads, railways, rivers and utilities. In this case, only transportation by roads will be used in the analysis of roadway transportation network. In this study, the distances from palm oil biomass supply (OPF) to the palm oil bio-refinery and finally to the Pengerang Integrated Complex are identified through network optimization by the implementation of GAMS simulation. These distances are inputted into the optimization model for the calculation of transportation cost. Figure 4.2 illustrates all of the possible network transportation by roads in Johor generated by using ArcGIS.

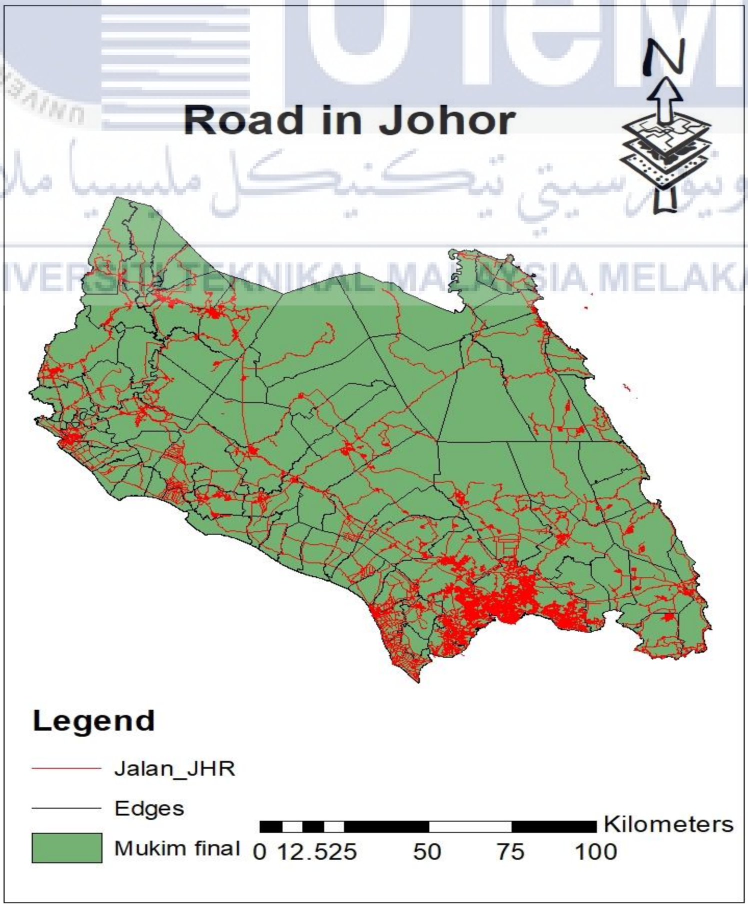

Figure 4. 2 Road map in Johor

4.2.3 Suitability Analysis of Potential Bio-Refinery Sites

The possible sites for centralized bio-refinery are determined by the spatial analysis methods of multiple parameters, which includes different land use and accessibility restrictions, to determine the optimum location. A series of screening processes is performed to identify the candidate of bio-refinery. First, the sensitive areas such as forest and reserves, wetlands, water bodies and urban areas from the land use map are eliminated. Next, the current screened map is now only overlaid with the transportation buffers. Sahoo (2016) indicates that facility location should be located at the maximum of 3 km away from road networks to ensure the connectivity and smooth traffics for the transportation of biomass.

The map is then assigned into district. The purpose of assigning the map into district is to create representative locations for later analysis. The districts that have been assigned may not have accurate information but rather generalised areas to represent the potential locations which will later be useful for network analysis purposes. After the spatial analysis of GIS had employed, there is about 78 potential locations are identified. Among these identified potential locations, a bio-refinery facility are to be built with the considerations of economic and environmental criteria through optimisation. Figure 4.3 below is the result generated by using ArcGIS.

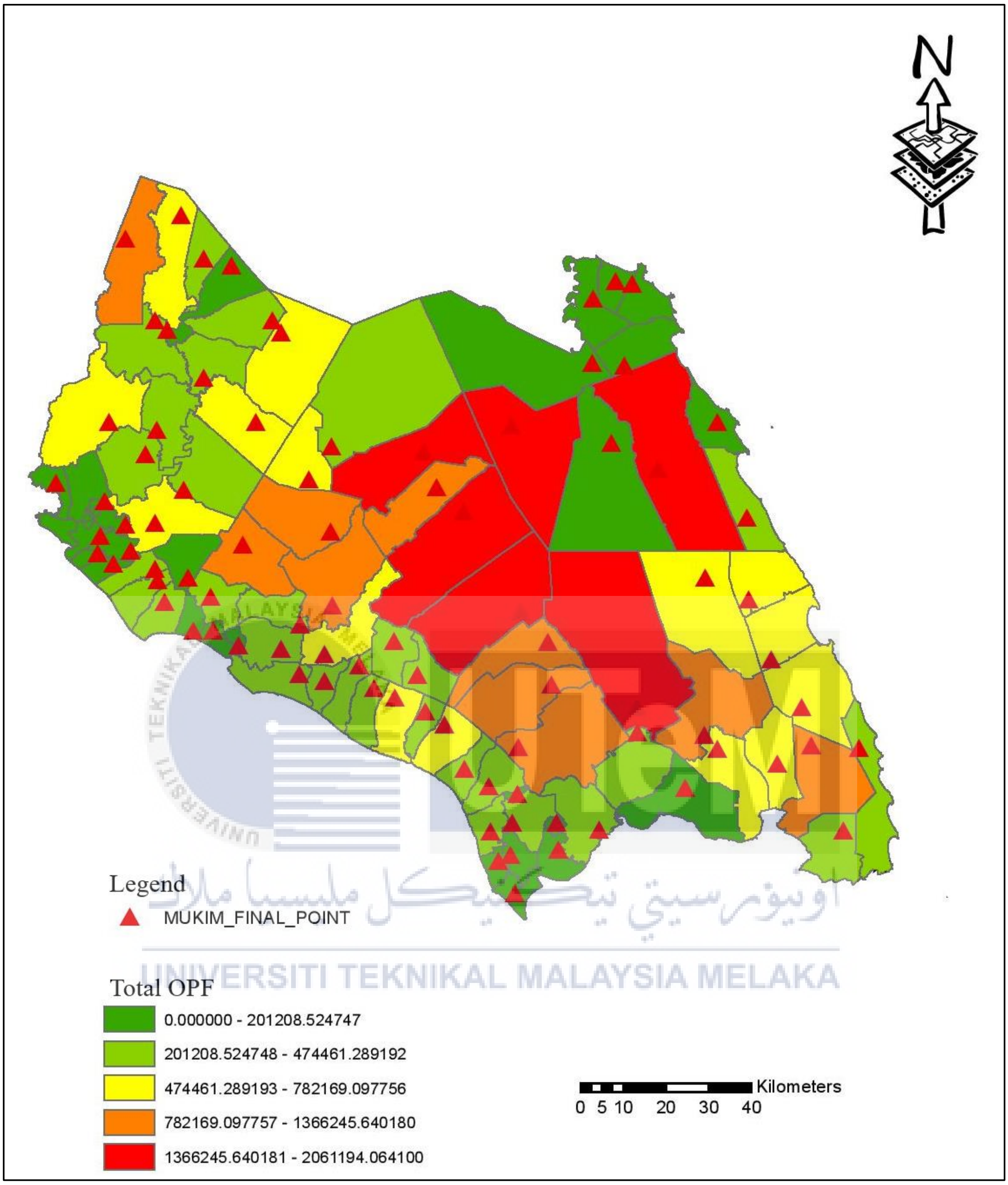

Figure 4. 3 Feedstock availability and potential location for bio-refinery in Johor

Based on the spatial analysis that is performed by using ArcGIS, the result indicates that there are about 78 potential locations suitable to set up the bio-refinery in Johor. The location, area of oil palm plantation, a total of biomass (OPF), and travel distance are included in Table 4.1. All of the information in the table below are generated by ArcGIS.

Table 4. 1 Potential locations of bio-refinery for this study

NO.	Location	Oil Palm Plantation Area (Hectare)	Total OPF Biomass (Tonne)	Travel Distance (Km)
1	Api Api	6826.14	51196.07	103.01
2	Ayer Baloi	11949.83	89623.72	106.23
3	Ayer Hitam	2825.18	21188.85	163.44
4	Ayer Masin	2817.43	21130.76	103.14
5	Bagan	3459.58	25946.86	155.62
6	Bandar	110.15	826.15	183.51
7	Benut	11497.68	86232.63	117.67
8	Bukit Serampang	9329.06	69967.95	194.80
9	Buloh Kasap	15465.49	115991.15	206.93
10	Chaah	14899.35	111745.12	156.67
11	Chaah Bahru	24274.91	182061.82	145.92
12	Gemereh	2.77	20.75	197.06
13	Gerisek	7462.90	55971.78	180.95
14	Jabi	3863.28	28974.60	209.90
15	Jalan Bakri	1728.78	12965.83	177.33
16	Jelutong	165.59	1241.95	82.02
17	Jemaluang	305.74	2293.01	109.55
18	Jementah	5967.66	44757.47	203.67
19	Jeram Batu	5248.67	39364.99	89.35
20	Johor Lama	14717.90	110384.25	37.31
21	Jorak	14595.08	109463.09	169.79
22	Kahang	37569.58	281771.85	135.30
23	Kampung Baharu	6407.61	48057.11	136.44

24	Kluang	43393.56	325451.69	120.21
25	Kota Tinggi	19969.27	149769.53	54.14
26	Kundang	1662.96	12472.18	194.09
27	Labis	16466.72	123500.38	176.02
28	Layang-Layang	21477.15	161078.62	106.84
29	Lenga	6987.94	52409.52	177.35
30	Linau	9216.71	69125.33	145.91
31	Lubok	2236.71	16775.36	159.85
32	Machap	7513.08	56348.12	118.81
33	Mersing	39261.97	294464.81	102.52
34	Minyak Beku	9752.10	73140.75	142.47
35	Niyor	23837.35	178780.10	130.49
36	Pagoh	8346.31	62597.31	189.77
37	Paloh	38467.36	288505.21	137.15
38	Pantai Timor	8999.11	67493.31	27.00
39	Parit Bakar	668.85	5016.41	181.51
40	Parit Jawa	4942.50	37068.77	174.65
41	Pengkalan Raja	857.92	6434.37	91.85
42	Penyabong	435.34	3265.06	126.84
43	Peserai	1748.90	13116.77	150.79
44	Plentong	3453.21	25899.09	56.68
45	Pontian	9988.66	74914.94	98.95
46	Pulai	5696.55	42724.16	76.57
47	Renggam	40188.09	301410.71	106.27
48	Rimba Terjun	6102.18	45766.34	97.68
49	Sedenak	26166.58	196249.34	93.97
50	Sedili Besar	11002.57	82519.29	68.91
51	Sedili Kechil	15838.72	118790.40	36.20
52	Sembrong	2938.82	22041.13	159.71
53	Senai Kulai	26164.53	196233.94	80.55
54	Serkat	3185.60	23892.03	109.16
55	Sermin	7826.79	58700.92	206.28
56	Serom	2791.25	20934.39	185.23

57	Simpang Kanan	6276.45	47073.41	144.39
58	Simpang Kiri	9705.96	72794.67	159.47
59	Sri Gading	15462.53	115968.95	129.16
60	Sri Menanti	6711.06	50332.97	175.43
61	Sungai Balang	6908.97	51817.28	165.48
62	Sungai Karang	2718.19	20386.43	100.78
63	Sungai Kluang	8096.28	60722.09	122.38
64	Sungai Pinggan	6175.47	46316.04	112.22
65	Sungai Punggor	7888.04	59160.31	126.02
66	Sungai Raya	2036.64	15274.82	179.92
67	Sungai Segamat	5879.26	44094.42	186.72
68	Sungai Terap	445.13	3338.45	184.14
69	Sungai Tiram	12234.73	91760.50	46.58
70	Tangkak	12965.30	97239.71	200.02
71	Tanjung Kupang	1829.82	13723.64	84.77
72	Tanjung Semberong	28763.07	215723.00	132.18
73	Tebrau	9244.23	69331.73	66.03
74	Tenggaron	9134.27	68507.02	117.79
75	Teriang	2987.24	22404.28	133.30
76	Ulu Benut	8832.74	66245.56	109.42
77	Ulu Sungai Johor	40695.00	305212.47	86.60
78	Ulu Sungai Sedili Besar	15763.01	118222.57	76.68

The location for potential facilities for bio-refinery will be narrowed down to several locations by satisfying the capacity constraint at bio-refinery. Then, the shortlisted potential location will be selected by using AHP method so that the most suitable location to set up bio-refinery can be determined. Among the shortlisted potential locations, only one place is chosen to set up bio-refinery to supply the butanol to the demand centre.

4.3 Model Formulation

A spatial biomass supply chain optimization model need to consider several important parameters such as economic, environmental and technical in order to achieve the least cost supply chain of green diesel. The parameters will be used to determine the most efficient path for the supply chain in order to obtain least overall cost of supply chain and least emissions of the supply chain system. All the economic, environment and technical parameters that are used in this study are compiled in Table 4.2. All of these parameters are inputted in GAMS software to run optimization for biofuel supply chain.

Table 4. 2 Technoeconomic analysis

PARAMETER	UNIT	VALUE	REFERENCES
ECONOMIC PARAMETER			
CAPEX (Biorefinery)	USD	21 251 620	Adapted from Baral & Ajay (2016)
OPEX (Biorefinery)	USD/y	7 630 450	Adapted from Baral & Ajay (2016)
Transportation (Truck)	USD/t.km	0.20	Lam et al. (2013)
Transportation (Oil Tanker)	USD/L.km	0.15	Kang et al. (2009)
Biomass (OPT)	USD/t	15.00	Ahmad et al. (2016)
Biomass (OPF)	USD/t	9.00	Gabdo & Abdlatif (2013)
Cultivation and harvesting cost (OPT)	USD/t	10.00	Zahari et al. (2015)
Cultivation and harvesting cost (OPF)	USD/t	10.00	Zahari et al. (2015)
ENVIRONMENTAL PARAMETER			
Emissions (Truck)	tCO_2/t.km	0.000595	Paolucci et al. (2016)
Emissions (Oil Tanker)	tCO_2/L.km	0.00015	Syafiie et al. (2016)
Emissions (Cultivation (OPF))	tCO_2/t	0.1055	Rivera-Mendez et al. (2017); Loh (2017)
Emissions (Harvesting (OPF))	tCO_2/t	0.0222	Rivera-Mendez et al. (2017); Loh (2017)

TECHNICAL PARAMETER			
Diesel Demand	L/y	9,253,000	Aimi Hazwanie (2018)
Bio-butanol Demands (10% of Diesel Demand)	L/y	925,300	Aimi Hazwanie (2018)
Capital Recovery Factor		R= 7% N= 20 years Crf=0.09439	Vlysidis et al. (2011)
Biorefinery Capacity	t/y	1 017 830	This Study
Conversion Factor of Emissions	tCO2/t.biofuel	0.58	Syafiie et al. (2016)

4.3.1 Material Balance

In this study, set i represents the oil palm plantation location which is the supplier of OPF biomass, set j represents the bio-refinery location where the conversion process of OPF biomass into bio-butanol takes place and set k represents Pengerang Integrated Complex as the demand center of butanol. Next, ($Fbiomass_{i,j}$) denotes as the flowrates from biomass supply to bio-refinery. ($Fbutanol_{j,k}$) denotes as the flowrates of butanol from bio-refinery to the demand center that is Pengerang Integrated Complex.

Raw biomass to be supplied to the bio-refinery and the butanol to be supplied to the demand center are governed by the respective availabilities constraints (A_i and demandPIC). The availabilities are described as followed:

BIOMASS AVAILABILITY CONSTRAINT

$$Availability_i \geq \sum_j Fbiomass_{i,j} \qquad \forall\ i \qquad (1)$$

DEMAND CONSTRAINT AT DEMAND CENTRE

$$\sum_j Fbutanol_{j,k} \geq demandPIC \qquad \forall\ k \qquad (2)$$

The total production capacity of butanol from OPF biomass at bio-refinery can be defined as:

BIOREFINERY CAPACITY CONSTRAINT

$$Cap \times Capunit_j \quad = \quad \sum_k Fbutanol_{j,k} \qquad \forall\ j \qquad (3)$$

CONVERSION CONSTRAINT

The conversion of OPF biomass to butanol can be described as:

$$\sum_i Fbiomass_{i,j} \times Ccf \quad = \quad \sum_k Fbutanol_{j,k} \qquad \forall i,j \qquad (4)$$

4.3.2 Economics

The first objective function of this model is to achieve the optimum cost of green diesel supply chain by minimizing the total cost (C^{total}) of the system. There are four elements that are being considered in order to reduce the total cost. The elements are cost of OPF biomass (C^{OPF}), the cost of transportation to transport the biomass from plantation to the bio-refinery and from bio-refinery to Pengerang Integrated Complex (C^{transp}), the capital expenditure or CAPEX for bio-refinery (C^{capex}) and the last one is the operating expenditure or OPEX of bio-refinery (C^{opex}). The equation for minimization of total cost is written as:

$$Min\ C^{total} = C^{OPF} + C^{transp} + C^{Capex} + C^{Opex} \qquad (5)$$

OPF biomass cost (C^{OPF}) is interpreted by the multiplication between the flowrates of biomass ($Fbiomass_{i,j}$) and the price of OPF biomass (P^{OPF}). This is written as:

$$C^{OPF} \quad = \sum_{i,j}(Fbiomass_{i,j} \times C_{copf}) \qquad (6)$$

Next, the cost of transportation (C^{transp}) is calculated by multiplying the flowrate of biomass ($Fbiomass_{i,j}$), flowrates of bio-alcohol ($Fbutanol_{j,k}$) with the respective transportation distances (($Dist_{i,j}$) and ($Dist_{j,k}$)) and respective transportation prices (P^{truck} and ($P^{oil\ tanker}$). This can be defined as:

$$C^{transp} = \sum_{i,j}(Fbiomass_{i,j} \times C_{truck} \times Dist_{i,j}) + \sum_{j,k}(Fbutanol_{j,k} \times C_{tanker} \times Dist_{j,k}) \quad (7)$$

The capital expenditure or CAPEX in this model can be regarded as the investment to set up a new bio-refinery. (C^{capex}) is calculated by multiplying the total CAPEX of bio-refinery (T_{capex}), with the capacity unit of machine that is used to produce bio-alcohol ($CapUnit_j$). So, (C^{capex}) can be described as:

$$C^{capex} = \sum_j(T_{capex} \times CapUnit_j) \quad (8)$$

The operating expenditure or OPEX is considered as the cost that is used for operation of the bio-refinery. The flowrate of butanol ($Fbutanol_{j,k}$) times with the total OPEX of bio-refinery (T_{opex}). So, it can be written as:

$$C^{opex} = \sum_j(Fbutanol_{j,k} \times T_{opex}) \quad (9)$$

4.3.3 Environments

The second objective function of this model is about environmental. Generally this objective function is to mitigate the total emission of the system (E^{total}). The emissions are resulted from the emissions of OPF biomass cultivation (E^{cultiv}), the emission from harvesting of OPF biomass ($E^{harvest}$), OPF biomass and bio-butanol transportation (E^{transp}) and last but not least from the technological emissions ($E^{technology}$). The minimization of total emissions can be represented as:

$$Min\ E^{total} = E^{cultiv} + E^{harvest} + E^{transp} + E^{technology} \quad (10)$$

The emission from cultivation of OPF biomass (E^{cultiv}) and the emission from harvesting of OPF biomass ($E^{harvest}$) is calculated by multiplying the respective emission factors with the biomass flowrate ($Fbiomass_{i,j}$). The two equations can be defined as:

$$E^{cultiv} = \sum_{i,j}(Ebiomass_{i,j} \times E_{copf}) \quad (11)$$

$$E^{harvest} = \sum_{i,j}(Ebiomass_{i,j} \times E_{hopf}) \quad (12)$$

There are two means of transportation involve in this supply chain system that are the truck and the oil tanker. So, the transportation activity (E^{transp}) are described as the emissions from the truck (E^{truck}) and the oil tanker ($E^{oil\ tanker}$).

$$E^{transp} = E^{truck} + E^{oil\ tanker} \quad (13)$$

$$E^{truck} = \sum_{i,j}(Ebiomass_{i,j} \times E_{truck} \times Dist_{i,j}) \quad (14)$$

$$E^{oil\ tanker} = \sum_{j,k}(Ebutanol_{j,k} \times E_{tanker} \times Dist_{j,k}) \quad (15)$$

The technological emissions ($E^{technology}$) for the production of bio-alcohol is the flowrate of alcohol multiply with the emission factor of biomass to (E_{cf}).

$$E^{technology} = \sum_{j,k}(Ebutanol_{j,k} \times E_{cf}) \quad (16)$$

4.4 Results and Discussions

4.4.1 Spatial Optimization of Oil Palm Biomass

Spatial optimisation model developed is applied to a case study in Johor in order to obtain the least total cost and the least emissions of biofuel supply chain system. In this study, only one bio-refinery will be set up because it is more economical in term of cost compared to set up multiple bio-refineries in one state. The bio-refinery will be set up at one of the plantations. Table 4.3 and Table 4.4 shows result of optimization that is performed by using GAMS software. These locations are shortlisted by GAMS based on the capacity of bio-refinery. The capacity of bio-refinery are 1017830 t/year and the OPF supply in total are

1044152.314 t/year. So, the biomass supply is greater than demand of bio-refinery. Hence the capacity constraint of bio-refinery is satisfied. Figure 4.4 and Figure 4.5 portray the logistic cost and GHG emission for each location.

Table 4. 3 Optimization Result

Plantation (*i*)	Demand Centre (*k*)	Distance (*i* to *k*) (Km)	Logistic Cost from (*i* to *k*) (Million USD/year)	Biomass Availability (OPF) (Tonne)
Pantai Timor	Pengerang	27.00	9.00	67493.31
Sedili Kechil	Pengerang	36.20	14.40	118790.40
Johor Lama	Pengerang	37.31	14.60	110384.24
Sungai Tiram	Pengerang	46.58	16.20	91760.49
Kota Tinggi	Pengerang	54.14	17.80	149769.53
Sedili Besar	Pengerang	68.91	20.78	82519.28
Ulu Sungai Sedili Besar	Pengerang	76.68	22.73	118222.57
Ulu Sungai Johor	Pengerang	86.60	24.52	305212.46
	Total OPF Biomass			1044152.28

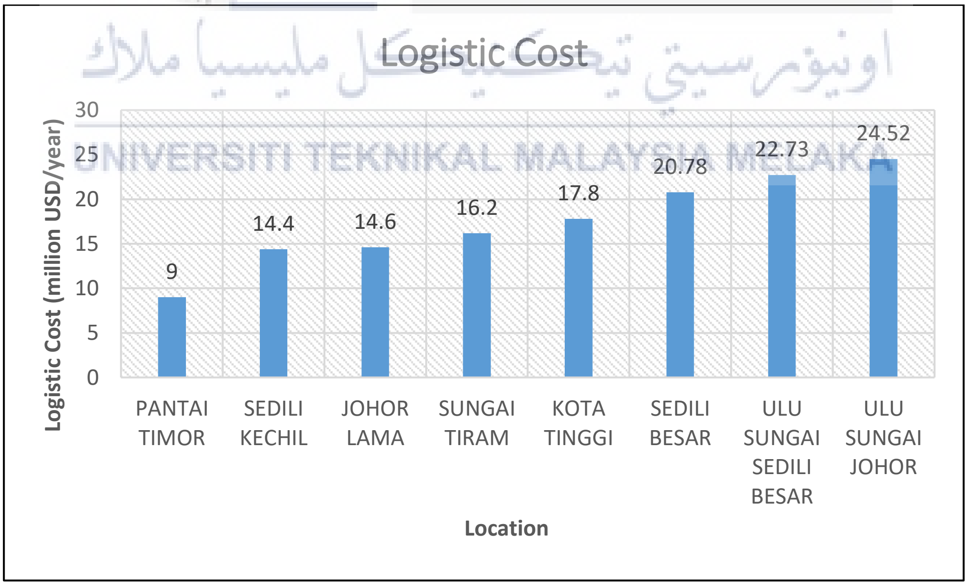

Figure 4. 4 Logistic Cost

Table 4. 4 Optimization Result for Green House Gas Emission

Plantation (*i*)	Demand Centre (*k*)	Distance (*i* to *k*)	GHG Emission (*i* to *k*) (t.CO_2/year)
Pantai Timor	Pengerang	27.00	0.128
Sedili Kechil	Pengerang	36.20	0.144
Johor Lama	Pengerang	37.31	0.144
Sungai Tiram	Pengerang	46.58	0.149
Kota Tinggi	Pengerang	54.14	0.154
Sedili Besar	Pengerang	68.91	0.163
Ulu Sungai Sedili Besar	Pengerang	76.68	0.161
Ulu Sungai Johor	Pengerang	86.60	0.167

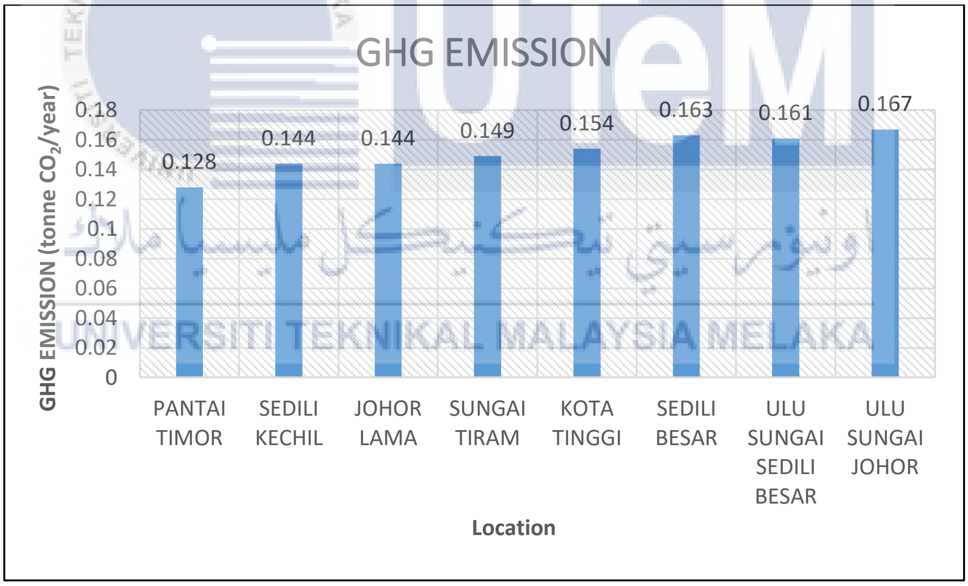

Figure 4. 5 Green House Gas (GHG) emission

In the cost and emission scenario above, Pantai Timor is the best candidate as the location to set up bio-refinery. Based on the result obtained from GAMS, Pantai Timor has the upper hand in this situation as the logistic cost, 9 million USD/year and the GHG emission, 0.1280 t.CO_2/year which is the least compared to other locations.

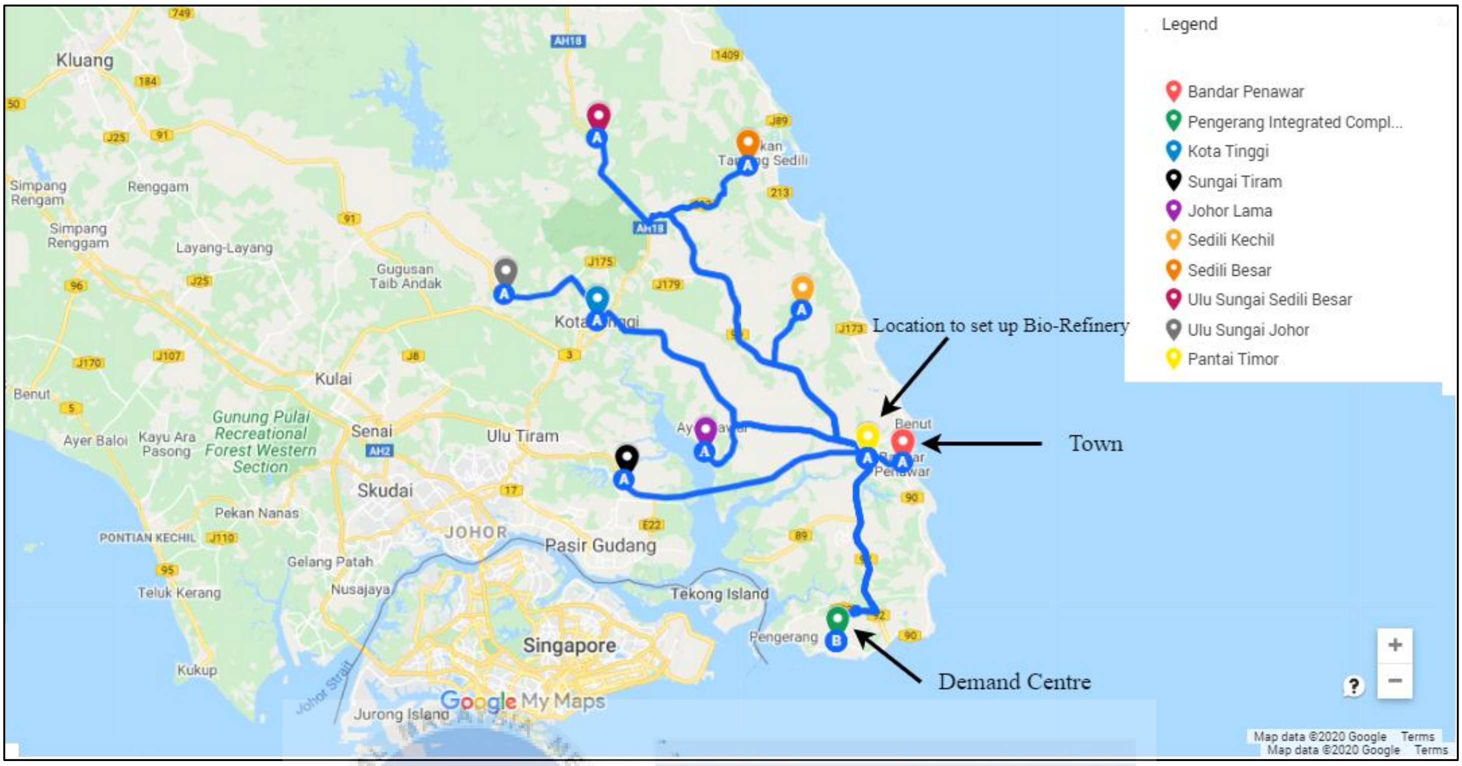

Figure 4. 6 Supply Chain of Biofuel in Johor

Figure 4.6 above is generated by using Google Map. The figure above is to give a clear view about the flow of this biofuel supply chain. Based on Figure 4.6 above, Pengerang Integrated Complex which is the demand centre that located in south Johor. Pantai Timor can be considered as a strategic place to set up bio-refinery since the place located at the center. After the OPF feedstock had been collected from other plantations, the feedstock will undergo conversion process at Pantai Timor. In addition, Pantai Timor also is located near to the town that is Bandar Penawar. So, this factor contributes an added value to Pantai Timor because new bio-refinery needs manpower to operate the facility.

4.4.2 Analytical Hierarchy Process

The determination of bio-refinery in this supply chain model also is tested through analytical hierarchy process by using Expert Choice software. Several criteria are being considered in determining the suitable place among the shortlisted locations. The criteria that are being considered including logistic cost, distance from plantation to demand centre, feedstock availability at plantation, social measures within the location radius, and the emission of CO_2 from plantation to demand centre. Figure 4.7 below shows the criteria that inputted in Expert Choice.

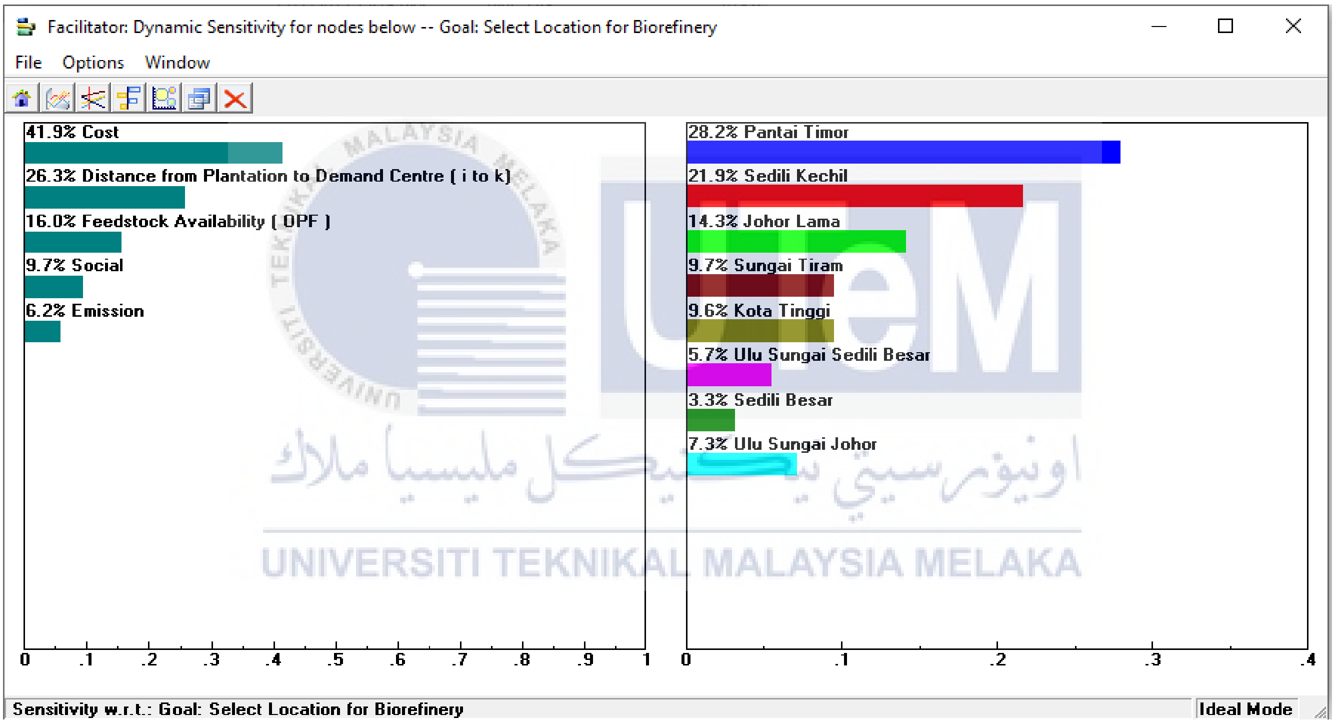

Figure 4. 7 Dynamic sensitivity

Based on Figure 4.7, Pantai Timor is leading as the location set up bio-refinery compared to other alternatives. Each criteria has its own numerical weight that influences in assessing the objective. In the left box, cost criteria has the highest percentage with 41.9% and emission criteria has the least percentage with 6.2%. Cost criteria represents the logistic cost of each alternative. So, the location with the least logistic cost will has the advantage to be selected as the candidate. Next, the distance criteria refers to the distance of each location to the demand centre. Feedstock availability criteria is based on the OPF biomass that can be supplied by each plantation. Social economy criteria is evaluated based on the socioeconomic behaves within a society. For example, the location that is nearest to the town is likely to be chosen since the bio-refinery needs manpower in order to be operated. Lastly is the emission criteria. Emission criteria depends on the amount of CO_2 emission. In overall, “Cost” and “Distance” are the two relatively important criteria under the performance assessment area. This provides insight into what criteria are most important to the selection of potential biorefinery in Johor. The results have important implications for the biofuel supply chain that this study place more emphasis on those criteria and Pantai Timor was selected as the potential biorefinery among those 8 possible locations.

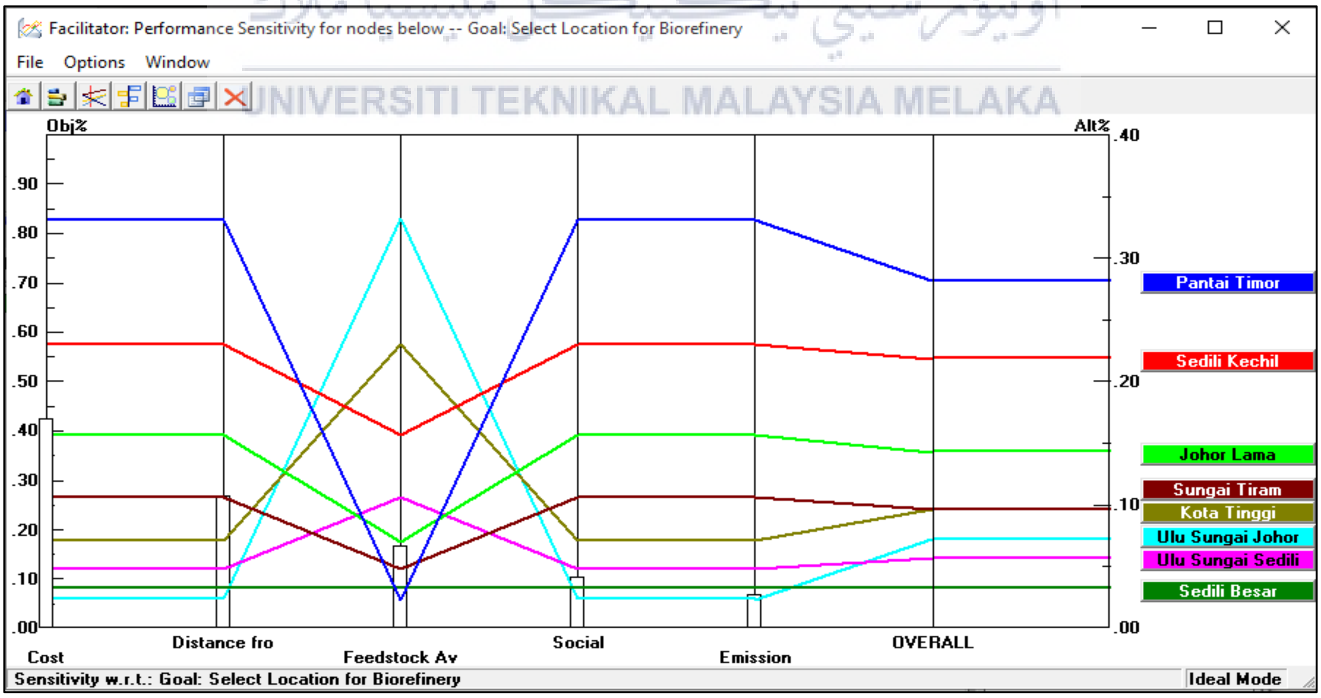

Figure 4. 8 Perfomance sensitivity

This spatial optimization model also is tested in term of performance view. Figure 4.8 above displays the performance of each criteria for each location. Pantai Timor top all of the criteria except the feedstock availability. Based on the evaluation of each criteria, this proves that Pantai Timor is the ideal location to set up bio-refinery. Figure 4.9 below shows the ranking of the potential location.

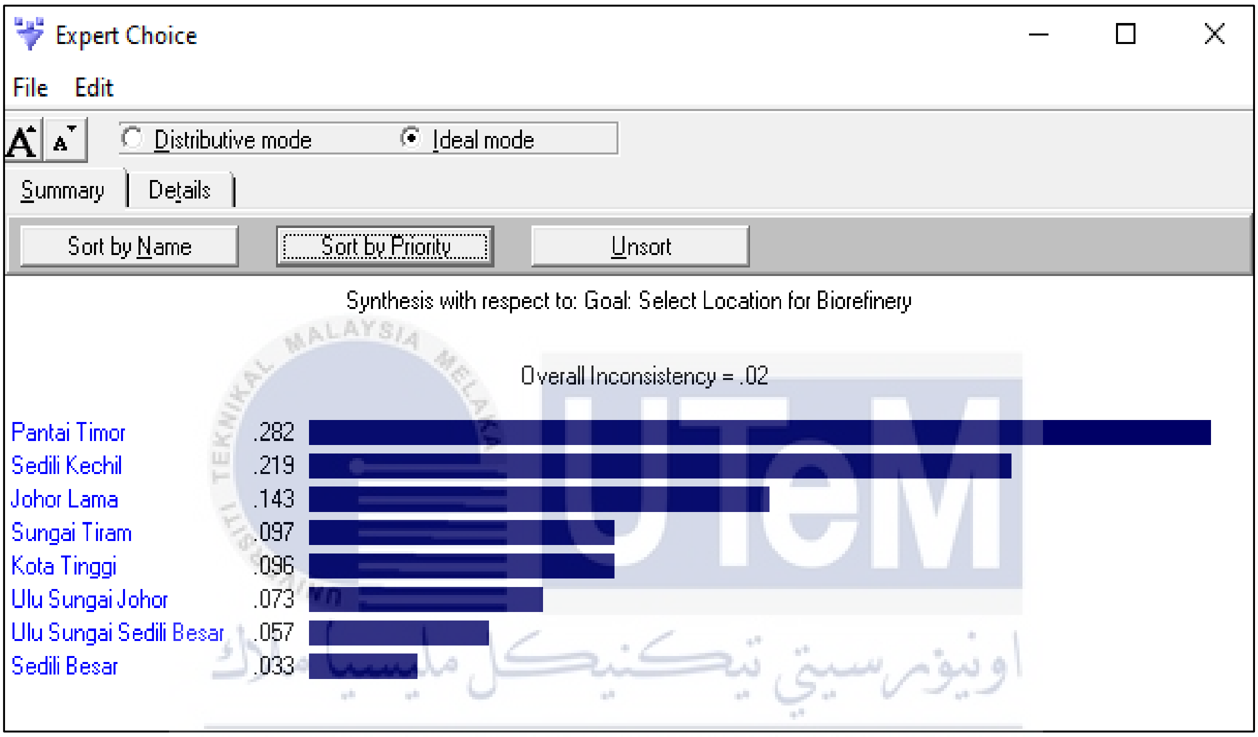

Figure 4. 9 Ranking of potential location to set up bio-refinery

4.4.3 Preliminary Conclusion

Table 4. 5 Overall result biofuel supply chain

Biorefinery (j)	Demand Centre (k)	Total Supply Chain Cost (million USD/year)	Total GHG Emission ($t.CO_2$/year)
Pantai Timor	Pengerang	11.24	0.128

A spatial optimization model has been developed successfully to evaluate the most optimal biofuel supply chain system in term of economic and environmental performance. This indicates that the location factor has a substantial impact on the economic and environmental performance of a supply chain system. As shown in Table 4.5, the result from GAMS shows that the total cost for overall supply chain is 11.24 million USD/year while the total GHG emission is about 0.128 $t.CO_2$/year. Figure 4.9 below visualizes the optimal biofuel supply chain for this study.

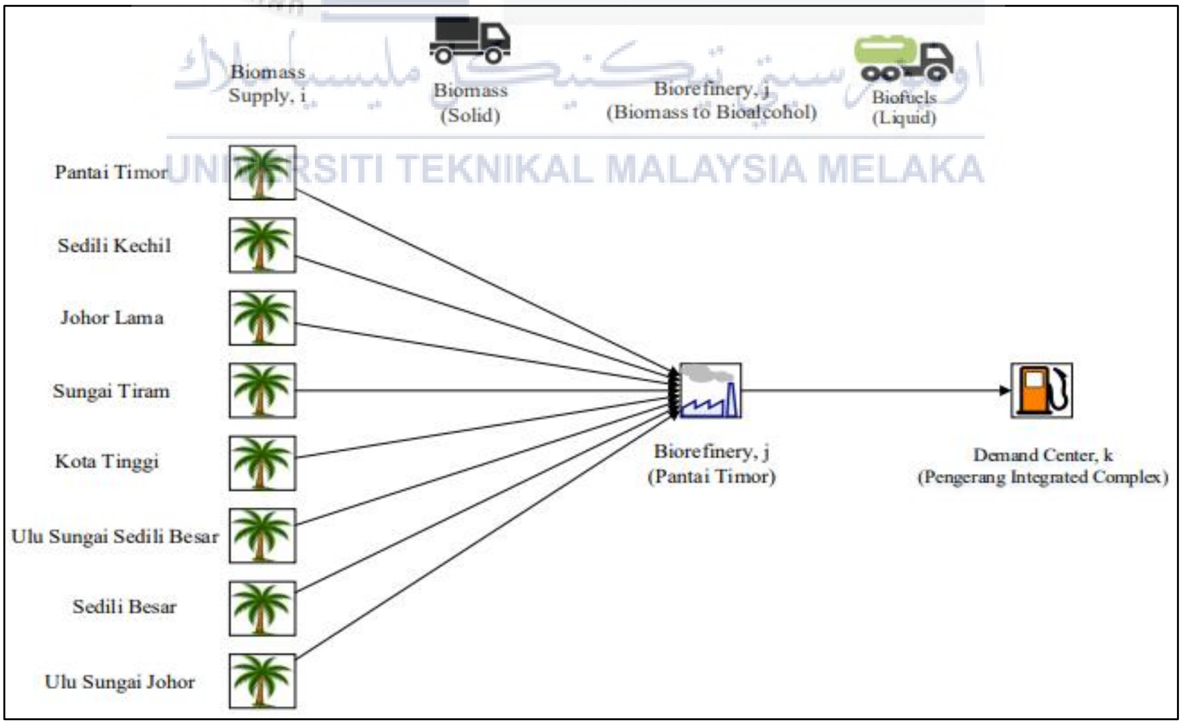

Figure 4. 10 Superstructure of Optimal Biofuel Supply Chain

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Introduction

This chapter presents the conclusion of this study about the optimization of supply chain model that integrates comprehensive spatial modeling techniques with the strategic biofuels supply chain network design. Detailed regarding the conclusions and future works are described in the following section.

5.2 Conclusion

In this study, the optimization for the design of biofuel supply chain is done. Simulation software such as ArcGIS and GAMS are implemented to identify the most optimal supply chain network. This general modelling framework incorporated the mathematical optimization programming that is linear programming and AHP method. Multi-objective optimization of cost and emission of biofuel supply is performed to achieve a more sustainable design. Linear programming model is developed to determine the optimal feedstock supplies, bio-refinery capacity, and location of bio-refineries. Specifically, this study demonstrated the framework for supply chain of biofuel in Johor. The minimum value for cost and emission of supply chain can be obtained through the selection and combination of supply chain configurations. Based on the findings of this study, there are about 8 locations of plantations for OPF biomass supplies. The 8 plantations can supply up to 1044152.28 t.OPF/year. Next, the production capacity at bio-refinery is about 1017830 litres of Butanol per year. Demand at Pengerang Integrated complex are 925,300 litres of Butanol per year. The result of optimization of supply chain model indicates that Pantai Timor is the ideal location to set up bio-refinery. In overall, all of the objectives in this study are achieved. The first objective to develop a GIS-AHP optimization framework of oil palm biomass to biofuel production via Linear Programming (LP). The second objective is to a strategic optimal network design of oil palm biomass to biofuel including the resources availability assessment, optimal biorefinery localization, transportation network analysis and optimization (GAMS, AHP & ArcGIS).

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5.3 Future Works

The introduction of biofuels blends in the transport sector will be more imminent in the future. So, sufficient planning must be made to ensure efficient supply chain management. Over-pressure for the introduction of biofuels blends (butanol) would only backfire without the help of the requisite hard and soft infrastructure. However, there should be scope for change in the future, such as;

i. Further studies on the biofuel supply chain model are required, such as consideration of additional supply chain constraints and parameters. For example, the model of geographical information, weather, and seasonal resources are some of the main factors in the management of the supply chain

ii. Key element identification for biomass technology is also important to ensure that all the characteristics of the biomass element are considered. Experimental research on the range of element acceptance for the respective biomass technologies is important to ensure consistency in process efficiency. This opens up a new direction for researchers to further study the relationship between the characteristics of the biomass element with respect to the process efficiency of each biomass technology.

iii. Enhance the model by taking into account a centralized and decentralized approach, consideration of the storage point, and scheduling. This will create a more stable model to be applied in the real-life situations of the industry.

iv. Consideration of uncertainties in the availability and quality of resources, logistical issues, process disruption, and market fluctuations. There is no doubt that the biomass industry is always in a dynamic state with many unforeseen scenarios. Thus, the optimization model can be improved to handle these unexpected variations and to provide a better decision-making tool.

5.4 Gantt Chart

This Gantt chart presents a graphical overview of timetable that helps to organize and monitor specific tasks in the final year project 1 and final year project 2. The horizontal axis of this chart represents the total time frame of this project in week and the vertical axis of this chart represents the tasks of the project. The bars are darkened to indicate the completion of sections of tasks.

Table 5. 1 Gantt Chart for FYP

Gantt Chart for Final Year Project 1																			
Project Activity	Week																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Project and title selection	Final Year Project Briefing							Mid-Semester Break								Study Week	Final Examination		Semester Break
Study on the research gap about the supply chain of oil palm biomass and optimization method																			
Chapter 1: Introduction																			
Submission of Progress Report I																			
Chapter 2: Literature Review																			
Chapter 3: Methodology																			
Developing K-Chart and process flow chart																			
Construct superstructure and formulate mathematical modelling																			
Spatial analysis by using ArcGIS																			
Optimization of modelling by using AIMMS																			
Submission of FYP I report																			
Preparation of presentation slide																			
FYP I SEMINAR: Presentation																			

Gantt Chart for Final Year Project 2																			
Project Activity	Week																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Improvement on Literature Review	Final Year Project Briefing							Mid-Semester Break								Study Week	Final Examination		Semester Break
Improvement on Methodology																			
Developing Coding by using GAMS - Cost Optimization Model																			
Developing Coding by using GAMS - Emissions Optimization Model																			
Extract Output of the results for Cost and Emission Optimization Model																			
Chapter 4 – Results and Discussions																			
Submission of Progress Report 2																			
Improvement on Results and Discussions																			
Conclusion																			
Submission of PSM 2 Report																			
Preparation for Online Presentation																			
PSM 2 Seminar																			

APPENDIX

COST OPTIMIZATION CODING

```
Sets
i           'Oil Palm Plantation (Supply)

' /ApiApi, AyerBaloi, AyerHitam, AyerMasin, Bagan, Bandar, Benut
,BukitSerampang, BulohKasap, Chaah, ChaahBahru, Gemereh, Gerisek
,Jabi, JalanBakri, Jelutong, Jemaluang, Jementah, JeramBatu
,JohorLama, Jorak, Kahang, KampungBaharu, Kluang, KotaTinggi
,Kundang, Labis, Layang-Layang, Lenga, Linau, Lubok, Machap
,Mersing, MinyakBeku, Niyor, Pagoh, Paloh, PantaiTimor, ParitBakar
,ParitJawa,  PengkalanRaja, Penyabong, Peserai, Plentong
,Pontian, Pulai, Renggam, RimbaTerjun, Sedenak, SediliBesar
,SediliKechil, Sembrong, SenaiKulai, Serkat, Sermin, Serom
,SimpangKanan, SimpangKiri, SriGading, SriMenanti, SungaiBalang
,SungaiKarang, SungaiKluang, SungaiPinggan, SungaiPunggor
,SungaiRaya, SungaiSegamat, SungaiTerap, SungaiTiram, Tangkak
,TanjungKupang, TanjungSemberong,  Tebrau, Tenggaron, Teriang
,UluBenut, UluSungaiJohor, UluSungaiSediliBesar/   // 78 plantations

j           'Potential Biorefinery (Process)      ' / PantaiTimor /
k            'Pengerang Integrated Complex (Demand) ' / Pengerang   /  ;

Free variable
Ctotal       'Total cost of biobutanol supply chain (Liters per year)' ;
```

```
Positive variable

Fbiomass(i,j)   'Flowrate of biomass OPF from oil palm plantation ith to biorefinery jth (ton per year)'

Fbutanol(j,k)   'Flowrate of biomass OPF from biorefinery jth to demand kth (Liters per year)         '
;

Integer variable

CapUnit(j)      'unit of production area in biorefinery plant' ;       // No unit


Scalar

Crf          'Capital recovery factor                                              '

m            'Correlation exponent                                                  '  / 0.8   /

r            'Interest rate for capital recovery factor                             '  / 0.07   /

n            'Plant lifetime for capital recovery factor (years)                    '  / 20    /

Ccf          'Conversion factor of biomass OPF to biobutanol (Liters per ton)        '  / 588.54 /

Ecf          'Conversion emission factor of biomass OPF to biobutanol (ton CO2 per ton) '  / 0.58   /


Parameters

demandbio      'Demand biomass OPF in biorefinery jth (Ton per year)             '

Tcapex         'Total Capital expenditure (USD per L)                            '

Topex          'Total Operating expenditure (USD per L)                          '

Tbiomass       'Total biomass of BestCost                                        '

Bestc          'Lowest cost from oil palm plantation ith to biorefinery jth      '

Bestd          'Lowest distance from oil palm plantation ith to biorefinery jth  '

Best5c(i,j)    'Best 5 -> Cost combinations                                      '

Best5a(i,j)    'Biomass availability from Best5c                                 '

Copf           'Price of biomass OPF (USD per ton)                               '  / 9 /

Ctruck         'Price of truck for biomass OPF transportation (USD per ton.km)   '  / 0.2/

Ctanker        'Price of oil tanker for biobutanol transportation (USD per L.km) '  / 0.15/

Ccapex         'Capital expenditure (USD)                                        '  / 21251620  /

Copex          'Operating expenditure (USD per year)                             '  / 7630450 /

Cap            'Biorefinery production capacity of biobutanol (L per year)       '  / 1017830 /

demandPIC      'Total biobutanol demand in Pengerang , Malaysia (L per year)  '  / 925300 / ;
```

```
Crf       = [r*power((1+r),n)] / [power((1+r),n) -1] ;
Tcapex    = (Crf*Ccapex) / Cap                    ;
Topex     = Copex / Cap                           ;
demandbio = demandPIC / Ccf                       ;
Display Crf, Tcapex, Topex, demandbio ;

Parameter A(i)        'Biomass availability (OPF) in palm oil plantation itj (ton per year)' /
ApiApi           51196.07434
AyerBaloi        89623.71593
AyerHitam        21188.84641
AyerMasin        21130.75625
Bagan            25946.8574
Bandar           826.1482005
Benut            86232.62505
BukitSerampang   69967.94841
BulohKasap       115991.1504
Chaah            111745.1186
ChaahBahru       182061.8191
Gemereh          20.75226053
Gerisek          55971.77971
Jabi             28974.60355
JalanBakri       12965.83292
Jelutong         1241.948944
Jemaluang        2293.013462
Jementah         44757.46596
JeramBatu        39364.99446
JohorLama        110384.2472
Jorak            109463.0864
Kahang           281771.8456
Kluang           325451.6943
KotaTinggi       149769.5326
```

Kundang	12472.18161
Labis	123500.3839
Layang-Layang	161078.6179
Lenga	52409.52212
Linau	69125.32696
Lubok	16775.35705
Machap	56348.12368
Mersing	294464.8108
MinyakBeku	73140.74914
Niyor	178780.1034
Pagoh	62597.30506
Paloh	288505.2121
PantaiTimor	67493.31239
ParitBakar	5016.406888
ParitJawa	37068.77441
PengkalanRaja	6434.365481
Penyabong	3265.058264
Peserai	13116.77184
Plentong	25899.08503
Pontian	74914.9404
Pulai	42724.15899
Renggam	301410.712
RimbaTerjun	45766.33751
Sedenak	196249.342
SediliBesar	82519.28538
SediliKechil	118790.4023
Sembrong	22041.13358
SenaiKulai	196233.9378
Serkat	23892.03276
Sermin	58700.91524
Serom	20934.38888

SimpangKanan 47073.40837

SimpangKiri 72794.67062

SriGading 115968.9534

SriMenanti 50332.97163

SungaiBalang 51817.27605

SungaiKarang 20386.43343

SungaiKluang 60722.09254

SungaiPinggan 46316.03831

SungaiPunggor 59160.3109

SungaiRaya 15274.82376

SungaiSegamat 44094.42202

SungaiTerap 3338.45109

SungaiTiram 91760.49658

Tangkak 97239.71435

TanjungKupang 13723.63725

TanjungSemberong 215722.9958

Tebrau 69331.7291

Tenggaron 68507.02001

Teriang 22404.28399

UluBenut 66245.55757

UluSungaiJohor 305212.4651

UluSungaiSediliBesar 118222.5721 / ;

Table dist(i,j) 'Distance from supply ith to biorefinery jth (km)'

PantaiTimor

ApiApi 103.0120986

AyerBaloi 106.2263906

AyerHitam 163.4421609

AyerMasin 103.1392574

Bagan 155.6200251

Bandar 183.505707

Benut 117.6715243

BukitSerampang 194.8024447

BulohKasap 206.9313667

Chaah 156.6706608

ChaahBahru 145.9223211

Gemereh 197.0567397

Gerisek 180.9501436

Jabi 209.8987051

JalanBakri 177.3319318

Jelutong 82.02398542

Jemaluang 109.549911

Jementah 203.6686884

JeramBatu 89.3462027

JohorLama 28.0

Jorak 169.786171

Kahang 135.2979691

KampungBaharu 136.4388398

Kluang 120.2105317

KotaTinggi 44.0

Kundang 194.0867218

Labis 176.0213333

Layang-Layang 106.838097

Lenga 177.3537324

Linau 145.9099476

Lubok 159.8488036

Machap 118.8072255

Mersing 102.5173615

MinyakBeku 142.4656791

Niyor 130.4932751

Pagoh 189.7707577

Paloh 137.1463682

PantaiTimor	0
ParitBakar	181.510944
ParitJawa	174.6531556
PengkalanRaja	91.84763463
Penyabong	126.8380604
Peserai	150.7855548
Plentong	68.65852936
Pontian	98.94858887
Pulai	76.56980384
Renggam	106.271987
RimbaTerjun	97.68113975
Sedenak	93.97020827
SediliBesar	58.91248418
SediliKechil	27.0
Sembrong	159.7131224
SenaiKulai	80.54869952
Serkat	109.1583605
Sermin	206.2795729
Serom	185.2278723
SimpangKanan	144.3937335
SimpangKiri	159.4674665
SriGading	129.1607722
SriMenanti	175.43369
SungaiBalang	165.4830176
SungaiKarang	100.780945
SungaiKluang	122.3829288
SungaiPinggan	112.2226511
SungaiPunggor	126.0228954
SungaiRaya	179.9216273
SungaiSegamat	186.7234556
SungaiTerap	184.1380124

```
SungaiTiram        36.0
Tangkak            200.0199793
TanjungKupang      84.77439722
TanjungSemberong   132.1825118
Tebrau             77.60816512
Tenggaron          117.7917561
Teriang            133.2963801
UluBenut           109.4219138
UluSungaiJohor     66.03018776
UluSungaiSediliBesar 56.68490626   ;

Table Bdist(j,k)   'Distance from biorefinery jth to demand kth (km)'
                   Pengerang
PantaiTimor        31.0        ;

Equations
supply(i)    'Biomass availability constraint        '
capacity(j)  'Biorefinery capacity constraint        '
demand(k)    'Satisfy demand PIC constraint          '
cost         'Objective for minimizing cost          '
emissions    'Objective for minimizing CO2 emissions'        ;

supply(i)..     sum(j,Fbiomass(i,j))      =L= A(i)              ;
capacity(j)..   sum(k,Fbutanol(j,k))      =L= Cap*CapUnit(j)     ;
demand(k)..     sum(j,Fbutanol(j,k))      =G= demandPIC          ;
cost..          Ctotal =E=

[sum((i,j),Fbiomass(i,j)*Copf)
+  sum((i,j),Fbiomass(i,j)*dist(i,j)*Ctruck)]
+ [sum((j,k),Fbutanol(j,k)*Bdist(j,k)*Ctanker)
+  sum((j),Tcapex*CapUnit(j))
```

```
+  sum((j,k),Fbutanol(j,k)*Topex)]   ;

Model COM 'transport' / supply, capacity, demand, cost /  ;

Option LP = CPLEX ;

 Parameter Report1 |  'Summary report'  ;
 Parameter Report2 |  'Summary report'  ;
 Parameter Report3 |  'Summary report'  ;

 Solve COM using MIP minimizing Ctotal  ;

 Bestc       = smin((i,j),Fbiomass.m(i,j))  ;
 Bestd       = smin((i,j),dist(i,j))       ;

 Best5c(i,j)  = Fbiomass.m(i,j)$(dist(i,j) <= 68.65) ;
 Best5a(i,j)  = A(i)$Best5c(i,j)            ;
 Tbiomass     = sum((i,j),A(i)$Best5c(i,j))  ;

 Report1(i,j,"Cost")       = Fbiomass.m(i,j) ;

 Report2(j,k,"Cost")       = Fbutanol.l(j,k) ;

 Report3(i,j,"Best5c")     = Best5c(i,j)     ;
 Report3(i,j,"Biomass")    = Best5a(i,j)     ;
 Display Ctotal.l, Report1, Report2, Bestc, Bestd, Report3, Tbiomass, CapUnit.l ;

 execute_unload 'SCO_CostResults.gdx', Ctotal.l Fbiomass.m Fbutanol.l
 execute 'gdxxrw.exe SCO_CostResults.gdx o=SCO_CostResults.xls var=Ctotal.l rng=Ctotal!a1'
 execute 'gdxxrw.exe SCO_CostResults.gdx o=SCO_CostResults.xls var=Fbiomass.m
rng=Fbiomass.m!a1'
```

```
  execute 'gdxxrw.exe SCO_CostResults.gdx o=SCO_CostResults.xls var=Fbutanol.l
rng=Fbutanol.l!a1'
```

EMISSION OPTIMIZATION CODING

```
Sets
i          'Oil Palm Plantation (Supply)

' /ApiApi, AyerBaloi, AyerHitam, AyerMasin, Bagan, Bandar, Benut
,BukitSerampang, BulohKasap, Chaah, ChaahBahru, Gemereh, Gerisek
,Jabi, JalanBakri, Jelutong, Jemaluang, Jementah, JeramBatu
,JohorLama, Jorak, Kahang, KampungBaharu, Kluang, KotaTinggi
,Kundang, Labis, Layang-Layang, Lenga, Linau, Lubok, Machap
,Mersing, MinyakBeku, Niyor, Pagoh, Paloh, PantaiTimor, ParitBakar
,ParitJawa,  PengkalanRaja, Penyabong, Peserai, Plentong
,Pontian, Pulai, Renggam, RimbaTerjun, Sedenak, SediliBesar
,SediliKechil, Sembrong, SenaiKulai, Serkat, Sermin, Serom
,SimpangKanan, SimpangKiri, SriGading, SriMenanti, SungaiBalang
,SungaiKarang, SungaiKluang, SungaiPinggan, SungaiPunggor
,SungaiRaya, SungaiSegamat, SungaiTerap, SungaiTiram, Tangkak
,TanjungKupang, TanjungSemberong,  Tebrau, Tenggaron, Teriang
,UluBenut, UluSungaiJohor, UluSungaiSediliBesar/   // 78 plantations

j          'Potential Biorefinery (Process)      ' / PantaiTimor /
k          'Pengerang Integrated Complex (Demand) ' / Pengerang   /  ;

Free variable
Etotal        'Total emissions of biobutanol supply chain (ton CO2 per year)'  ;

Positive variable
Ebiomass(i,j)   'Flowrate of emissions from oil palm plantation ith to biorefinery jth (ton per year) '
Ebutanol(j,k)   'Flowrate of emissions from biorefinery jth to demand kth (ton per year)            '  ;
```

```
Scalar

Ecf          'Conversion emission factor of biomass OPF to biobutanol (ton CO2 per ton) '  / 0.58 /   ;

Parameters

Tbiomass      'Total biomass of Best5e                                   '

Beste        'Lowest emission from oil palm plantation ith to biorefinery jth            '

Bestd        'Lowest distance from oil palm plantation ith to biorefinery jth            '

Best5a(i,j)    'Biomass availability from Best5e                                  '

Best5e(i,j)    'Best 5 -> Emission combinations                                   '

Ecopf        'Emissions cultivation of biomass OPF (ton CO2 per ton)                   '  / 0.1055   /

Ehopf        'Emissions harvesting of biomass OPF (ton CO2 per ton)                    '  / 0.0222   /

Etruck       'Emissions of truck for OPF transportation (ton CO2 per ton.km)             '  / 0.000595
/

Etanker      'Emissions of oil tanker for biobutanol transportation (ton CO2 per ton.km)      '  /
0.00015/ ;


Parameter A(i)          'Biomass availability (OPF) in palm oil plantation itj (ton per year)' /

ApiApi             51196.07434

AyerBaloi          89623.71593

AyerHitam          21188.84641

AyerMasin          21130.75625

Bagan              25946.8574

Bandar             826.1482005

Benut              86232.62505

BukitSerampang       69967.94841

BulohKasap         115991.1504

Chaah              111745.1186

ChaahBahru          182061.8191

Gemereh             20.75226053

Gerisek            55971.77971

Jabi               28974.60355

JalanBakri          12965.83292

Jelutong           1241.948944
```

Jemaluang	2293.013462
Jementah	44757.46596
JeramBatu	39364.99446
JohorLama	110384.2472
Jorak	109463.0864
Kahang	281771.8456
Kluang	325451.6943
KotaTinggi	149769.5326
Kundang	12472.18161
Labis	123500.3839
Layang-Layang	161078.6179
Lenga	52409.52212
Linau	69125.32696
Lubok	16775.35705
Machap	56348.12368
Mersing	294464.8108
MinyakBeku	73140.74914
Niyor	178780.1034
Pagoh	62597.30506
Paloh	288505.2121
PantaiTimor	67493.31239
ParitBakar	5016.406888
ParitJawa	37068.77441
PengkalanRaja	6434.365481
Penyabong	3265.058264
Peserai	13116.77184
Plentong	25899.08503
Pontian	74914.9404
Pulai	42724.15899
Renggam	301410.712
RimbaTerjun	45766.33751

Sedenak 196249.342

SediliBesar 82519.28538

SediliKechil 118790.4023

Sembrong 22041.13358

SenaiKulai 196233.9378

Serkat 23892.03276

Sermin 58700.91524

Serom 20934.38888

SimpangKanan 47073.40837

SimpangKiri 72794.67062

SriGading 115968.9534

SriMenanti 50332.97163

SungaiBalang 51817.27605

SungaiKarang 20386.43343

SungaiKluang 60722.09254

SungaiPinggan 46316.03831

SungaiPunggor 59160.3109

SungaiRaya 15274.82376

SungaiSegamat 44094.42202

SungaiTerap 3338.45109

SungaiTiram 91760.49658

Tangkak 97239.71435

TanjungKupang 13723.63725

TanjungSemberong 215722.9958

Tebrau 69331.7291

Tenggaron 68507.02001

Teriang 22404.28399

UluBenut 66245.55757

UluSungaiJohor 305212.4651

UluSungaiSediliBesar 118222.5721 / ;

Table dist(i,j) 'Distance from supply ith to biorefinery jth (km)'

	PantaiTimor
ApiApi	103.0120986
AyerBaloi	106.2263906
AyerHitam	163.4421609
AyerMasin	103.1392574
Bagan	155.6200251
Bandar	183.505707
Benut	117.6715243
BukitSerampang	194.8024447
BulohKasap	206.9313667
Chaah	156.6706608
ChaahBahru	145.9223211
Gemereh	197.0567397
Gerisek	180.9501436
Jabi	209.8987051
JalanBakri	177.3319318
Jelutong	82.02398542
Jemaluang	109.549911
Jementah	203.6686884
JeramBatu	89.3462027
JohorLama	28.0
Jorak	169.786171
Kahang	135.2979691
KampungBaharu	136.4388398
Kluang	120.2105317
KotaTinggi	44.0
Kundang	194.0867218
Labis	176.0213333
Layang-Layang	106.838097
Lenga	177.3537324

Linau	145.9099476
Lubok	159.8488036
Machap	118.8072255
Mersing	102.5173615
MinyakBeku	142.4656791
Niyor	130.4932751
Pagoh	189.7707577
Paloh	137.1463682
PantaiTimor	0
ParitBakar	181.510944
ParitJawa	174.6531556
PengkalanRaja	91.84763463
Penyabong	126.8380604
Peserai	150.7855548
Plentong	68.65852936
Pontian	98.94858887
Pulai	76.56980384
Renggam	106.271987
RimbaTerjun	97.68113975
Sedenak	93.97020827
SediliBesar	58.91248418
SediliKechil	27.0
Sembrong	159.7131224
SenaiKulai	80.54869952
Serkat	109.1583605
Sermin	206.2795729
Serom	185.2278723
SimpangKanan	144.3937335
SimpangKiri	159.4674665
SriGading	129.1607722
SriMenanti	175.43369

```
SungaiBalang        165.4830176
SungaiKarang        100.780945
SungaiKluang        122.3829288
SungaiPinggan       112.2226511
SungaiPunggor       126.0228954
SungaiRaya          179.9216273
SungaiSegamat       186.7234556
SungaiTerap         184.1380124
SungaiTiram         36.0
Tangkak             200.0199793
TanjungKupang       84.77439722
TanjungSemberong    132.1825118
Tebrau              77.60816512
Tenggaron           117.7917561
Teriang             133.2963801
UluBenut            109.4219138
UluSungaiJohor      66.03018776
UluSungaiSediliBesar 56.68490626  ;

Table Bdist(j,k)    'Distance from biorefinery jth to demand kth (km)'
                    Pengerang
PantaiTimor         31.0        ;
Equations     emissions    'Objective for minimizing CO2 emissions'  ;

emissions..    Etotal =E=

[sum((i,j),Ebiomass(i,j)*Ecopf)
+  sum((i,j),Ebiomass(i,j)*Ehopf)
+  sum((i,j),Ebiomass(i,j)*dist(i,j)*Etruck)]
+ [sum((j,k),Ebutanol(j,k)*Bdist(j,k)*Etanker)
+  sum((j,k),Ebutanol(j,k)*Ecf)]              ;
```

```
Model EOM 'transport'  / emissions / ;  // EOM = Emissions Optimization Model
Option LP = CPLEX ;

Parameter Report1 |  'Summary report'   ;
Parameter Report2 |  'Summary report'   ;
Parameter Report3 |  'Summary report'   ;

Solve EOM using MIP minimizing Etotal   ;
Beste       = smin((i,j),Ebiomass.m(i,j))  ;
Bestd       = smin((i,j),dist(i,j))       ;

Best5e(i,j)  = Ebiomass.m(i,j)$(dist(i,j) <= 68.65) ;
Best5a(i,j)  = A(i)$Best5e(i,j)           ;
Tbiomass     = sum((i,j),A(i)$Best5e(i,j))  ;

Report1(i,j,"Emission")   = Ebiomass.m(i,j) ;
Report2(j,k,"Emission")   = Ebutanol.m(j,k) ;
Report3(i,j,"Best5e")     = Best5e(i,j)     ;
Report3(i,j,"Biomass")    = Best5a(i,j)     ;

Display  Etotal.m, Report1, Report2, Beste, Bestd, Report3, Tbiomass  ;

execute_unload 'SCO_EmissionsResults.gdx',Etotal.l Ebiomass.m Ebutanol.m
execute 'gdxxrw.exe SCO_EmissionsResults.gdx o=SCO_EmissionsResults.xls var=Etotal.l rng=Etotal!a1'
execute 'gdxxrw.exe SCO_EmissionsResults.gdx o=SCO_EmissionsResults.xls var=Ebiomass.m rng=Ebiomass.m!a1'
execute 'gdxxrw.exe SCO_EmissionsResults.gdx o=SCO_EmissionsResults.xls var=Ebutanol.m rng=Ebutanol.m!a1'
```

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