STRUCTURAL SUSTAINABILITY STUDY FOR PRODUCTION OF ADVANCED BIOFUELS FROM INTEGRATED OIL PALM BIOMASS BIOREFINERY

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DECLARATION

I declare that this project report entitled " Structural Sustainability Study for Production of Advanced Biofuels from Integrated Oil Palm Biomass Biorefinery" is the result of my own work except cited in references.

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Date : 13 August 2020

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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DEDICATION

To my beloved mother, father, and friends.

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 biorefinery. 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 modeling techniques with the strategic oil palm biomass supply chain network design. This paper will also optimize supply chain optimization using Computer-aided tools such as GAMS and ArcGIS. Based on the findings, there are 78 potential facilities for oil palm biomass in Johor, which is the case study, in order to supply the advanced biofuels from integrated oil palm biomass for the targeted biorefinery. Furthermore, the least cost and optimal supply chain of gasoline were 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 CPLEX solver in GAMS software and finally, sensitivity analyses are carried out in order to gain management insight into how total cost supply chain changes due to existing uncertainties. All in all, it was a deep expectation that this work will address typical biofuels supply chain issues.

ABSTRAK

Biojisim telah lama dilihat sebagai alternatif buat masa depan dengan keperluan sumber tenaga yang mampan dan berpatutan yang semakin meningkat. Malaysia adalah antara pengeluar terkemuka di dunia dengan tanaman kelapa sawit terbesar di dunia. Oleh itu, biojisim dari sektor kelapa sawit merupakan sumber bahan mentah alternatif yang sangat menarik di Malaysia, termasuk juga dengan tenaga boleh diperbaharui. Terdapat minat yang semakin meningkat terhadap bahan api bio pada masa kini. Oleh itu, kajian ini memfokuskan pada perumusan berdasarkan model dan pengoptimuman bahan api bio maju dari kilang penapisan bio biojisim kelapa sawit. Pendekatan simulasi berdasarkan struktus atas menawarkan alternatif kepada laluan pengeluaran biojisim untuk meminimumkan jumlah kos rantaian bekalan. Oleh itu, kajian ini bertujuan untuk menganalisis model yang mengintegrasikan teknik pemodelan ruang yang komprehensif dengan reka bentuk rangkaian rantaian bekalan biojisim kelapa sawit yang strategik. Maka, ini jugalah akan mengoptimumkan pengoptimuman rantaian bekalan dengan menggunakan alat bantu komputer seperti GAMS dan ArcGIS. Berdasarkan penemuan tersebut, terdapat 78 tempat yang berpotensi untuk biojisim kelapa sawit di Johor, yang merupakan kes kajian, untuk memberi bekalan bahan api bio dari biojisim kelapa sawit terpadu untuk kilang penapisan bio yang disasarkan. Selanjutnya, rantai bekalan minyak yang paling murah dan optimum diperoleh berdasarkan pelbagai kekangan yang berfungsi sebagai batas atas dan bawah pemboleh ubah keputusan. Dengan perisian ArcGIS, data ruang disajikan dan kemudian diselesaikan oleh pemecah CPLEX dalam perisian GAMS dan akhirnya, analisis kepekaan dilakukan untuk mendapatkan cara pengurusan tentang bagaimana jumlah rantaian bekalan kos berubah disebabkan oleh ketidakpastian yang ada. Secara keseluruhan, ini adalah harapan yang mendalam bahawa karya ini akan menangani masalah rantaian bekalan bahan api bio khas.

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LIST OF ABBREVIATIONS

AIMMS	-	Advanced Interactive Multidimensional Modeling System
AOpAZRP	-	A is an Acid Treatment, Op an Oxygen and Peroxide Stage, Z an Ozone Stage, R a Reductive Treatment and P a Peroxide Stage
ArcGIS	-	Aeronautical Reconnaissance Coverage Geographic Information System
ASTM	-	American Society for Testing and Materials
Bio-DME	-	Bio Methanol
Bio-SNG	-	Biomethane Or Synthetic Natural Gas
C_{12}	-	Cyclo(12)carbon
C_{14}	-	Cyclo(14)carbon
C_{16}	-	Cyclo(16)carbon
C_{18}	-	Cyclo(18)carbon
C_2	-	Cyclo(2)carbon
C_3	-	Cyclo(3)carbon
C_4	-	Cyclo(4)carbon
$C_6H_{14}O$	-	2-Hexanol
CBP	-	Consolidated Bioprocessing
CFCs	-	Chlorofluorocarbons
CH_4	-	Methane
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
CPO	-	Crude Palm Oil
EFB	-	Empty Fruit Bunch
ETBE	-	Ethyl Tertiary-Butyl Ether
FELCRA	-	Federal Land Consolidation and Rehabilitation Authority

FELDA	-	Federal Land Development Authority
GAMS	-	General Algebraic Modeling System
GIS	-	Geographic Information System
H_2	-	Hydrogen
H_2SO_4	-	Sulfuric Acid
HDO	-	Hydrodeoxygenation
HHV	-	Higher Heating Value
KOH	-	Potassium Hydroxide
LSCM	-	Logistics & Supply Chain Management
MATLAB	-	Matrix Laboratory
MF	-	Mesocarp Fiber
MIP	-	Mixed Integer Linear Programming
MINLP	-	Mixed-Integer Non-Linear Programming Problems
MPOB	-	Malaysian Palm Oil Board
MTBE	-	Methyl Tertiary-Butyl Ether
NaOH	-	Sodium Hydroxide
O_2	-	Oxygen
OPF	-	Oil Palm Frond
OPT	-	Oil Palm Trunk
PKS	-	Palm Kernel Shell
POME	-	Palm Oil Mill Effluent
RISDA	-	Rubber Industry Smallholders Development Authority
RVP	-	Reid Vapor Pressure
SAW	-	Simple Addictive Weighting
SHCF	-	Separate Hydrolysis and Co-Fermentation
SHF	-	Separate Hydrolysis and Fermentation
SSF	-	Simultaneous Saccharification
Tg	-	Tera grams
US	-	United State
VOCs	-	Volatile Organic Compounds
ZnC_{12}	-	Zinc Chloride
ZrO_2	-	Zirconium Dioxide

BARON	-	The Branch-And-Reduce Optimization Navigator
COIN-OR	-	Computational Infrastructure for Operations Research
CPLEX	-	IBM ILOG CPLEX Optimization Studio
DICOPT	-	Discrete Continuous Optimizer
SNOPT	-	Sparse Nonlinear OPTimizer

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter discussed the structural sustainability study of integrated oil palm biomass biorefinery to produce advanced biofuels in Malaysia. This research is motivated in assessing the appropriateness of the modeling and optimization of oil palm biomass's supply chain to be implemented in Malaysia through the development of a new systematic modeling framework. The following sections will be discussing the research background, problem statement, research objectives, research scopes, and significance of research.

1.2 Research Background

Malaysia is a nation that has both fossil and renewable resources. Of petroleum energy, this country's proven reserves and international share (percent) is 3.7 million barrels and 0.2 percent crude, and 38.5 trillion cubic feet and 0.6 percent natural gas (British Petroleum, 2014). Such figures have, respectively, rated Malaysia as the 28^{th} and 15^{th} highest oil and gas reserves in the world. Malaysia has 22,500 MW of hydropower, 6,500 MW of solar power, and 1,700 MW of biomass energy potential for renewables (Mekhilef et al. 2000). Of these renewables, only biomass can be used for the production of multi-products ranging from energy, chemicals, and materials as a substituted feedstock to fossil fuels. The substitutions are evident to some extent because the production of Malaysia's major oil fields has declined and biomass resources are abundant in this country (Zafar, 2015). For more general reasons, discouraged qualities such as environmentally harmful and non-renewable carbon fuels have even elevated the chances for biomass to become the major green feedstocks soon.

Biomass is a renewable feedstock for the production of a range of energy, chemical, and material products. Globally, the use of biomass is intensified mainly due to its abundant supply, which is widely found in both terrestrial and aquatic forms. Also, biomass has the potential to generate wealth and new jobs and has positive effects on economic, environmental, and social sustainability as a whole. Biomass usage, in particular, serves as a low-carbon alternative option with potential reductions in greenhouse gas emissions (especially carbon dioxide) due to reduced dependence on fossil fuels due to its integration with the current supply chain and infrastructure. World biomass assessment is a complex process containing various factors (Hoogwijk et al. 2003; Slade et al. 2011; Thrän et al. 2010) with estimates of more than 73.9 Tg (i.e. 7.39×10^{10} g) published annually, mainly in terms of capacity for bioenergy production (Long et al. 2013).

There are several phases in the biomass supply chains that include developing, processing, transportation, aggregating, and conversion, each phase requiring a unique set of information, equipment, and operation (Samsatli, Samsatli, and Shah 2015). Growing is an event that provides sufficient capital for the use of biomass. These resources may be derived from forestry (e.g. wood, sawdust, bark, chips) or agricultural residues (e.g. wheat straw, soybean stalk, oil palm empty fruit bunch, rice husk, shrimp shell, animal manure) or dedicated crops (e.g. switchgrass, sorghum, miscanthus, jatropha, algae, fungi). All of the mentioned plant-based resources are classified as lignocellulosic biomass (Radloff et al. 2012).

1.3 Problem Statement

This study focuses on a supply chain of biofuels as shown in Figure 1. The supply chain is made up of three layers; biomass cultivation and harvesting sites, processing biomass for biofuels, and demand levels. There are biomass types, number of biomass outlets, refining plant sites, and number of demand points. Biomass materials are transported to the biofuel plants from raw material sources (via truck). Biofuel mixing and product sales take place respectively at the biofuel plants and demand locations. External customers are imposing demands for these products. In the meantime, all raw materials and finished goods were granted preliminary stocks at the factories. Costs such as holding inventory, backlog, and loss of sales are added at the expense of the producer. End product demand is a price function as shown in (Smith et al. 2009). The objective function is to maximize the estimated profit of the biorefinery plant by taking decisions such as (1) locations of new biorefineries for each period, (2) capacity of existing biorefineries for each period, (3) quantity of biomass for each period, (4) quantity of biofuel for each period, (5) quantity of biomass for each field for each period, (6) quantity of biofuel supplied from each refinery to each point of demand for each cycle, and (7) supply of biofuel in points of demand.

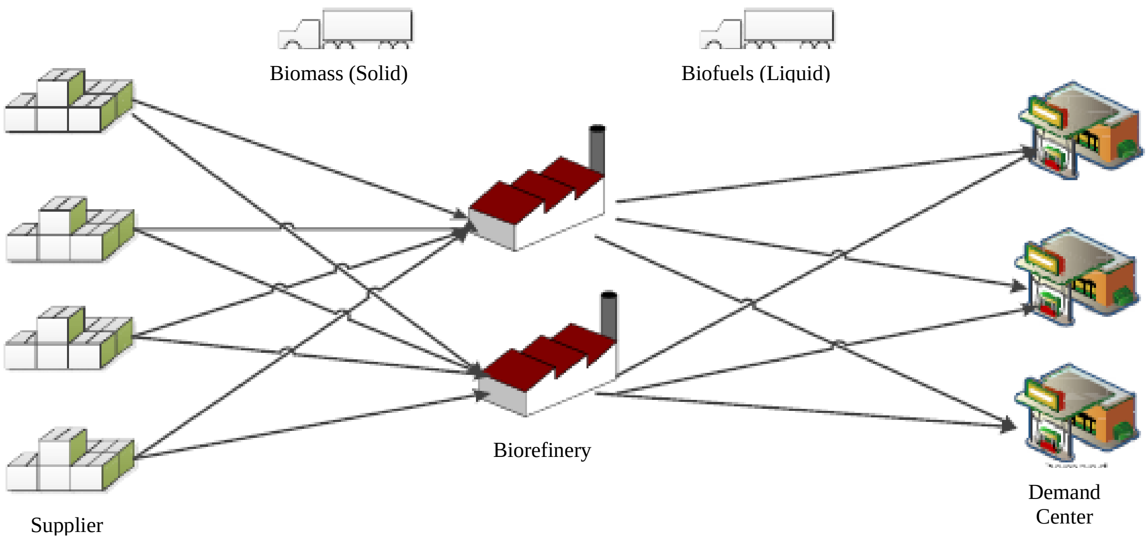


Figure 1: Centralized biofuel supply chain.

1.4 Research Objectives

Based on the problem statement, this research focuses on the model-based and optimization of advanced biofuels from integrated oil palm biomass biorefinery. Particularly, the research objectives are highlighted in the following:

i. To analyze the model that integrates comprehensive spatial modeling techniques with the strategic biofuels supply chain optimization network design.
ii. To optimize the supply chain using Computer-aided tools such as GAMS and ArcGIS
iii. To select the optimal potential biorefinery by using AHP through five criteria which are cost, distance, supply, social, and emission.

1.5 Research Scopes

To achieve the intended research objectives, the scopes of this research are specified as follows:

i. Reviewing overall development and statistic about biofuels generated from oil palm biomass (OPB) in Malaysia likewise in light of the process involved in the production of advanced biofuels such as bioethanol.
ii. Developing a spatial modeling methodology that integrates GAMS to achieve the optimal cost-structure of the supply chain optimization of oil palm biomass in producing advanced biofuels based on request demands.
iii. Performing oil palm biomass supply chain optimization design that incorporates model formulation to overcome certain limitations in biomass transportation in Malaysia.

1.6 Significant of Research

Biomass is one of the major worldwide essential vitality sources during the one century from now, and modernized bioenergy frameworks are recommended to be significant supporters of future manageable vitality frameworks and to manageable advancement in industrialized nations just as in developing nations (Berndes, Hoogwijk, and Van Den Broek 2003). Biomass can be utilized for the generation of energizes, and synthetics with decreased life cycle (ozone-depleting substance) emissions. Currently, these powers and synthetic substances are delivered essentially from petroleum gas and other petroleum derivatives.

Significant toward the field oil palm biomass modeling and optimization which is another extensive improvement approach that incorporates the spatial modeling method with oil palm biomass supply chain optimization network structure that would have the option to recognize (1) the spatial distributions of oil palm biomass supply, (2) locations to build oil palm biomass biorefinery, (3) location-allocation of supply and demand of oil palm biomass supply chain, (4) logistic networks while minimizing the total cost and the environmental effect.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature that was reviewed to come up with significant knowledge about the gasoline and the production of advanced biofuels from the integrated oil palm biomass. Section 2.2 explains about the background history of gasoline, chemical compositions, technical standards for gasoline. Section 2.3 discusses a few additives used in gasoline. Section 2.4 discusses the oil palm biomass in Malaysia included the alternative approaches through sustainable development of biofuels and the process of oil palm biomass into biofuels. Section 2.5 explains on the palm oil biomass feedstock spatial analysis. Section 2.6 presents the spatial modeling applied to supply chain optimization. Section 2.7 outlines the previous works in oil palm biomass supply chain modeling.

2.2 Gasoline

Gasoline is a volatile, flammable liquid mixture of hydrocarbons derived from gasoline and used as fuel for internal combustion engines. It is a dynamic material combination that varies widely in physical and chemical properties. Operating factors such as changes in fuel systems, engine speeds, fuel pumps, and air demand should be protected by gasoline. It also has to cover a variety of climates, altitudes, and patterns of driving. The properties of gasoline must be calibrated over an extremely wide range of circumstances to provide adequate engine performance. The prevailing quality standards represent compromises in some respects so that all the numerous requirements for performance and environmental regulations can be achieved (Reynolds 2009).

American Society for Testing and Materials International (ASTM) is setting the most commonly used gasoline quality guidelines. ASTM specifications are established by consensus based on the extensive experience and close cooperation of gasoline producers, ethanol producers, automotive equipment manufacturers, users of both commodities, and other stakeholders such as state fuel quality regulators (Reynolds 2009).

2.2.1 Chemical Composition and Physical Properties of Automotive Gasoline

The exact chemical composition of gasoline varies depending on its grade or octane level, but it is a mixture of fuel hydrocarbons in general. The research octane number (RON) represents the fuel content and the price is dependent on the proportions of two substances, actually iso-octane, a compound with the same chemical formula as octane but with a slightly different structure and properties, and regular heptane. The higher the octane gas volume, the greater the octane quantity, and the higher the fuel price. This higher fuel quality ensures that the fuel is ignited on time due to a spark from the spark plug and not early due to piston compression. More recently, gasoline is blended with an ethanol-known biofuel.

2.2.2 Technical Standards for Gasoline

The following Table 1 shows the current fuel requirements:

Table 1: Technical standards for petrol/gasoline (European Union 2018).

Parameter	Unit	Limits	
		minimum	maximum
Number of octane research (RON)		95	-
Octane number (RON) of the engine		85	-
Pressure of vapor, summer period	kPa	-	60.0
Distillation:			
Evaporated percentage at 100 ° C	%vol/vol	46.0	-
Evaporated percentage at 150 ° C	%vol/vol	75.0	-
Hydrocarbon analysis:			
Olefins	%vol/vol	-	18.0
Aromatics	%vol/vol	-	53.0
Benzene	%vol/vol	-	1.0
Content of oxygen	%mass/mass		3.7
Oxygenates:			
Methanol	%vol/vol		3.0
Ethanol	%vol/vol		10.0
Iso-propyl alcohol	%vol/vol	-	12.0
Tert-butyl alcohol	%vol/vol	-	15.0
Iso-butyl alcohol	%vol/vol	-	15.0
Ethers of five or more atoms of carbon per molecule	%vol/vol	-	22.0
Other oxygenates	%vol/vol	-	15.0
Sulphur content	mg/kg	-	10.0
Lead content	g/L	-	0.005

2.3 Additives in Gasoline

Gasoline that comprises essentially straight-chain alkenes and cycloalkanes has poor ignition components when burned in internal combustion engines. In fact, a combination of air and vaporized fuel of this sort can instantly sparkle in the piston of the engine before it is fully compressed and started, so the engines "knock" with a subsequent loss of power (Baird and Cann 2005). Lead octane added substances have generally been utilized to improve burning productivity of gasoline and avoid engine "knock". Knocking-in spark-ignition internal combustion engines happens where the combustion of some of the air/fuel mixture in the cylinder does not result from the expansion of the front flame of the spark plug, but one or more pockets of air/fuel mixture burst outside the boundary of the normal combustion front. In any case, in light of their harmful substance, these added substances have been eliminated lately in many places over the world.

In the 1980s, numerous purifiers began to supplant lead with aromatics because of the lower costs of those mixes at that time. Methyl Tertiary Butyl Ether (MTBE) has been broadly utilized since the 1990s when some environmental regulations began to restrict the aromatic content in gasoline. It was included in the fuel at first at a low rate as an octane enhancer and later was mixed at higher fixation as oxygenate to meet the perfect air prerequisite.

Oxygenates are added into gasoline to expand the general octane numbers besides improving ignition productivity (Yacobucci 2006). Furthermore, they can likewise lessen carbon monoxide (CO) levels since they create less carbon monoxide during ignition than the hydrocarbons they supplant. Moreover, when utilized as a piece of the gasoline formulation, MTBE prompts a decrease in discharges of fumes toxins.

Despite not being specifically included in ASTM standards, a variety of specially formulated additives are added to gasoline to improve fuel quality and performance and maintain fuel standards during distribution. These additives to gasoline are mixed in very small quantities.

2.3.1 Methyl Tertiary Butyl Ether (MTBE)

MTBE is a synthetic mixture that is constructed through the substance reaction of methanol and isobutylene. It is one of a gathering of synthetic substances ordinarily known as 'oxygenates' because it raises the oxygen substance of gasoline, which keeps the engine from 'thumping'. At room temperature, MTBE is an unpredictable, combustible, and vapid fluid that breaks up effectively in the water. It has been delivered in huge amounts and is exclusively utilized as a fuel added substance in unleaded gasoline in the United States (US) and throughout the world.

2.3.2 Ethyl Tertiary Butyl Ether (ETBE)

ETBE ($C_6H_{14}O$) is used as an appealing octane enhancer because it displays a lower Reid Vapor Pressure (RVP) blend and better water solvency than MTBE and ethanol. The azeotropic combination of ETBE and ethanol decreases the imprevisibility of ethanol making it acceptable as an added material for automotive fuel. (Guerra Que et al. 2019).

2.3.3 Ethanol

The most regularly utilized fuel added substance being used today is ethanol. Ethanol is broadly utilized since it is generally reasonable, is completely solvent in gasoline, is equipped for rising the worldwide effectiveness of an engine, and lessens dangerous contaminations (Schifter, González, and González-Macías 2016; Verma et al. 2016). Ethanol is regularly acquired at corner stores as either as E10 or E85 fuel. E85 fuel is 85 % ethanol and 15 % gasoline by volume. Practically all gasoline bought in the United States contains 10 % ethanol while a few engines are fit to keep running with E85. It has been found in numerous researches that ethanol will in general increment the normal pinnacle pressure and that the pinnacle pressure increments with rising ethanol rate. It has additionally been accounted for that ethanol in the fuel diminishes the particulate emissions that as engine discharges. This advantage can be acknowledged to the tune of a 90 % reduction in particulate matter (<1%) (Schifter et al. 2016). Moreover, a reduction of the cancer-causing benzene rings was seen as around half when E85 fuel was utilized.

The disadvantages to ethanol are that it has a low energy density of 789 kg/m^3 that it is increasingly costly to store as it will in general corrupt when within the sight of water. The low vitality density suggests that a vehicle running on fuel that has a high level of ethanol will have an altogether lower mpg rating than a vehicle that is working on unadulterated gasoline. Ethanol is commonly more affordable than gasoline on a volume premise, be that as it may, the money-saving advantage is normally overwhelmed by the absence of vitality thickness. As of the hour of composing, ethanol costs about 10 % more per mile than unadulterated gasoline. Additionally, accumulating ethanol turns out to be high as it corrupts when it associates with water; numerous corner stores are not furnished with the hardware that will securely store ethanol. Utilizing ethanol is a decent start to enhancing fossil powers with biofuels, however, some key fuel parameters must be fixed to empower the protected usage of added substances into the gasoline foundation.

2.4 Oil Palm Biomass in Malaysia

The oil palm (Elaeis guineensis) is the world's top-yielding oil crop, with a production of around eight times that of rapeseed and six times that of soya, as seen in Figure 2(a). Palm oil is obtained from mesocarp seed, which is then divided into stearin and palm oil. (Hazimah Abu Hassan 2012). Palm oil is used as a substitute for cooking oil in meat applications, while palm stearin is used mainly in the production of non-food and oleochemicals. At 47.6 million tons of palm oil produced worldwide in 2013, palm oil is extensively grown in tropical countries such as Malaysia and Indonesia. Reference is made to Figure 2(b) (Faostat 2013).

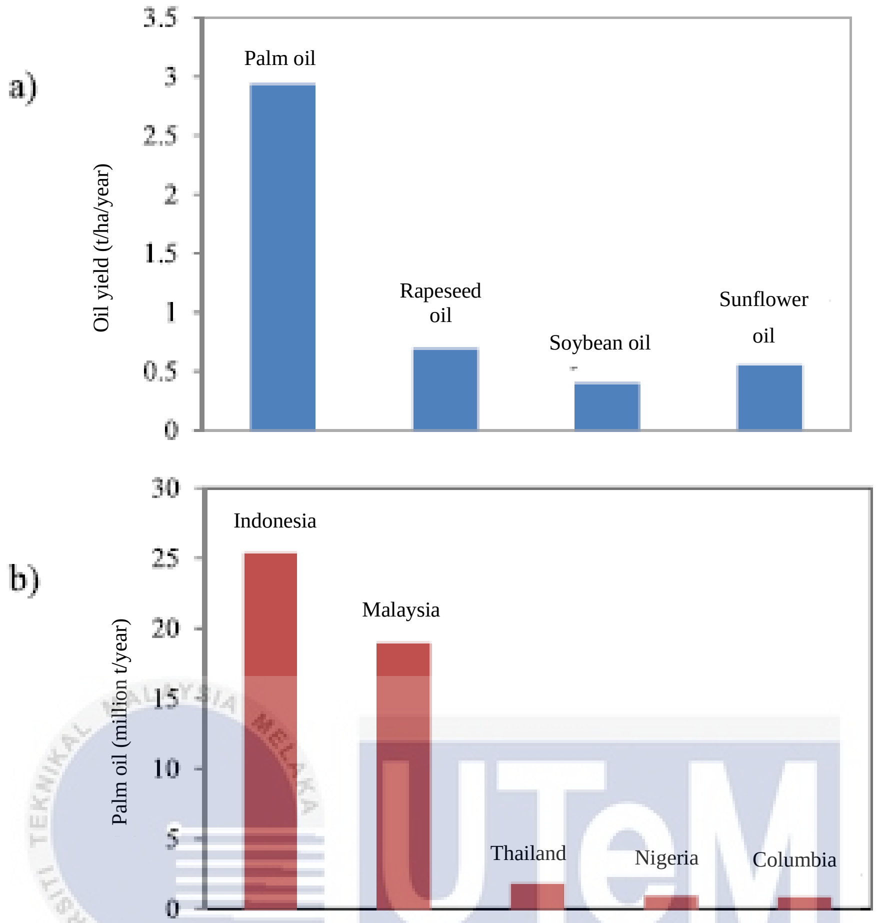


Figure 2 (a): The average oil yield (tons/hectare/year) for selected oil crops from 2010 to 2012 (Faostat 2013). (b) The main five suppliers of palm oil in the world with average palm oil production from 2011 to 2013 (Faostat 2013).

The demand for palm oil is rising annually, and palm oil has been the most commonly consumed vegetable oil since 2007 (Ash 2007). Global commercial palm oil consumption in 2018 is 19.72 million tonnes, and palm kernel oil is 5.96 million tonnes, with a gross palm oil consumption of 10.97 million tonnes, and rapeseed oil of 8.07 million tonnes, which is higher than soya oil. One explanation for the increasing demand for palm oil is that it is the cheapest source of edible oil relative to other large vegetable oils, such as soya and rape. Oil palm is a low-energy crop, since it is a seasonal crop that does not require annual sowing. (Lam et al. 2009). The cultivating of oil palms demands less energy input per ton of oil output than soya beans and rapeseed. (Sumathi, Chai, and Mohamed 2008).

The growing demand for palm oil is also driven by its comprehensive use in the oleochemical industries. The fatty acids and alcohols provided by these oils are important raw materials for the manufacture of surfactants. These surfactants are mainly used in the manufacture of household goods such as washing detergents, shampoos, soaps, and cleaning products.

Following an economic life of about twenty-five years, oil palm trees were replanted. (Murata et al. 2013). The production of palm fruit normally starts three years after planting, with a maximum yield of oil in the $(12–14)^{the}$ year after which the yield continues to decrease until the end of the economic life of the plantation. (Mohammed et al. 2011). With about 1000–3000 fruits per bunch, palm fruits grow in bunches. Each bunch weighs about (10 - 15) kg with about 25 % (weight/weight) per bunch of oil (Malaysian Palm Oil Board 2011). Palm oil is derived from the palm fruit mesocarp, the sticky, and fleshy outer layer of the seed or fruit kernel seen in Figure 3. The palm kernel is also abundant in butter, especially the palm kernel oil has exceptional unsaturated palm oil fat creations. Palm kernel oil is also rich in butter, but palm kernel oil has different fatty acid compositions than palm oil. Palm oil is primarily composed of fatty acids C_{16} and C_{18}, while palm kernel oil is composed of fatty acids C_{12} and C_{14}, which are both widely present in coconut oil. (Hazimah Abu Hassan 2012). Therefore, unlike palm oil, palm kernel oil is primarily used in soap processing (Sumathi et al. 2008).

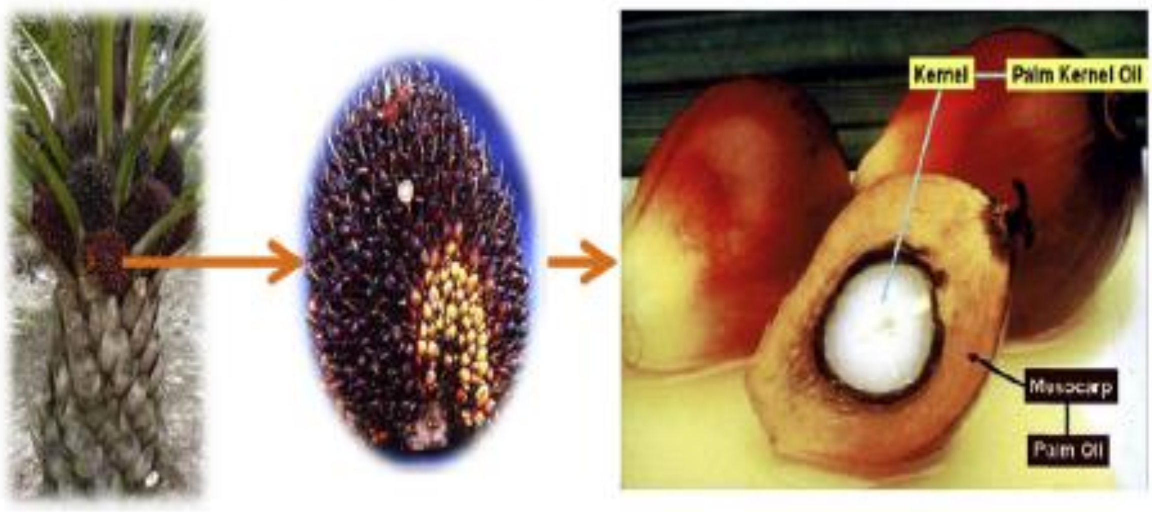


Figure 3: Oil palm tree, fresh fruit bunch, and longitudinal section of fresh oil palm fruit (Ahmad et al. 2019).

2.4.1 Palm Oil Processing: Alternative Approaches Sustainable Development of Biofuels and Chemicals

Empty fruit bunch (EFB), mesocarp fiber (MF), palm kernel shell (PKS), an oil palm frond (OPF), and oil palm trunk (OPT) (Table 3) (Agensi Inovasi Malaysia 2013) are lignocellulose (Table 2) and can be transformed to higher-value products and lead to higher economic returns for the palm oil industry by direct use, physical, biochemical and thermochemical storage. The use of oil palm biomass for biofuel and bioproduct production will provide solutions to environmental issues associated with disposal activities. As a result, the production of biorefineries for oil palm biomass is expected to increase the sustainability and competitiveness of the palm oil industry.

Table 2: Hemicellulose, lignin, Cellulose, and compositions of ash for oil palm biomass (Ahmad et al. 2019).

Oil Palm Biomass	Cellulose	Hemicellulose	Lignin	Ash	References
EFB	34.0-40.4	17.2-22.4	23.1-29.6	5-6.5	(Ahmad et al. 2016)
MF	23.0-28.8	25.3-30.5	25.5-28.97	2.6-5.8	(Abnisa, Arami-Niya, Daud, et al. 2013)
PKS	20.8-27.2	21.6-22.7	44-50.7	8.6-16.3	(Asadieraghi and Wan Daud 2014)
OPF	31.0-42.8	12.5-22.5	15.2-25	5-5.8	(J. P. Tan et al. 2016)
OPT	40.3-50.78	18.7-30.36	17.9-26.8	2.4-2.9	(Prawitwong et al. 2012)

Table 3: Overview of palm oil waste and global development of palm oil waste.(Ahmad et al. 2019)

Oil palm waste	Picture	Description	Generation site	Quantities (million t/year) (wet weight)	References
Empty fruit bunch (EFB)		Sterilization by-product and fresh fruit bunch threshing.	Mill	50.8	(Aditiya et al. 2016)
Mesocarp fiber (MF)		Fruitlet oil extraction by-product and peri carping by-product.	Mill	29.9	(Aditiya et al. 2016)
Shell (PKS)		By-product of cracking palm nut.	Mill	13.4	(Hambali and Rivai 2017)
Fronds (OPF)		Leaves of palm oil.	Plantation	131.2	(Hambali and Rivai 2017)
Trunks (OPT)		Felled oil palm tree trunks.	Plantation	37.7	(Awalludin et al. 2015)
Palm oil mill effluent (POME)		Liquid by-products from the process of sterilization and extraction of oil.	Mill	141.9	(Hosseini and Wahid 2014)

2.4.2 The Process of Oil Palm Biomass into Biofuels

Biomass primary handling and further processing are changing over the pre-processed biomass feedstocks into intermediates and the last products. In a conversion plant or for the most part, alluded to bio-refinery, biomass inputs must experience a few processing steps relying upon the elected conversion technology, which will, in the long run, decide products that will be produced. The determination between change conversion technologies or even the thought inside a conversion technology choice itself is directed predominantly by techno-economic feasibility.

2.4.3 Biomaterials Synthesis and Conversion of Physical

Referring to Table 4, using different uses and physical methods, oil palm biomass may be used to produce bio-based goods such as biochar, activated fuel, fiberboards and bio-composites. The prospects for transforming lignocellulosic oil palm biomass into bio-based items such as fiberboards and bio-composites have been extensively studied. Many early research on the use of oil palm biomass focused on the production of biomaterials from oil palm biomass (Jacob, Varughese, and Thomas 2006; Laemsak and Okuma 2000). Biomass biomaterials provide renewable alternatives to petrochemical-derived materials such as plastics and polymers.

Table 4: Biomaterials synthesized from oil palm biomass by physical and chemical procedure. (Ahmad et al. 2019).

Bio-products	Oil palm biomass	Thermochemical conversion	Research Findings	Reference
Activated carbon	EFB	Slow pyrolysis at 280 °C, followed by grinding and grinding at 600 °C, acid treatment, palletization, and carbonization.	-	(Aziz, Wahid, and May 2008)
	OPT	Acid biomass pretreatment followed by CO_2 carbonization at 500 °C.	1884 m^2/g BET surface area	(Hussein et al. 2001)
	PKS	Chemical activation by impregnation of KOH.	1148 m^2/g BET surface area	(Guo et al. 2007)
	PKS	$ZnCl_2$ impregnation of biomass followed by 500 °C heating and CO_2 activation through carbonization at 900 °C.	Granular activated carbon for adsorption of methane. Twice the adsorption capacity of methane after activation of carbon.	(Arami-Niya, Daud, and Mjalli 2010)
Additive of recycled paper	EFB	Biomass soda pulping, then mixing with recycled paper pulp.	Complete restoration of the recycled paper strength	(Wanrosli, Zainuddin, and Roslan 2005)
Aromatic compounds	Lignin of EFB	Pretreatment of alkaline accompanied by regeneration of lignin from black alcohol and lignin nitrobenzene oxidation.	Hydroxybenzoic acid 333 mg/L, vanillic acid 25,57 mg/L, vanillin 169 mg/L, syringaldehyde 815 mg/L	(Tang et al. 2015)
Biochar	OPF	Torrefaction in the range of (200 –300) °C at 30 min.	26.62 MJ/kg HHV (250 °C)	(Lau et al. 2018)
	OPT	Torrefaction for 40 min at 230 °C.	24.3 MJ/kg HHV	(Chin et al. 2013)
Binderless board	EFB	Steam biomass explosion followed by hot pressing.	-	(Mejía, Quintana, and Ogunsile 2014)
	OPF	Steam explosion pretreatment followed by mat formation. Before the hot-pressing process, the	-	(Laemsak and Okuma 2000)

		mat was pre-pressed and placed between Teflon sheets.		

Bio-products	Oil palm biomass	Thermochemical conversion	Research Findings	Reference
	OPT	With the addition of glucose and sucrose, hot pressing of biomass without extraction of hot water.	-	(Tay et al. 2011)
Biosorbents for aurum (III) recovery	OPF	Bleaching for 2 hours at 80 °C.	-	(Saman et al. 2018)
Adsorbent for crude oil removal	OPF	Modification of biomass with lauric acid.	Maximum capacity for adsorption of 1,176 g/g	
Paper pulp	EFB	Diethanolamine pulping, accompanied by the AOpAZRP series bleaching.	-	(Mohamad Haafiz et al. 2013)
	OPF	Pulping with NaOH and ethanol accompanied by processing of hand plates.	-	(Zainuddin et al. 2011)

2.4.3.1 Biochemical Conversion Processes

Biochemical processing methods usually include the pretreatment and disposal of biomass for oil palm production, preceded by fermentation or microbial cultivation. Biomass pretreatment and saccharification must be combined to break down polysaccharides (i.e. cellulose and hemicellulose) from biomass to fermentable sugars (e.g. glucose and xylose). Pretreatment for lignocellulosic biomass is necessary before saccharification, as the complex lignocellulosic structure is recalcitrant to biological or enzymatic degradation. Monomer sugars from lignocellulosic biomass can be used in fermentation for the production of fuels and chemicals.

Biochemical processes for conversion of oil palm biomass include separate hydrolysis and fermentation (SHF), separate hydrolysis and co-fermentation (SHCF), simultaneous saccharification and fermentation (SSF), simultaneous saccharification and co-fermentation (SSCF) (i.e. co-fermentation and pentose) and integrated bioprocessing (CBP). SHF is the most commonly studied method for the biochemical conversion of oil palm biomass, while SSF, SSCF, and CBP are particularly involved in work to reduce the number of processing steps by process integration. Strong synchronization of processes typically results in a lower cost of resources (Menon and Rao 2012).

2.4.3.2 Thermochemical Conversion Processes

Thermochemical transformation is another mechanism for adding value to oil palm biomass. Thermochemical transformation processes use water, catalysts, and/or chemical reactants to transform biomass into another type (Xu, Jiang, and Zhao 2016). The most widely used processes for the production of biofuels and chemicals are thermochemical extraction by pyrolysis, gasification and thermal liquefaction. The resulting compounds are typically three main phases in these thermochemical transition processes: solid biochar, bio-oil, and gas (Table 5). Such materials may be used directly or further modified for the manufacture of biofuels and green chemicals.

Table 5: Bio-product synthesized from oil palm biomass through thermochemical conversion (Ahmad et al. 2019).

Bio-product	Oil palm biomass	Thermochemical conversion	Research Findings	References
Alkenes	EFB (water-soluble fraction)	Hydrothermal liquefaction Fe-assisted	28 % Carbon output (C_2, C_3, C_4)	(Asadieraghi and Wan Daud 2014)
Aromatic hydrocarbons	PKS	Nannochloropsis sp. co-pyrolysis. (PKS / NC=1:1) catalyzed at 600 °C with Cu / HZSM-5	Yield of 42.65 %	(Chang et al. 2018)
Biochar	EFB	Assisted the pyrolysis microwave.	25 MJ/kg HHV	(Salema and Ani 2012)
	OPF	60 minutes of pyrolysis at 500 °C.	15.41 MJ/kg HHV	(Abnisa, Arami-Niya, Wan Daud, et al. 2013)
	OPT	Pyrolysis for 3 hours at 450 °C.	18.3 MJ/kg HHV	(Lu, Chen, and Zeng 2010)
	EFB	Hydrothermal supercritical liquefaction at 390 °C and 25 MPa for 1 hour.	EFB of 0.37 g/g	(Chan et al. 2014)
	MF	Hydrothermal supercritical liquefaction at 390 °C and 25 MPa for 1 hour.	MF of 0.37 g/g	(Chan et al. 2014)
	PKS	Hydrothermal supercritical liquefaction at 390 °C and 25 MPa for 1 hour.	PKS of 0.37 g/g	(Chan et al. 2014)
	EFB	Assisted the pyrolysis microwave.	Phenol of (60-70) %	(Salema and Ani 2012)
	OPF	60 minutes of pyrolysis at 500 °C.	25.03 MJ/kg HHV	(Abnisa, Arami-Niya, Wan Daud, et al. 2013)
	PKS	Assisted the pyrolysis microwave.	PKS of 0.36 g/g	(Mushtaq et al. 2015)
	OPF	Pyrolysis at 400–600 °C, 15–30 min retention time and	Yield of 40.66 % with a total concentration of	(Abas, Ani, and Zakaria 2018)

		50–100 g activated carbon load.	26.61 mg gallic acid/g phenolic content	

Bio-product	Oil palm biomass	Thermochemical conversion	Research Findings	References
	MF	Pyrolysis catalyzed in a slow-heating fixed-bed reactor at (450–600) °C with steel slag-derived zeolite (FAU-SL).	47 % (550 °C) of wt	(Kabir, Mohd Din, and Hameed 2018)
	PKS	(330–390) °C hydrothermal liquefaction, (25–35) MPa pressure and 0.20 ratio of biomass to water	(10.5–16.1) MJ/kg HHV	
	EFB	Co-pyrolysis of the sludge of palm oil.	-	(Chow et al. 2018)
5-HMF	EFB	Co-hydrothermal	18.39 MJ/kg HHV	(Shamsul, Kamarudin, and Rahman 2018)
Furfural	Pretreatment liquor of EFB	EFB pretreatment with bisulfite, followed by liquor acid hydrolysis using H_2SO_4.	18.8 g/L	(L. Tan et al. 2016)
Hydrogen	EFB	Supercritical gasification of liquid at 380 °C and 240 bars (EFB/water ratio of 3.75 %w/w).	80 mmol/mL	(Sivasangar et al. 2015)
Lactic acid	EFB	Hydrothermal therapy with the catalyst of the Pb (II) molecule.	-	(Chin et al. 2016)
Levulinic acid	EFB	Catalytic levulinic acid development for 3 hours at 120 °C utilizing Fe/HY.	71.5 % Theoretical efficiency	(Ramli and Amin 2015)
	OPF	Catalytic levulinic acid development for 3 hours at 120 °C utilizing Fe/HY.	68.2 % Theoretical efficiency	(Ramli and Amin 2015)
Lignin polyols	EFB	Polyethylene glycol and glycerol liquefaction and reaction sulfuric acid.	-	(Faris et al. 2015)

Phenol, acetone, and butanone	PKS	Catalytic oil cracking uses the ZrO_2-based FeOOH catalyst.	A phenol of 35 % and an acetone of 20 % and butanone of 12%	(Masuda et al. 2001)
Syngas	OPT	Heat helped gasify at 800 °C.	52.4 g of syngas, 2.86 g H_2, 685 kJ of energy	(Nipattummakul et al. 2012)

2.4.3.2.1 Gasification

Gasification is a thermochemical process involving partly oxidized heating at (800–1800) °C using O_2 or air (Awalludin et al. 2015). The use of air to gasify results in low-calorie syngas (4–7 MJ / kg) which is typically suitable for use with boilers, generators, or turbines. (Maity 2015; Samiran et al. 2016). Although the use of O_2 for gasification can theoretically improve the calorific value of syngas, it is expensive to remove O_2 from the air. The resulting gas compositions depend on the conditions of the system and the types of feedstock. (Guo, Song, and Buhain 2015). The resulting lower gasification level fuel (below 1000 °C) includes CO, H_2, CH_4, CO_2, aliphatic hydrocarbons, benzene, toluene, liquid, and tars (Samiran et al. 2016). High-temperature gasification syngas (above 1200 °C) is usually composed up of CO, H_2, CO_2, and liquid (Samiran et al. 2016).

Research on gasification compositions (via supercritical water gasification) of cellulose, xylan, and lignin found the highest composition of xylan H_2 possible as a result of formic acid decomposition due to xylan degradation. Thanks to the separation of soluble intermediates from cellulose, the CO concentration was the lowest possible, and CH_4 was the highest from lignin thanks to the cleavage of highly branched methoxyl groups. CH_4 can be present because of the splitting of the aliphatic system. (Sivasangar et al. 2015).

Figure 4 describes the method of gasification for biomass and future fuels and chemical products as a prospective route to biorefinery by direct synthesis or an automated cycle of upgrading. Crude syngas can be used directly for electricity generation (Guo et al. 2015). Bio-SNG (CH_4-rich syngas) compressed or liquefied can be used as an automotive fuel. Methanol can be generated by syngas catalytic synthesis with an H/CO ratio of 2:1.

Using specific catalytic synthesis, syngas can be converted to bio-dimethyl ethyl (Bio-DME) and can be used as an alternate chlorofluorocarbon propellant (CFC) and a linear alcohol mixture of fuel additives such as EcaleneTM (Power Ecalene Fuels, Inc.)(Luque et al. 2008). Using Fischer–Tropsch synthesis and Hydro-Thermal Upgrading (Luque et al. 2008; Maity 2015), diesel-like biofuel can be generated from syngas upgrades. H_2 synthesized by steam reforming from syngas can be used for fuel cells with hydrogen (Guo et al. 2015). EFB studied the incorporation of gasification and the Fischer-Tropsch synthesis into bio-oil production. (Ng and Sadhukhan 2011).

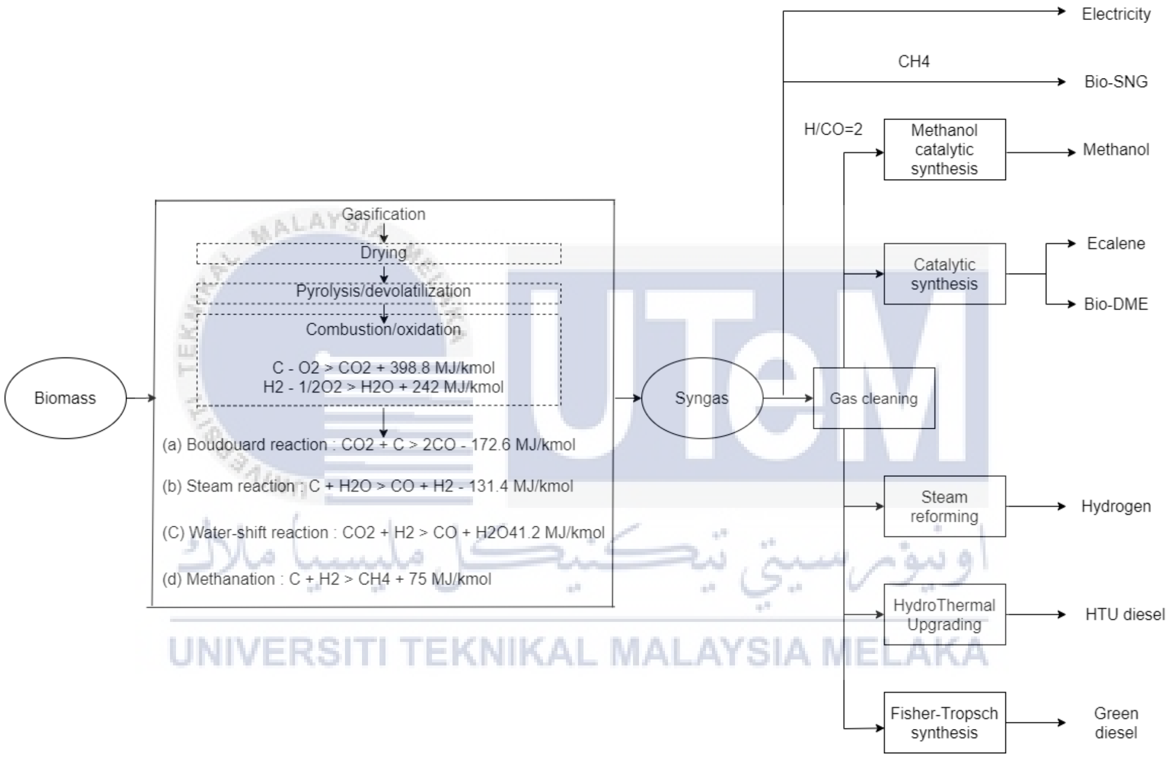


Figure 4: The method of the gasification cycle and the future implementation of the resulting gasification products through the incorporation of the plant upgrade as a prospective route for biorefinery (Ahmad et al. 2019).

2.4.3.2.2 Pyrolysis

The use of bio-oil as bio-fuel produced from biomass is beneficial due to the feasibility of the processing and transport of biofuels. However, bio-oil pyrolysis can be corrosive and have low thermal stability(Awalludin et al. 2015). Bio-oil needs to be purified due to its high acidity, impurities, organic toxins, water and oxygen, differing viscosity and poor energy content, it can not be used directly as a replacement for diesel or petrol oils (Luque et al. 2008; Melero, Iglesias, and Garcia 2012). The improvement also aims at enhancing the properties of bio-oil by growing the amount of humidity and acidity, as well as rising the heating quality and the safety of storage. Upgrading technologies include blending, catalytic extraction, emulsification, esterification, hydrogenation, hydrodeoxygenation (HDO), molecular distillation, steam reformation, and supercritical fluidization. (Guo et al. 2015).

Pyrolysis is the thermochemical extraction of biomass at (300–900) °C temperature and atmospheric pressure without air (Awalludin et al. 2015; Guo et al. 2015; Maity 2015). The resultant pyrolysis products are bio-oil (carboxylic acid mixtures, ketones, aldehydes and/or aromatics), biochar and syngas (H_2, CO, CH_4 and/or CO_2 mixtures) (Hosseini and Wahid 2014; Luque et al. 2008), where the material composition depends on the method of pyrolysis phase. The main types of pyrolysis processes are slow pyrolysis and rapid pyrolysis. Slow pyrolysis involves heating biomass for several hours or days at (300–600) °C, with the resulting products being biochar (35 % of dry biomass), bio-oil (30 % of dry biomass) and syngas (335 % of dry biomass). Quick pyrolysis utilizes fast biomass heating up to 500 °C within 2 s, where the resulting bio-oil is generated at (50–70) % of dry biomass, (10–30) % of bio-oil and (15–20) % of syngas (Guo et al. 2015). The corresponding pyrolysis products with potential applications are illustrated in Figure 5.

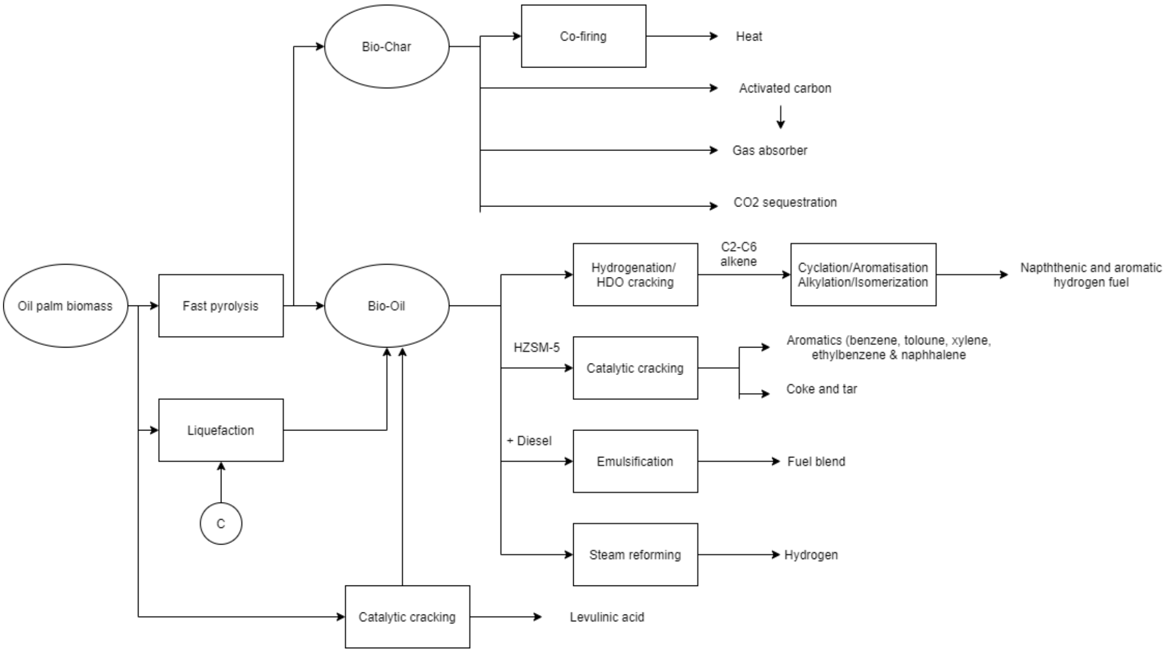


Figure 5: Possible products from pyrolysis, liquefaction, and catalytic cracking by integrating technological development as a potential avenue for biorefinery (Ahmad et al. 2019).

2.5 Palm Oil Biomass Feedstock Spatial Analysis

The contribution of the biomass industry relies on a variety of factors, including the cost of production and the supply chain network. Many types of biomass sources are large, voluminous, and sometimes seasonally accessible. Uncertainties in the availability of raw materials and the final market for the commodity often hinder the management of the supply chain of biomass. MPOB (2016) estimates that 61 % of the total area planted with oil palms is privately owned, followed by 16 % of the area planted by individual smallholders. State agencies (6 %), Federal Land Development Authority (FELDA) (13 %), Federal Land Consolidation and Rehabilitation Authority (FELCRA) (3 %), and Rubber Industry Smallholders Development Authority (RISDA) (1 %), respectively, own the remaining planted regions. Dispersed management of palm oil plants in combination with remote sites strengthens the supply chain. Biomass generation, unlike wind, solar, and hydro, involves the processing, selection, transport, pre-treatment, and storage of feedstock. The economy of renewable energy production and other bio-based industries relies heavily on availability at a fair price of a stable, long-term supply of biomass feedstock.

In general, feedstock logistics is part of the biomass supply chain optimization cycle which involves four main processes from field to throat biorefinery to biomass feedstock production. This is a vital link between the processing of biomass and the use of biomass to generate high-value items such as bioenergy, bio-materials, and bio-chemicals. Essential aspects include the option of biomass feedstock storage, storage growth and design, cost-benefit analysis, and environmental sustainability. For feedstock logistics designs or processes, the use of optimization models to make feedstock logistics systems cost-effective, reliable and commercially viable is a factor in these considerations. (Miao et al. 2012; Zhang et al. 2013).

Figure 6 demonstrates the logistics of palm oil biomass feedstock. Most of these waste materials are found in palm oil plantations or estates, depending on the amount of palm oil waste, while some are stored in palm oil mills.

Figure 6: Palm oil biomass feedstock logistic processes involving harvesting and collection, storage, pre-processing, and transport to biorefinery facilities (Yatim, Ngan, and Lam 2018).

2.5.1 Harvest and Collection

The first step of the palm oil biomass feedstock logistic cycle is the processing and transport of palm oil waste from plantations or mills to storage facilities. Factors such as the scale of plantations or estates, the volume of palm oil waste, the pace of harvesting and collection, the location of waste, the supply of labor, and the methods of harvesting and collection shall decide the quality, profitability and cost of harvesting and collection. New fruit bunches (FFBs) are harvested and gathered in the plantations and then transported to crude palm oil (CPO) mills. Empty fruit bunches (EFBs) and palm kernel shells (PKS) and mesocarp fiber are also available in mills and can be shipped to storage facilities in mills or other locations for downstream processing.

On the other hand, palm fronds and trunks are not widely available, so they can only be gathered so handled during planting and pruning. The palm fronds are currently left in the plantation as a replacement for topsoil and natural fertilizer. Collection and deployment methods range from simple manual sorting of wheelbarrows, buffalo carts, or motorized carts to advanced mechanization. Oil palm trunks are accessible every (25–30) year at the end of the plantation life cycle. The trunks are either chipped or ground and left in the plantation as fertilizer. A limited number of trunks are processed and used in wood-based industries such as flooring, plywood, and furniture.

At the end of 2015, 86 % of the 5.64 million hectares planted were mature plantations, while 14 % were immature trees (Malaysian Palm Oil Board 2019). Approximately 240 million tons of palm oil trunks will be available during replanting with an unevenly distributed supply of palm oil trunks due to geographical locations and various plantation maturities (Agensi Inovasi Malaysia 2013a). Supply uncertainties due to geographical and timing limitations present challenges to the processing methods and future usage of these wastes, as many downstream industries rely on a reliable supply of biomass over time. As a result, all direct and indirect costs associated with the harvesting and processing process must be considered by the downstream industries.

2.5.2 Storage

Adequate storage of biomass is essential in order to manage seasonal production and ensure adequate supply to downstream industries. Decisions such as storage methods and storage costs are taken during the storage process of feedstock logistics in such a way that the quality and requirements of biomass are not compromised. The amount of storage required depends largely on the type of biomass and the properties of biomass, including the moisture content. For example, high-humidity feedstock, such as oil palm fronds intended for wet use, is more suitable for fermentation and anaerobic digestion processes, whereas low-humidity feedstock is optimal for thermal processes (McKendry 2002; Zahari et al. 2012). In order to avoid excessive degradation of feedstock, constant monitoring of the wet storage system is required, while spontaneous combustion and excess decomposition problems should be taken into account in the dry storage system (Badger and Fransham 2006). In addition, the effects of shrinkage, compositional, and pretreatment and soluble sugar capture must also be considered before determining which storage device should be used (Carpenter et al. 2014; Kenney et al. 2013).

Storage costs and the continuous availability of biomass feedstock are essential to ensuring the viability of a sustainable logistic network capable of supplying significant quantities of biomass to biorefinery facilities. Depending on the size, quantity, and characteristics of the feedstock, the storage facilities may be located in the same place as the origin of the feedstock. The method of on-site storage can cost less, but is exposed to a high risk of biomass loss, and biomass moisture can not be managed, which can lead to potential problems at the biorefinery conversion level (Rentizelas, Tolis, and Tatsiopoulos 2009). For certain cases, feedstock volumes are small and the establishment of storage facilities at the same location as the feedstock source may not be economically viable. Storage facilities (e.g. a few days supply) may need daily feedstock refilling for a comparatively limited capacity compared to a plant with a large storage capacity. Therefore, to avoid supply shortages and disruption of conversion processes, reliable and flexible transport arrangements are becoming necessary, particularly for a small storage facility in a biorefinery plant.

2.5.3 Preprocessing/Pretreatment

Different types of biomass undergo various forms of pre-processing or pre-treatment processes that turn the biomass feedstock into a physical, chemical, or biological state or shape more suitable for transport or conversion to liquid fuels and fine chemicals. Types of preprocessing methods include densification, on-site pyrolysis, grinding, drying, chemical handling, silage, fractionation, and mixing (Chin et al. 2013; Oudenhoven et al. 2016; Rodriguez et al. 2015; Tabil, L.Adapa P., and Kashaninejad 2011). In the case of oil palm biomass, trunks and fronds may be chipped, dried, and/or pelletized, while empty bunches of fruit and mesocarp fiber may be cut, dried, and/or compacted. Due to their very low moisture content, Palm kernel shells can be easily used or shipped without further processing.

Based on the composition and the by-products produced, the option of the pre-processing system and the pre-treatment technology used for a specific biomass can be selected. Such factors have a significant effect on pre-processing and pre-treatment costs (Kumar et al. 2009). For example, due to the high upfront investment costs needed for the pre-processing of biomass, such as shredding, drying and pressing of biomass, most millers were hesitant to use empty fruit bunches (EFBs) to generate renewable energy instead of burning EFBs to generate fertilizers (Samiran et al. 2016; Shafawati and Siddiquee 2013). For the pre-processing period, a significant proportion of their overall costs will be needed, downstream industries are likely to find certain cost-effective pre-processing solutions that do not need, for example, biomass drying. Insufficient knowledge of the properties of oil palm biomass in relation to its usage as bioenergy and biomaterial feedstock limits the construction of cost-effective and reliable pre-processing technologies and equipment. One reason for the lack of knowledge of biomass resources by downstream industries is that much of this knowledge is limited to research laboratories of local universities and research institutes and that there is inadequate cooperation between two-way networks and science and industry (Hansen and Ockwell 2014).

2.5.4 Transportation

Transportation of biomass feedstock is important because it bridges the growth, processing, and conversion of biomass into a full biorefinery network. As a consequence, safe, scalable, and effective transport will dramatically increase cost competitiveness and boost the profitability of the Malaysian biomass industry. Biomass forms, sizes, planned end-user, places of supply and demand, and availability of equipment and facilities often influence the efficiency of the transport network (Miao et al. 2012).

Existing transportation systems are largely fixed with well-established configurations and volumes that comply with road and transportation laws and are restricted to several transportation options such as truck, rail, or barge. Understanding these constraints helps downstream industries to design and manage efficient transport systems that can minimize the costs of mobilizing biomass within the logistics systems of feedstock. Several key technical and operational aspects closely linked to the transportation of feedstock must also be addressed, such as handling operations and queuing systems required to unload feedstock from transport mode (e.g., truck) to interim storage before conversion (Hess, Wright, and Kenney 2007; Miao et al. 2012). In terms of feedstock for oil palm biomass, road transport is likely to be the preferred mode of moving biomass from plantations to biorefinery facilities due to remote oil palm plantations.

The fragmented ownership of the plantations has confused the management of the feedstock, as various owners have their priorities for harvesting and gathering time. Today, most crude palm oil is being shipped from mills to port-based bulking and processing facilities. A similar system is likely to be envisaged for the biomass supply chain to store reasonably vast volumes of biomass in localized storage and processing facilities. Since trucking is widely used for the transport of wood, it can also be socially unpopular as it can harm roads and improve traffic flow in rural areas. Innovative transport systems, such as upgraded containers and compact vehicles, will reduce the effect on traffic and the environment.

2.6 Spatial Modelling

Spatial modeling has been an important part of geographic information systems (GIS) and remote sensing. In tandem with traditional mathematical and machine learning algorithms, GIS spatial analysis has been used in a wide variety of fields, from epidemiology (Auchincloss et al. 2012) to climate science (Patenaude, Milne, and Dawson 2005) to geoscience (Pradhan, Lee, and Buchroithner 2010) and natural resources (Martin et al. 2005; Reynolds-Hogland, Mitchell, and Powell 2006; Wells et al. 2016). Nonetheless, the current methodology used in most GISs to integrate computational and machine learning algorithms and method raster models limits the kinds of analyzes that can be done. This approach can typically be described as a series of sequential steps : (1) construct a sample data set using the GIS; (2) import a sample; data obtained in statistical applications such as SAS, R, or MATLAB; (3) explain a relationship (e.g. a predictive regression model) between response and predictive variables that can be used in the GIS. Create predictive surfaces, and then (4) construct a symbolic space model inside the GIS that uses the GIS.

Outputs from the mathematical model for the development of spatially different surfaces. Often this is multi-platform, the complexity of this method involves the development of a platform that streamlines and automates certain aspects of the operation. System, in particular export and import steps connecting similar applications. Nevertheless, a number of difficulties present significant constraints to the creation of final outputs in this manner, including additional machine learning, the integration of predictive model outputs, the management of large data sets, and the management of long processing times and the heavy storage space needs associated with this workflow. (Hogland and Anderson 2015).

2.6.1 Spatial Analysis Model Using GIS

The Geographic Information System can be very helpful for monitoring the supply chain. Geography matters a great deal, as the measures to be done or the problems to be addressed are of a spatial nature. GIS is emerging as a very important tool for industries like logistics and the use of transport services. routing-to find the shortest path between two points and to consider an alternate route in the case of any difficulties in the shortest route-is the key challenge to be solved in handling the supply chain. GIS and spatial modeling can be very useful in resolving routing issues, as they can analyze a wide variety of alternative approaches from various viewpoints with speed and precision. The task of controlling the supply chain is very difficult. The problem can be minimized by introducing Geographic Information Systems, which efficiently mitigate ambiguity by identifying tacit geographical differences and correlations that can form the basis for successful decisions. Systems such as ArcLogistics Route can eliminate pain from applications such as Vehicle Tracking and Dispatch, Path Planning, Factory Processes, Factory and Depot Management, Routing and Scheduling. GISs is committed to leveraging the inherent importance of geography in most of the data sets we are presented with today (Naqi, Akhter, and Ali 2010).

GIS technology is all about simulation software or the ability to track points on a map. It is the capacity to establish relational relationships and to determine the nature of each relationship. An example will be the ability to track the component through the assembly chain by defining main production sites and routes from the manufacturer to the packaging plant, and from the manufacturing plant to the distributor and to the customer.

2.6.2 The Importance of Spatial Analysis

Spatial analysis allows you to solve complicated location-oriented problems and help consider where and what's going on in the universe. This goes beyond visualization to let you research the features of the locations and the relationships between them. Spatial insight offers the decision-making fresh insights.

2.7 Research Gap

Table 6 summarizes the prior research on oil palm biomass supply chain optimization models. Various criteria are classified to include distinction and to highlight the study differences in previous plays. Such requirements shall include the purpose of the model, approach, and results. In addition, six studies on oil palm biomass supply chain analysis have been reported.

Based on Table 6, the literature review and gap analyses on this study lead to the strategy to overcome the problems of the supply chain through various decision making that could improve the economic and environmental aspects. On top of that, various methods were used to solve the mathematical formulation of each case study such as the Advanced

Interactive Multidimensional Modeling System (AIMMS), Simple Additive Weighting Method (SAW), and GAMS. This optimization software is designed for modeling and solving linear, non-linear, and mixed-integer optimization problems. Accordingly, the particular findings could be defined considering their objectives in managing the supply chain model to meet their optimal criteria.

Table 6: Research Gap.

Year	Author	Objectives	Methodology	Findings
2019	Abdul Halim Abdul Razik, Cheng Seong Khor, Ali Elkamel	To exhibit a model-based methodology in business decision-making for upgrading the operational arranging of a biomass-to-bioproducts supply chain.	AIMMS	Ideal item blend involving various items from various preparing stages (counting preprocessing) can be required to be accomplished, with benefit predominantly inferred through the offers of biofilter, bioethanol, and byproduct.
2018	Rangga Primadasa	To build up Logistics & Supply Chain Management (LSCM) systems for the palm oil industry in Indonesia by making the 8 mainstays of LSCM structures as the premise of its decent footing.	Validate using simple additive weighting method (SAW)	LSCM System for the palm oil industry in Indonesia has seven columns including data innovation administration, provider the administration, disposal of waste, client relationship the board, coordination administration, top administration duty, ceaseless improvement.

2017	Keivan Ghasemi Nodooshan		• Robust optimization • Robust Counterpart Mathematical Model • Coded in GAMS software and solved by the commercial solver CPLEX on a personal computer	Areas assume a significant job in the optimality of various situations which features the advantages of using progressively exact finding instruments like GIS
2017	Abdul Halim Abdul Razak	To settle those issues by demonstrating and streamlining biomass supply chains for assembling vitality, synthetic concoctions, and materials depending on their particular handling courses	• General Algebraic Modelling System (GAMS)	• Ideal outcomes showed that a yearly benefit of $22,618,673 was relied upon to be accomplished, and this worth. was contributed mostly by the offers of bio-filler, bio-ethanol, and side-effects from the processing plant • The ideal choices about transportation sums and modes have legitimately impacted the general monetary gainfulness just as

				biomass openness and portability.
2014	Qi Li and Guiping Hu	To give a two-organize stochastic programming structure for the biofuel store network streamlining issue thinking about vulnerabilities.	• General Algebraic Modeling System (GAMS) • Two-stage stochastic programming is one of the most widely used modeling frameworks to study decision making under uncertainties.	• Cellulosic biofuels assume an undeniably significant job in meeting RFS2 and decreasing vitality reliance. • The half-breed thermochemical creation pathway of bio-oil gasification which consolidates quick pyrolysis and gasification is one of the promising generation pathways for cutting-edge biofuel creation.
2014	Akansha Singh, Yunfei Chu, and Fengqi You	To streamline the area and limit of a system of biorefineries regarding the absolute net present an incentive within the sight of rivalry among biorefineries,	• Mixed-integer nonlinear program (MINLP) with black-box functions • Genetic algorithm (GA) in matrix laboratory (MATLAB) to	The upgraded biorefinery arrange had a net present estimation of 10.7% more prominent than that of the underlying system

		among ranchers, and among biorefineries and the nourishment retail.	solve the optimization problem	
2012	F. Oliveira, V. Gupta, S. Hamacher, I.E. Grossmann	To decrease the likelihood of bringing about insignificant expenses while protecting the decomposable structure of the issue	• A Lagrangean Decomposition Approach • AIMMS 3.11 and solved with CPLEX 12.1 on Intel i7 1.8GHz CPU with 4GB RAM.	• Numerical outcomes propose that different definitions of the non-anticipative conditions have a significant effect on the performance of the calculation. • The proposed half-breed approach has prevalent execution when contrasted and the customary subgradient calculation regarding quicker computational occasions for the issue tended to in this work.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents the overall spatial modeling framework developed for the supply chain of bioethanol from integrated oil palm biomass biorefinery. The research gap which has been distinguished in the previous chapter is proposed to be settled through the development of this flowchart. In the following section, details regarding the overall flow of methodology in the flowchart will be clarified.

3.2 Process Flowchart

Figure 7 illustrates the process flowchart on developing the supply chain network design for the production of advanced biofuels from integrated oil palm biomass biorefinery that addressed the present research gap. The flowchart integrates the application of few tools which are ArcGIS and GAMS in accomplishing the proposed research objectives to analyze the strategic and operational optimization for the production of advanced biofuels from integrated oil palm biomass biorefinery. The software which will be used to incorporate these methods are ArcGIS 10.3 and GAMS 4.68.6. This framework will be applied in Johor for a case study that was chosen because of the presence of oil palm plantation and the availability of established transportation networks for logistics planning.

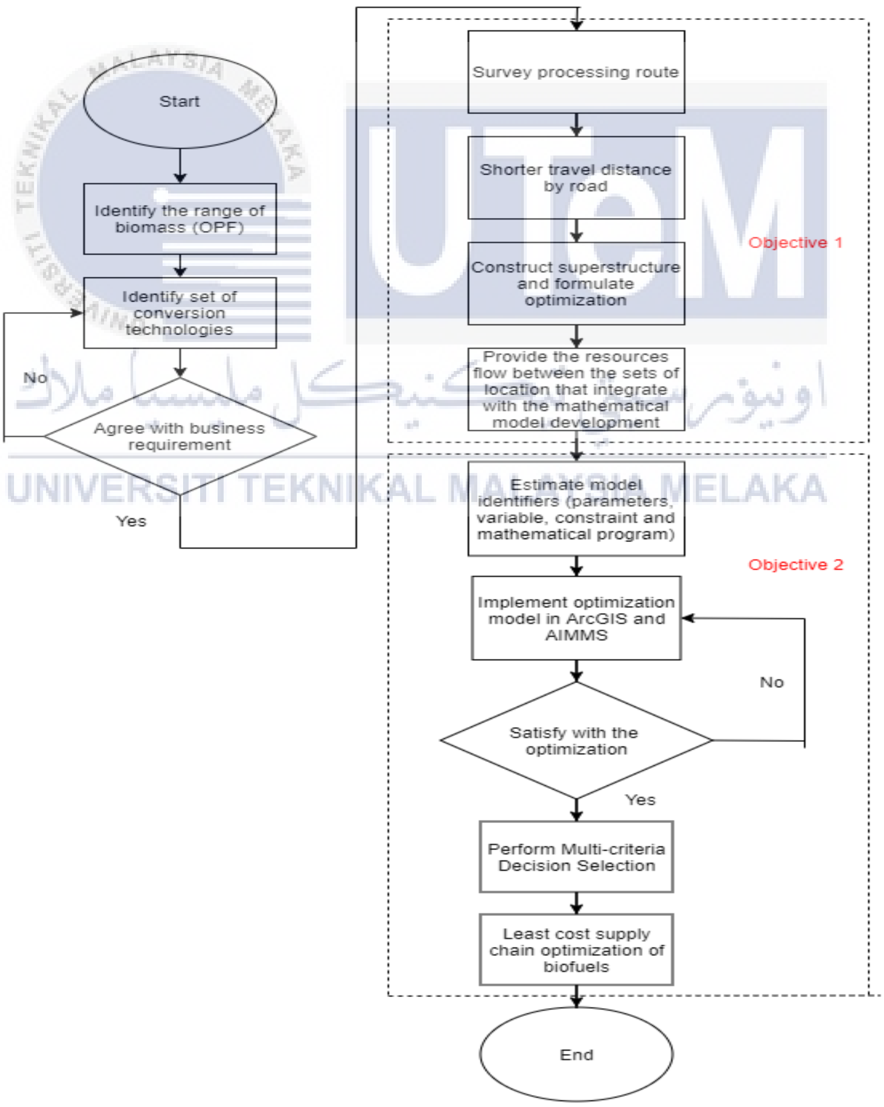


Figure 7: Process flowchart of the supply chain for gasoline.

3.3 K-Chart

K-chart is shown as a Tree diagram as shown in Figure 8. A K-chart is made up of issues, methodologies, results, and timeline. A K-chart essentially organizes the issues within the field under review from the large ones to the specific ones. The broader issues were put in the Tree diagram's higher branches and dissected underneath it into different specific issues (sub-issues). Then the issues are classified as common, complementary, and centered issues. Thicker (or colored) rows differentiate the things under consideration. These are the main study issues, while other issues are only intended for literature reviews (General Issues). The blue-colored box was selected in this study.

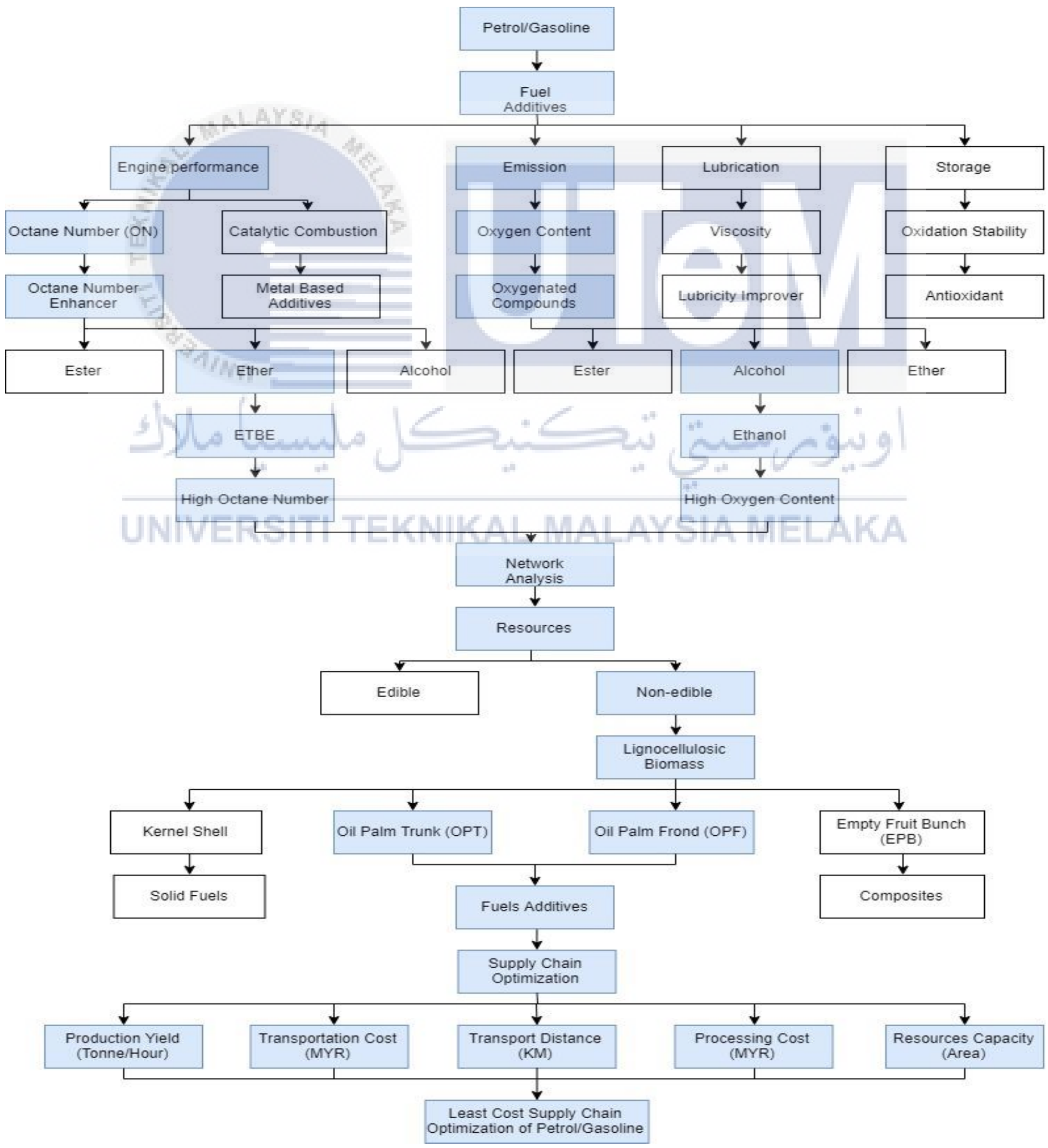


Figure 8: K-chart.

3.4 Spatial Optimization Modeling Framework

A new graphical spatial modeling framework has been developed to resolve the existing research gap in biofuel supply chain analysis, as seen in Figure 9. This framework incorporates the use of several different tools GIS and MILP, to achieve the intended research objectives of developing strategic and operational planning optimization for the supply chain of biofuels.

The software that will be used to integrate these methods is ArcGIS 10.3 and GAMS 28.2.0. This framework will be applied to the Peninsular Malaysia case study in Johor, which was selected based on the existence of large oil palm plantations and the high number of palm oil mills for biomass supplies and the availability of established transport networks for logistic planning. The accompanying sub-sections will include information on the main steps involved in the framework, including the availability of resources, network analysis, and optimization.

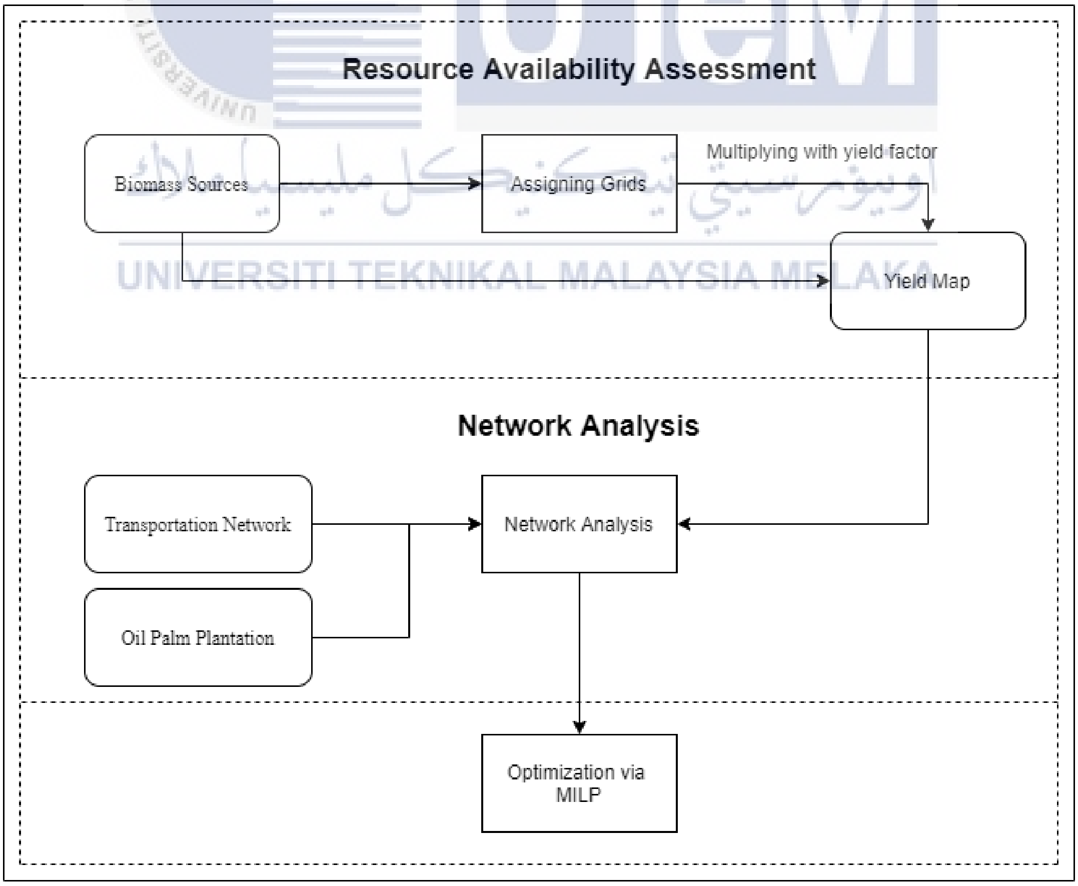


Figure 9: Spatial modeling framework.

3.4.1 Resource Availability Assessment

Spatially dispersed biomass supplies have led by geographical tools such as GIS to the needs for effective quantification of regional biomass resources. In Malaysia, the production of palm oil has helped produce a wide range of biomass such as EFB, MF, PKS, OPF, and OPT. Many of this biomass is produced in the palm oil mills EFB, MF, and PKS, while the rest is produced from the plantations OPF and OPT. Figure 10 portrays the resource availability of oil palm biomass (OPF and OPT) in Johor, Malaysia.

To quantify the availability of this biomass, biomass availability factors will be multiplied with the biomass production rates from palm oil mills and oil palm plantation areas. The factors for availability are OPT 40 ton/ha. y and OPF 7.5 ton/ha.y. Data for OPT and OPF production are obtained from SIRIM (2014) for every oil palm plantation in Johor, Malaysia. For the oil plantation area, Johor, Malaysia 's land use map for the year 2013 (MaCGDI, 2013) is computerized to retrieve the oil palm plantation layer in vector format that will be used in GIS. This oil plantation layer would be allocated to districts to obtain the availability of oil palm plantation biomass, which is the availability factor multiplied by the oil palm plantation area.

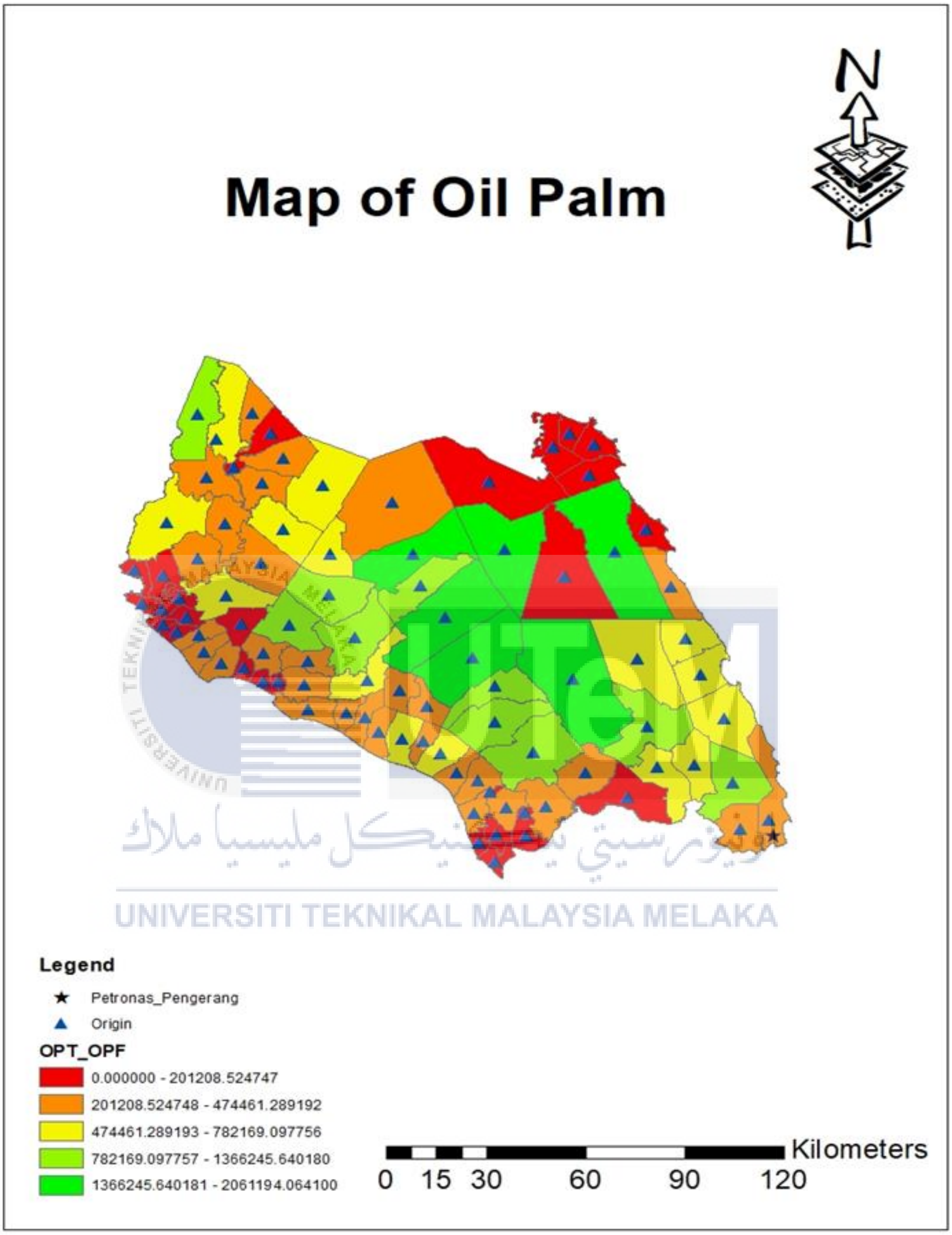


Figure 10: Oil palm biomass (OPT and OPF) in Johor, Malaysia.

3.4.2 Network Analysis

Network analysis was carried out by taking into account detailed road transport routes from each location to the respective demand center in Johor as shown in Figure 11. Network analysis can address a range of linear network issues such as roads, railways, rivers, facilities, and utilities. The network analyst included in ArcGIS will use the "***OD cost matrix***" tool to evaluate the road transport network. The OD cost matrix identifies and calculates the least expensive routes in the network from different sources to multiple destinations. Although the OD cost matrix solver does not generate lines that match the network, the values stored in the lines attribute table represent the network length, not the straight-line path. This research would define the distances between the supply of biomass to biorefinery facilities and the demand center of biorefinery facilities by network analysis. Such distances will be inputted in the transport cost calculation of the optimization model.

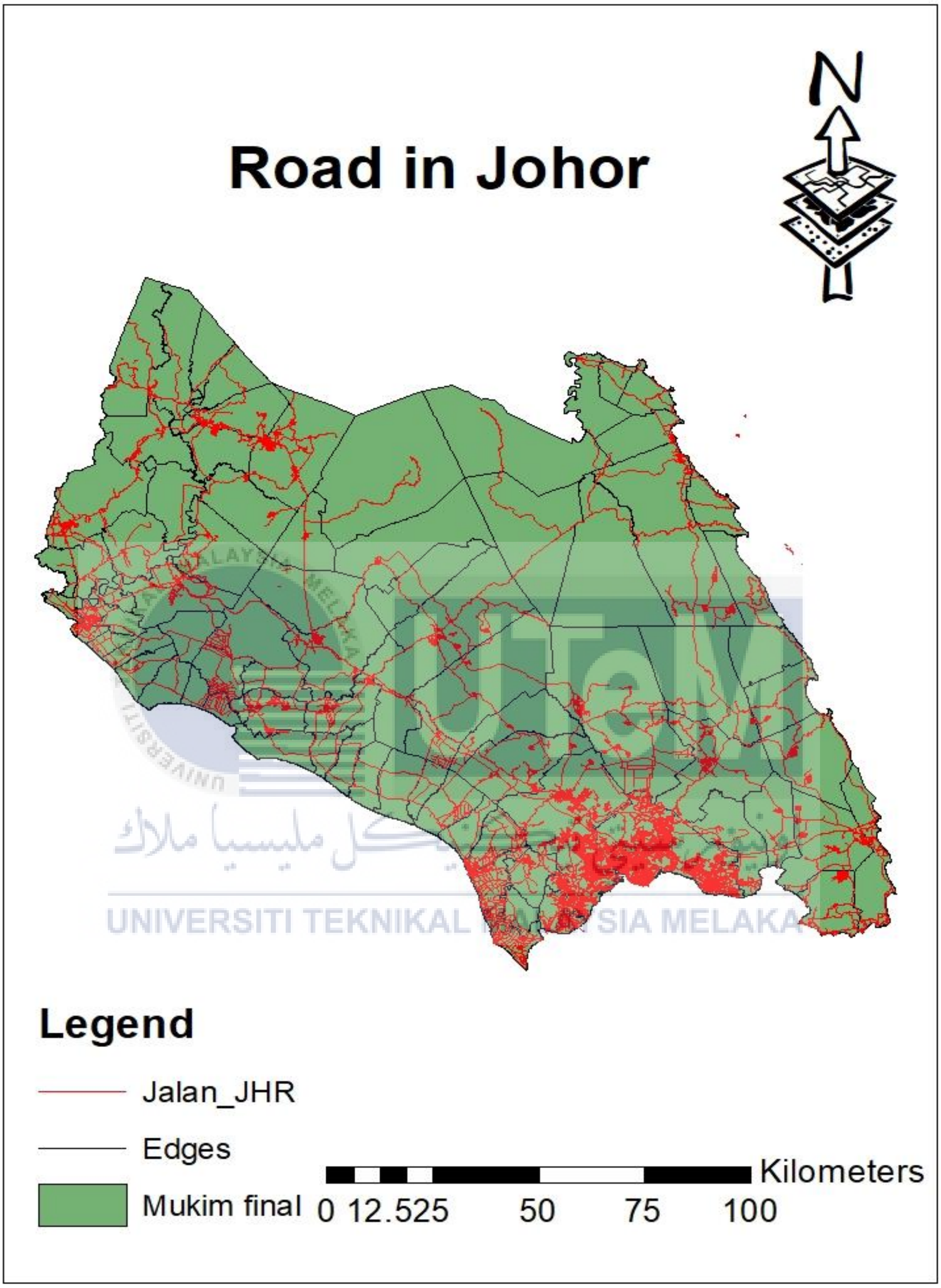


Figure 11: Transportation network in Johor.

3.4.3 AHP for The Potential Biorefinery Selection

AHP was used in this study as a basic objective (choosing the best location of biorefinery before optimizing the supply chain of biofuels) and alternatives (potential biorefinery) are possible. Where different criteria are involved, AHP is one of the very few multi-criterion decision-making (MCDM) methods capable of handling a wide range of criteria, especially when one of the criteria is qualitative. (Bernadette Nambi Karuhanga 2010). AHP is an effective and robust MCDM tool for complex problems that consider both quantitative and qualitative aspects. It is also user-friendly since AHP is well supported by widely-produced software (e.g. Expert Choice in this study), which also provides a performance sensitivity analysis. This is also one of the tools used to determine the relative importance of a set of characteristics or parameters and is capable of giving appropriate priority to each criterion.

AHP is an incredibly flexible decision-making approach that can be used in a wide variety of scenarios for various criteria problems, including supplier-selection decisions, facility-location decisions, scheduling, risk and potential modeling, choice of technology, strategy, and product design, and so on. AHP allows decision-makers to manage complex problems in the context of a hierarchical structure or a set of interconnected third parties, with several layers ranging from root (objective) to leaves (alternatives) (Cheng and Li 2001) reported that AHP had two simple implementations. The first is to assign weights to a set of pre-determined elements (e.g. parameters, factors) and then to agree on a range of possibilities or alternatives. Second, it can help to classify the elements to identify the key elements. AHP is then used in this study to help classify potential biorefineries before optimizing the supply chain of biofuels. Figure 12 indicates the priorities of five criteria with respect to goals that are created in Expert Choice.

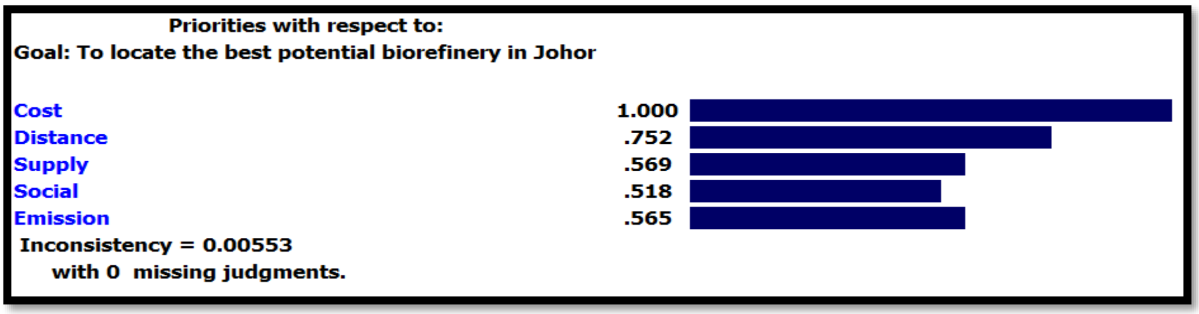


Figure 12: The priorities of five criteria with respect to goal that are created in Expert Choice

3.4.4 Optimization Model Structure

Optimization models were developed through the development of the spatial modeling methodology with the biofuel supply chain biomass network design for the strategic system as illustrated in Figure 13. The model should determine the optimum cost structure which includes various economic factors such as fuel costs, biomass costs, transportation costs, biorefinery costs (capital and operating expenditure), and emission cost at single planning. Different economic, environmental, and technological variables that are affected by different constraints can affect the minimization of these costs. The system would choose the best way to reduce emissions by configuring the most acceptable technologies, capacities and locations to be elected to identify the optimum cost structure.

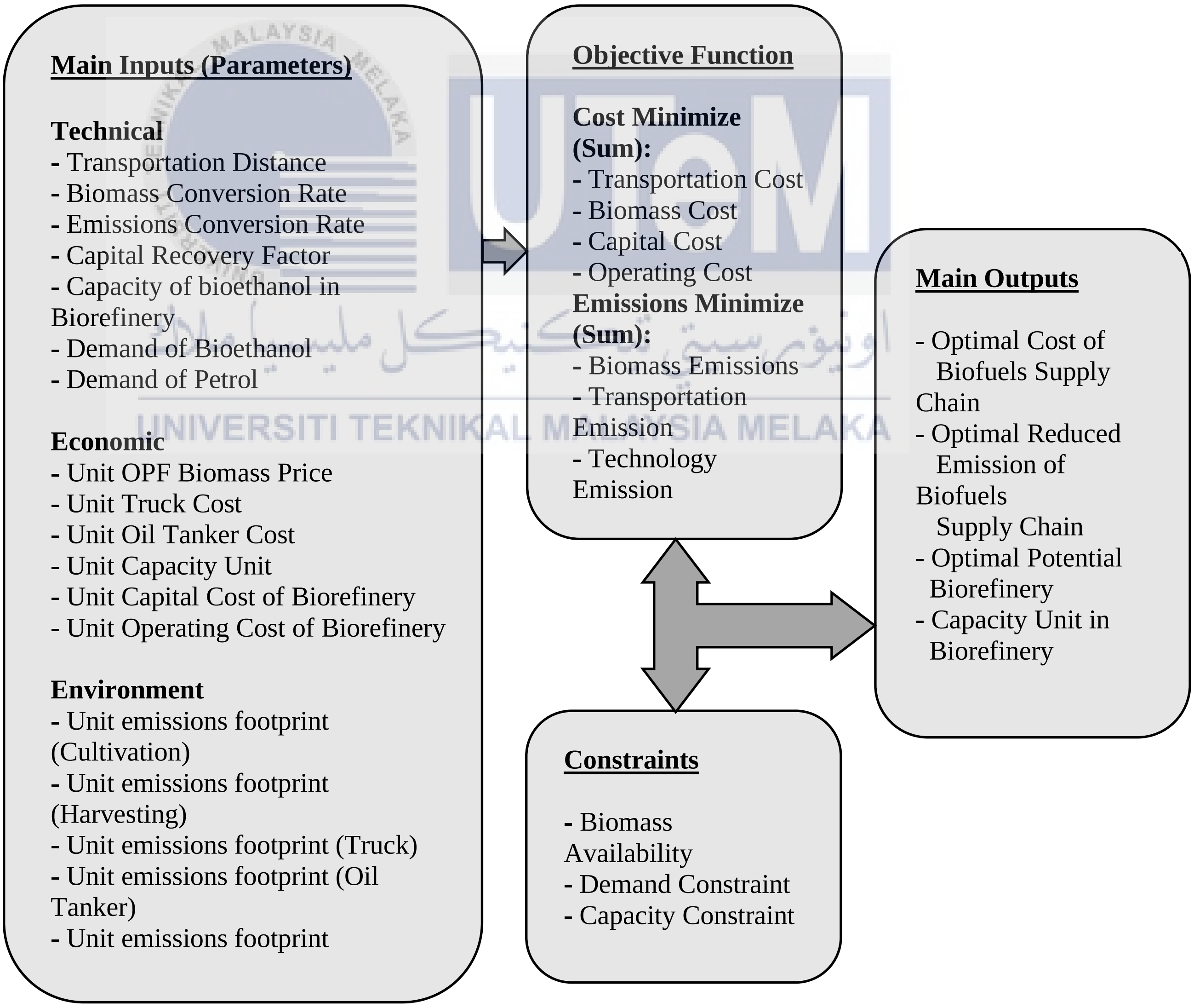


Figure 13: Optimization model structure for biofuels supply chain.

The process flowchart was concentrate on the standard approach used to address optimization issues. This will consist of several major phases including identifying the range of biomass, identifying a set of conversion technologies, survey processing route, construct the superstructure and formulate optimization, implement optimization model in ArcGIS and GAMS and perform of sensitivity analysis as illustrated in Figure 14.

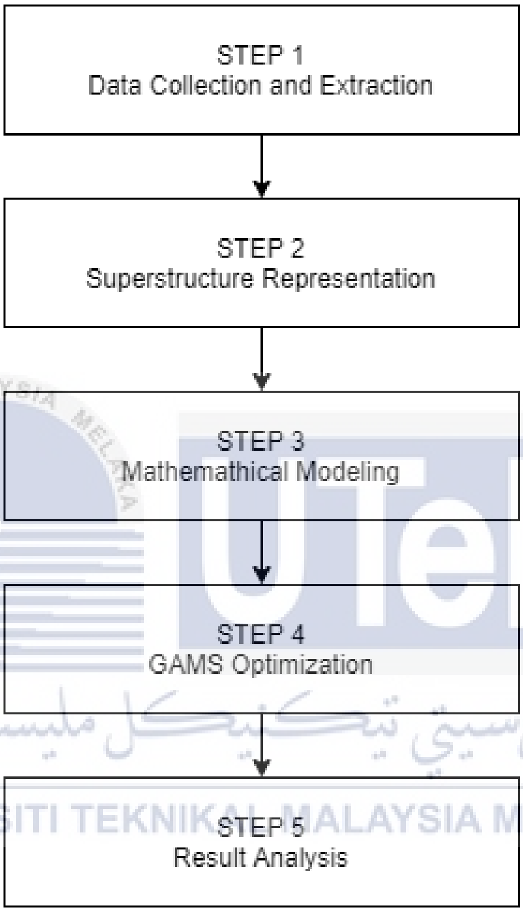


Figure 14: Generic methodology in solving an optimization problem.

3.4.4.1 Data Collection

It is important to establish a comprehensive database consisting of an existing spatial database with the models' economic, environmental, and technological inputs in designing the optimization models. It is possible to obtain these data from the following resources:

i. Industrial records:
   For an existing process, each oil palm-based industry has records of input resources, process capacity, process yield, and economic data. Communication with industrial staff can provide reasonably well-estimated data for unrecorded data. For each industry, these data represent actual operational data.

ii. Literature review:
   There is a wide range of reliable published source materials for economic, environmental, and technical information purposes.

iii. Related organization:
   The Malaysian Palm Oil Board (MPOB) is the Malaysian oil palm production management and monitoring body. This organization may retrieve statistical data on the availability of oil palm, such as planting area or oil palm biomass

3.4.4.2 Superstructure Representation

Superstructure can be described as the network diagram that includes all possible network configurations between supply and supply chain system demand. The superstructure will provide the flow of resources between the sets of locations that are useful for the development of mathematical models.

The superstructure for this research is illustrated in Figure 13 based on the oil palm biomass supply chain network that includes the location of biomass supply *i*, biorefinery facility *j*, and demand center *k*. There are 78 biomass plantations *i* for biomass supply that represented in i=1,2,3…n. As shown in Figure 15, oil palm biomass is harvested in farms and pretreated in the biorefinery into small particles ready to be processed into biofuels. Pretreated biomass is processed in the biorefinery facilities to be converted and upgraded to produce advanced biofuel. In this study, it is assumed that the conversion and upgrade of biofuels are carried out in the same facility and then transported to the Petronas Pengerang which is the location of demand for biofuels.

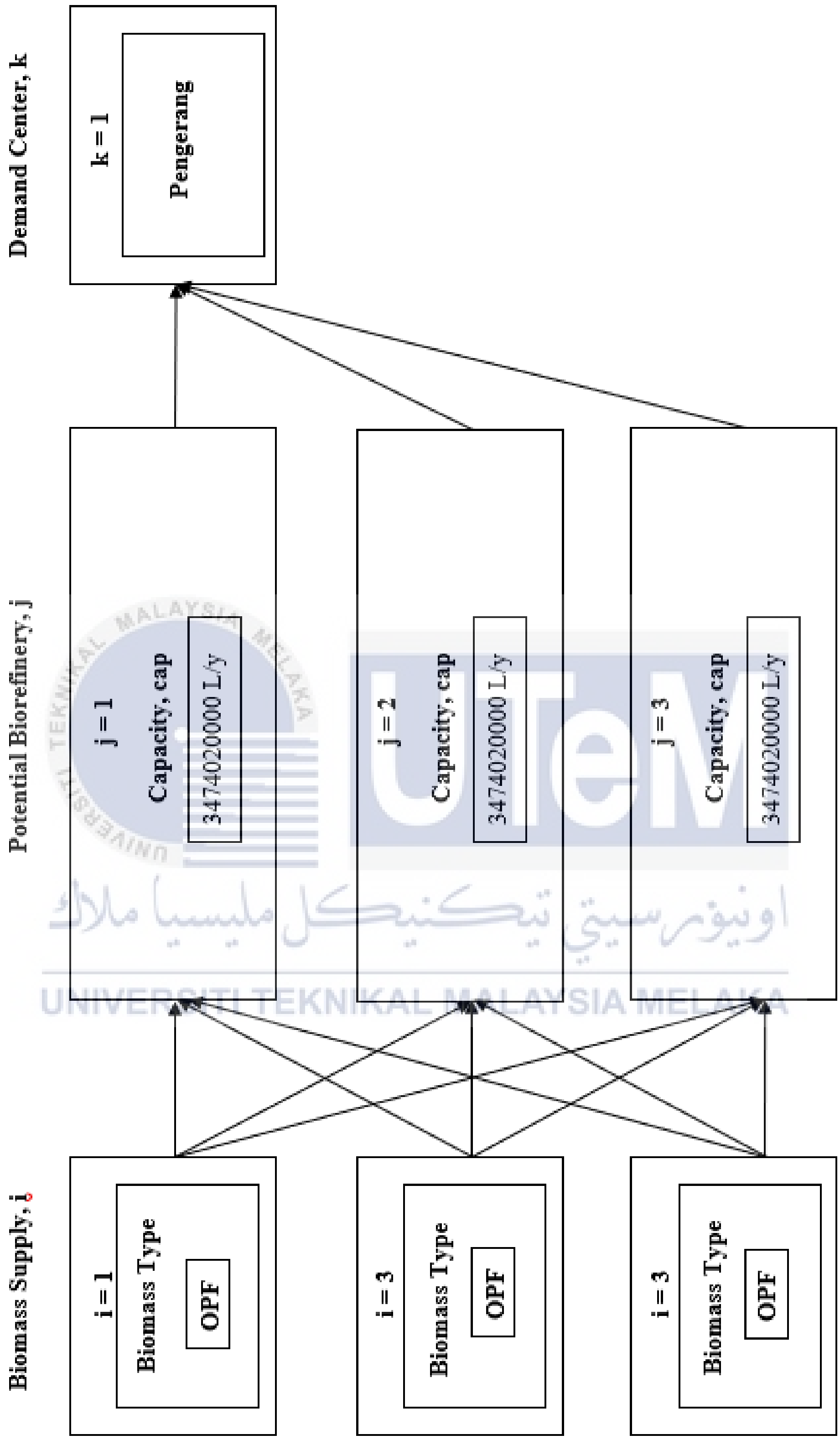


Figure 15: Biofuels supply chain network design.

3.4.4.3 Mathematical Modelling

Mathematical modeling is based on Mixed-integer linear programming (MILP), which is often used in supply chain planning and optimization. MILP contains problems in which only certain variables, x is bound to be integers, while other variables are permitted to be non-integers. There are several important aspects of the optimization model that need to be considered, such as objective function, decision variables, parameters, and constraints. There are two objective function works for this study by minimizing the total cost and emissions of the supply chain that is limited by various constraints that served as the upper and lower boundaries of the decision variables. The input parameters can affect the system function configuration decision variables. The mass balance technique commonly used in process systems engineering will be used to integrate resource flow into the model. This will be supported to describe the power interaction in the system with the energy balance technique.

3.4.4.4 ArcGIS and GAMS Programming

The mathematical model developed will be used in ArcGIS and GAMS after the mathematical formulations have been completed. ArcGIS is a Geographic Information System (GIS) developed by Esri (Company Name) to work with maps and spatial information. It is used to create and use maps, to collect geographic data, to analyze mapped data, to share and explore geographic information, to use maps and geographic information in a variety of applications, and to store geographic information in a database.

The built-in model will be solved by the GAMS solver to optimize the biofuels supply chain at the lowest cost. To solve the MILP problem, this study will use a CPLEX solver in GAMS. Both ArcGIS and GAMS are software that can be integrated into the data collected as the ArcGIS is used to construct and design the modeling to provide the resulted data for the optimization in the CPLEX solver of GAMS. Several benefits function that can be used in GAMS including:

i. Designed for modeling and solving linear, nonlinear, and mixed-integer optimization problems.
ii. The system is tailored for complex, large-scale modeling applications and allows the user to build large maintainable models that can be adapted to new situations. Allow a succinct description of most mathematical optimization problems.
iii. The system is available for use on various computer platforms.
iv. GAMS contains an integrated development environment (IDE) and is connected to a group of third-party optimization solvers such as The Branch-And-Reduce Optimization Navigator (BARON), Computational Infrastructure for Operations Research (COIN-OR) solvers, IBM ILOG CPLEX Optimization Studio (CPLEX), Discrete Continuous Optimizer (DICOPT) and Sparse Nonlinear OPTimizer (SNOPT).

3.4.4.5 Result and Analysis

The findings of the optimization problem will be evaluated based on the research objectives and scope. Analysis of sensitivity will be performed to identify the model-related influencing variables.

3.5 Gantt Chart

A Gantt chart is a timeline used to show how the plan will run as a project management tool. Table 7 and 8 portrays the overall planning process for this final year project 1 and 2 which is included various project activity for two semesters.

Table 7: Gantt Chart of Final Year Project 1.

Project Gantt Chart for Final Year Project 1																			
Represent Planning Progress																			
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-Term Break								Study Week	Final Examination of Semester		Semester Break
Study on The Research Gap About the Supply Chain of Oil Palm Biomass and Optimization Method																			
Chapter 1: Introduction - Research Background, Objective, Problem Statement, Research Scope, Significant Research																			
Submission of Progress Report I																			
Chapter 2: Literature Review																			
Chapter 3: Methodology																			
Developing K-chart and Process Flowchart																			
Construct Superstructure and Formulate Optimization																			
Design the Map in the ArcGIS																			
Submission of FYP I Report: Psmonline and email																			
Preparation of Presentation Slide, Poster and Summary																			
FYP I Seminar: Presentation to Panels																			

Table 8: Gantt Chart of Final Year Project 2.

Project Gantt Chart for Final Year Project 2																			
■ Represent Planning Progress																			
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-Term Break								Study Week	Final Examination of Semester		Semester Break
Improvement on Methodology			■	■															
Developing Coding in the GAMS - Cost Optimization Model			■	■	■	■													
Developing Coding in the 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 Chapter 4											■	■	■						
Conclusion												■	■						
Submission of FYP 2 Report: Psmonline and Email															■				
Preparation of Presentation Slide, Poster and Summary													■	■					
FYP 2 Seminar: Presentation to Panels															■				

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the preliminary analysis which is focusing on the spatial optimization of the biofuel supply chain. The regional case study selected for the preliminary analysis in Johor, Malaysia. Detailed discussions regarding the preliminary analysis are described in the following section.

4.2 Preliminary Analysis

Figure 16 demonstrates the conceptual framework for biofuel supply chain planning with GIS and MILP integration, consisting of resource availability assessment, suitability analysis of possible pre-treatment sites, and optimization. ArcMap 10.3 and GAMS 24.6.1 (CPLEX solver) are used as work platforms for GIS analysis and optimization. Several assumptions are made to clarify the limits of this analysis. They are described as:

i. The combustion of the oil palm biomass is considered CO_2 neutral.

ii. CO_2 emissions are accounted for from many sources: biomass cultivation (i.e. fertilization, fertilizer, soil preparation), biomass harvesting (i.e. land-use change, pruning), transport by truck and oil tanker and biorefinery construction (i.e. land-use change)

iii. The production rate of the biorefinery is specified at 3474020000 L/y.

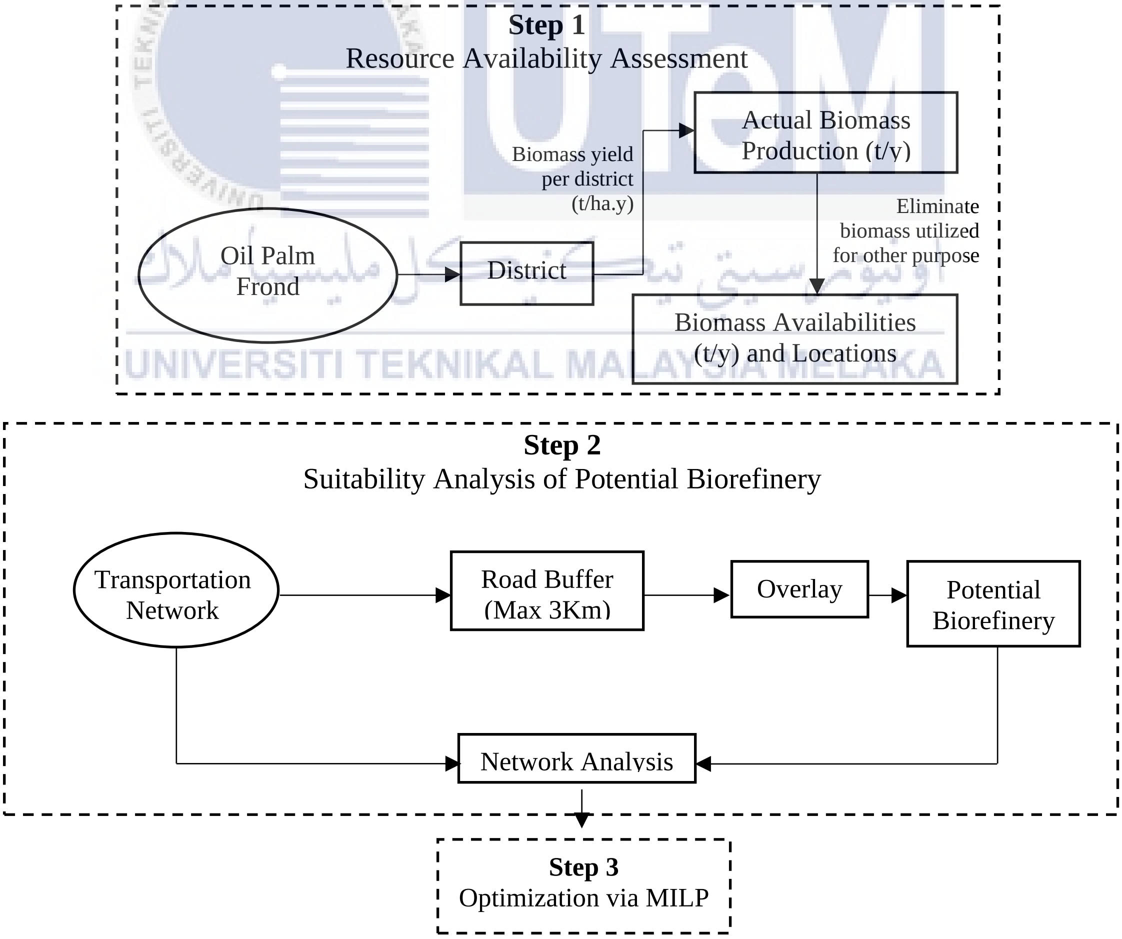
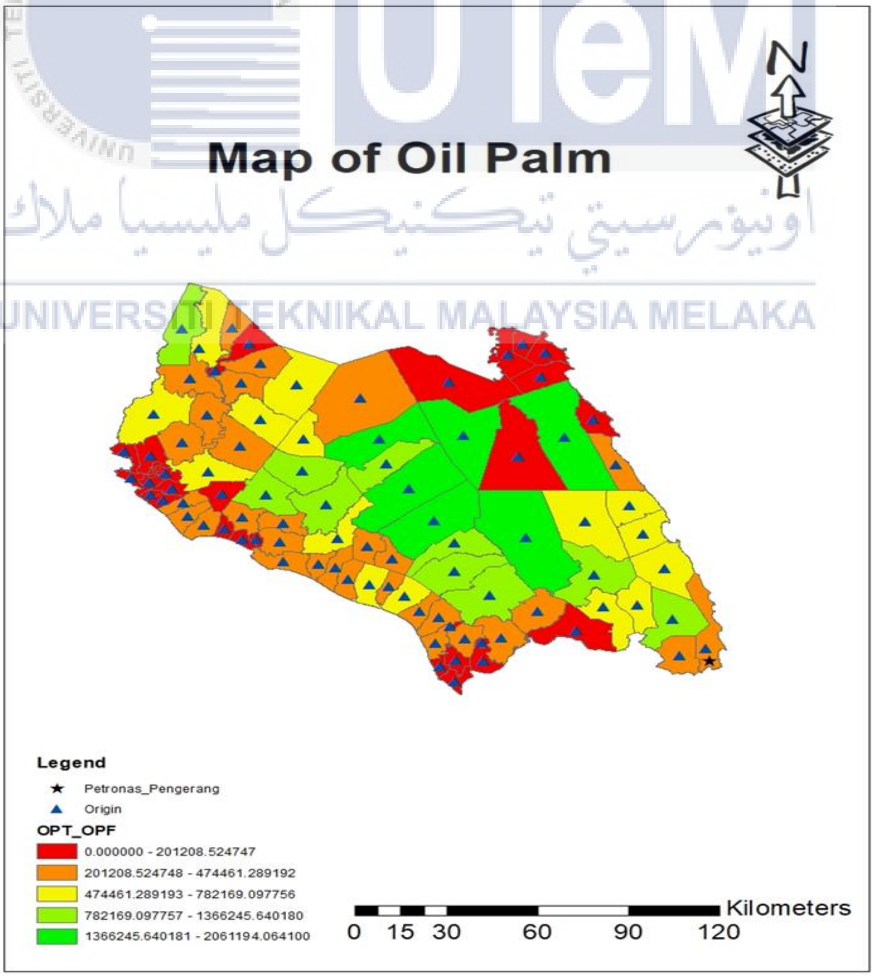


Figure 16: Integrated GIS-based biomass resource assessment with spatial modelling approach.

4.3 Resources Availability Estimation

In view of the apparent geographically distributed nature of biomass supplies, the estimate of the availability of biomass and the location of its supply involves the needs of GIS-based resource assessments. This approach is useful for quantifying plantation and plant resource capacity. The related biomass types in this study include oil palm fronds (OPFs). EFB sources derive from process-based residues (palm oil mills), while OPT and OPF sources derive from palm oil plantations. As shown in Figure 17, Johor has 78 oil palm plantations that mainly process oil palm fronds (OPFs) for the production of crude palm oil (CPOs). Oil palm frond (OPF) is the most abundant oil palm biomass produced in oil palm plantations compared to other biomass. Over 50 million tons of OPF was estimated to have been produced annually in Malaysia (Abdullah et al. 2016), which is available throughout the year as the fronds are cut regularly during the harvesting of fresh fruit bunches (FFB). The OPF consists of a petiole, which is the basal part of the branch, and numerous long leaflets on each side of the branch.



From the Malaysian Center for Geospatial Data Information (MaCGDI, 2010), as shown in Figure 18, the land use map of Johor which consisted of several types of land classification for the year 2010. It shows multiple levels of land classification such as woods and parks, woods and wetlands, water bodies, agricultural areas, plantations of oil palms, built-up areas, and road networks. The oil palm plantation layer is useful for estimating OPF availabilities among these layers.

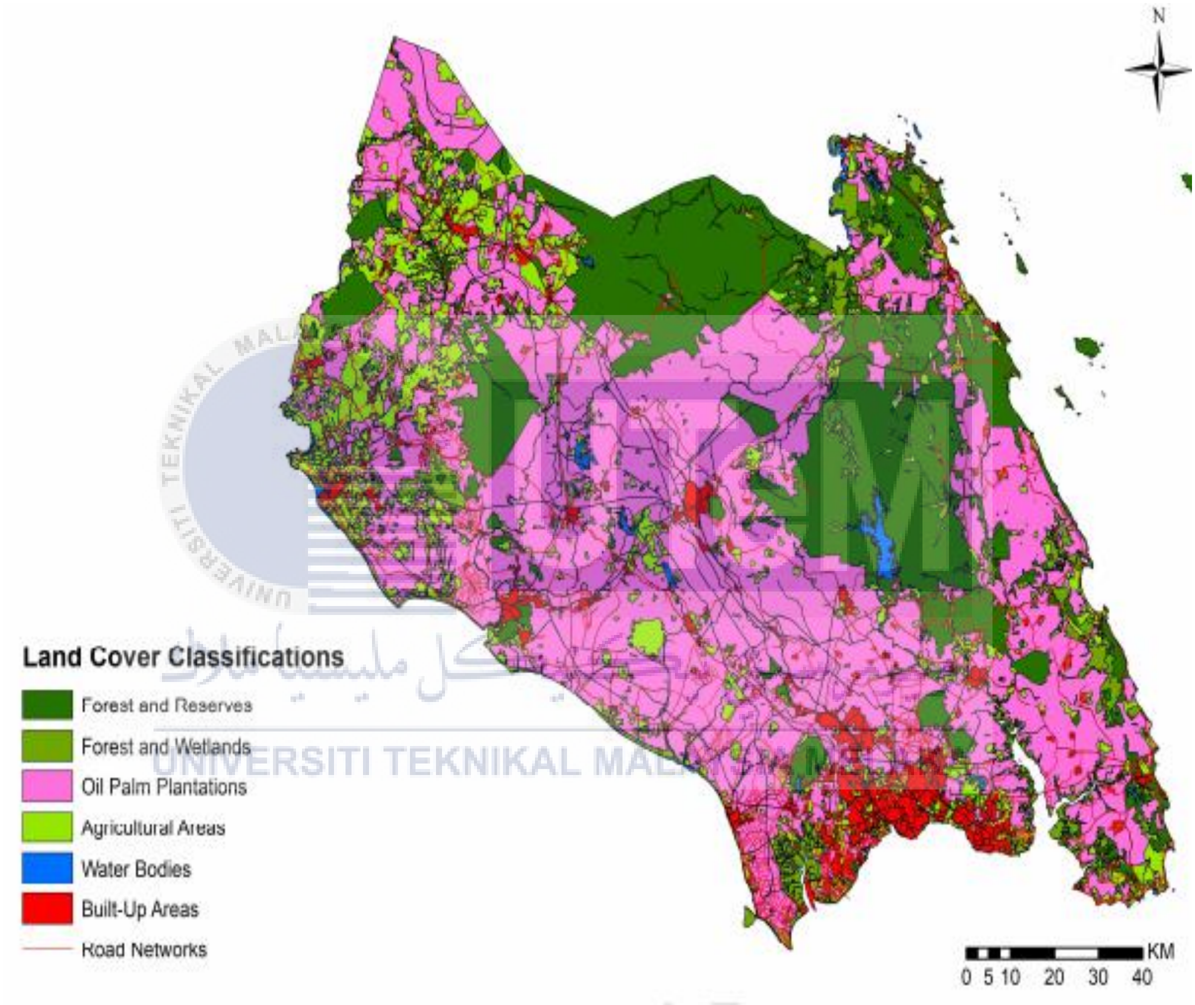


Figure 18: Land use map (MaCGDI, 2010).

In oil palm plantations, OPT and OPF can be collected at yields of 1.49 t/ha.y and 0.29 t/ha.y through replanting activities while pruned OPF can be obtained at 3.9 t/ha.y annually (Loh 2017). In this analysis, the life-cycle of the oil palm tree is 25 years. Figure 19 illustrates the spatial distributions of OPF in Johor estimated from the land use map's oil palm plantation layer.

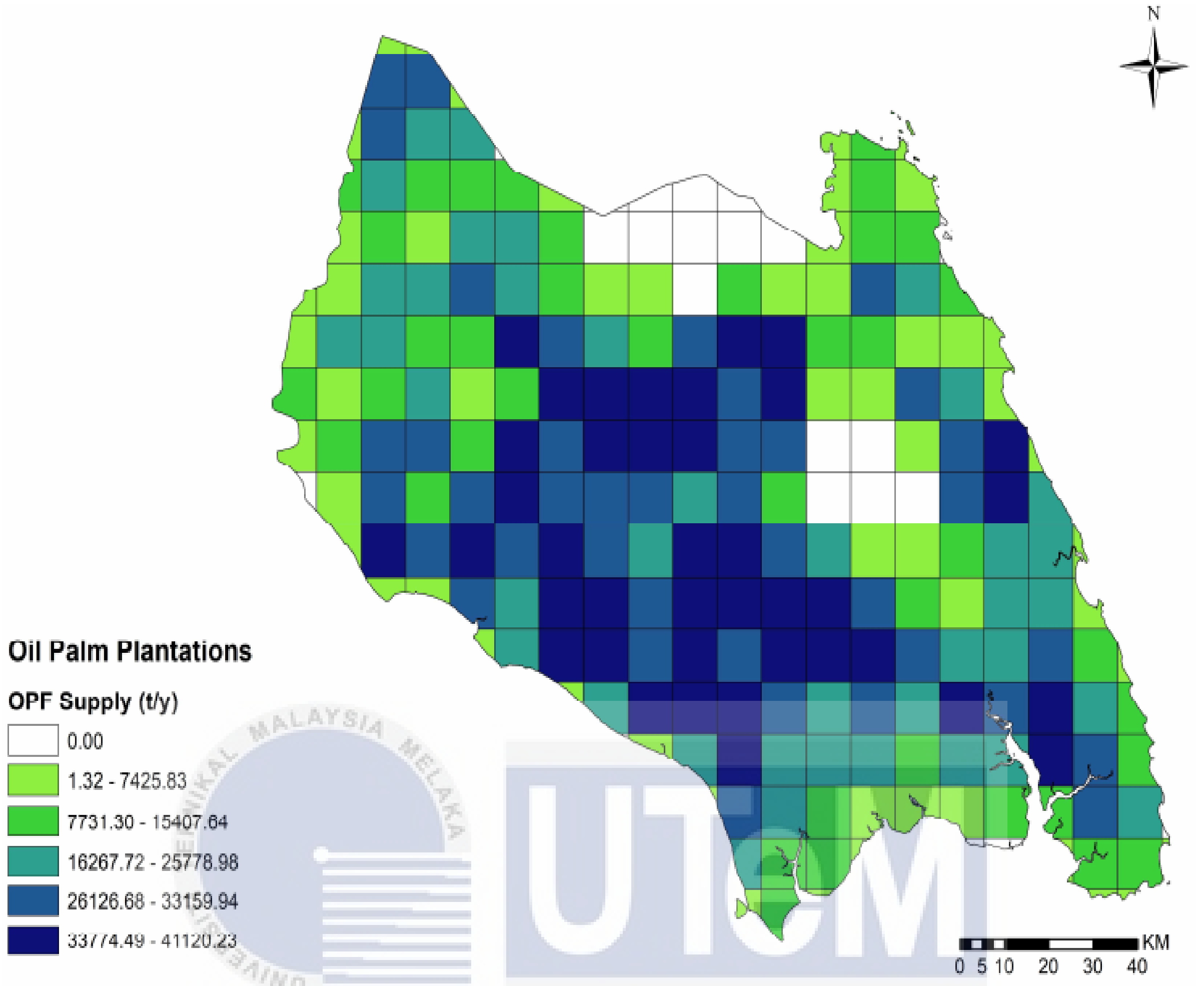


Figure 19: OPF availability in oil palm plantations.

4.4 Suitable Analysis of Potential Biorefinery

Potential locations of centralized biorefinery are identified using multi-criteria spatial analysis methodology that requires various land use and accessibility restrictions to assess the optimal locations. First, some vulnerable areas, such as forests and parks, wetlands, water sources, and urban areas are eliminated from the land use map. Second, the existing map that has been screened overlays with the transport buffers. It suggests that facility sites should be situated at an average distance of 3 km from the road networks (Sahoo et al. 2016) to guarantee the connectivity and smooth flow for the transport of biomass.

The map is divided into districts after the optimum sites have been identified. Assigning the map to districts is intended to establish representative positions for further review. These districts are not meant to be the exact locations, but rather generalized areas to represent the potential locations that will later be useful for purposes of network analysis. Table 9 shows the 78 Potential locations are identified after all associated spatial analyzes based on GIS are used. Later, these areas would be eliminated from the future map by the constraints of the optimization model by not choosing them as the places to construct the facilities. Among these potential locations that are identified, one biorefinery is to be constructed through optimization with considerations of economic and environmental criteria.

Table 9: The potential biorefinery in Johor, Malaysia.

NO	MUKIM	Area Oil Palm Plantation (ha)	OPF (Ton)	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	13634.56	102259.20	0.00
9	Buloh Kasap	9329.06	69967.95	194.80
10	Chaah	15465.49	115991.15	206.93
11	Chaah Bahru	14899.35	111745.12	156.67
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	11.08
39	Parit Bakar	668.85	5016.41	181.51
40	Parit Jawa	4942.50	37068.77	174.65
41	Pengkalan Raja	8015.20	60114.02	12.25
42	Penyabong	857.92	6434.37	91.85
43	Peserai	435.34	3265.06	126.84
44	Plentong	1748.90	13116.77	150.79
45	Pontian	3453.21	25899.09	56.68
46	Pulai	9988.66	74914.94	98.95
47	Renggam	5696.55	42724.16	76.57
48	Rimba Terjun	40188.09	301410.71	106.27
49	Sedenak	6102.18	45766.34	97.68
50	Sedili Besar	26166.58	196249.34	93.97
51	Sedili Kechil	11002.57	82519.29	58.91
52	Sembrong	15838.72	118790.40	39.26
53	Senai Kulai	2938.82	22041.13	159.71
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	56.58
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	77.61
78	Ulu Sungai Sedili Besar	15763.01	118222.57	68.66

4.5 Network Analysis

Transport is one of the key indicators used to assess the economic performance of the supply chain network. The network research shall be carried out by considering detailed road transport networks to assess the best transport routes from each location to their respective destinations. Network research may address a variety of linear network-related queries, such as bridges, rail, waterways, infrastructure, and services. For this analysis, the Network Analyst tool for ArcMap uses the **'OD cost matrix**' method to evaluate the road transport network. Network Analyst allows users to dynamically model realistic network conditions, including speed limits, latency, and traffic patterns, in addition to allowing users to set custom parameters. This technique of spatial analysis uses network data to quantify distances between points or nodes on the network. Such distances are to be used to measure the transport expense of the optimization model.

The same type of transportation by truck is considered for the supply of biomass to the biorefinery as shown in Figure 20. Due to the same type and capability of truck considered, the transport price is presumed to be the same for all transport activities carried out by truck. The transport activities commence with the cultivation and harvesting of biomass from oil palm plantations before being transported to the biorefinery. The bioethanol produced at the biorefinery is then transferred to the Pengerang Integrated Complex (PIC) in Pengerang, Johor. The PIC received supplies of bioethanol from the biorefinery via an oil tanker.

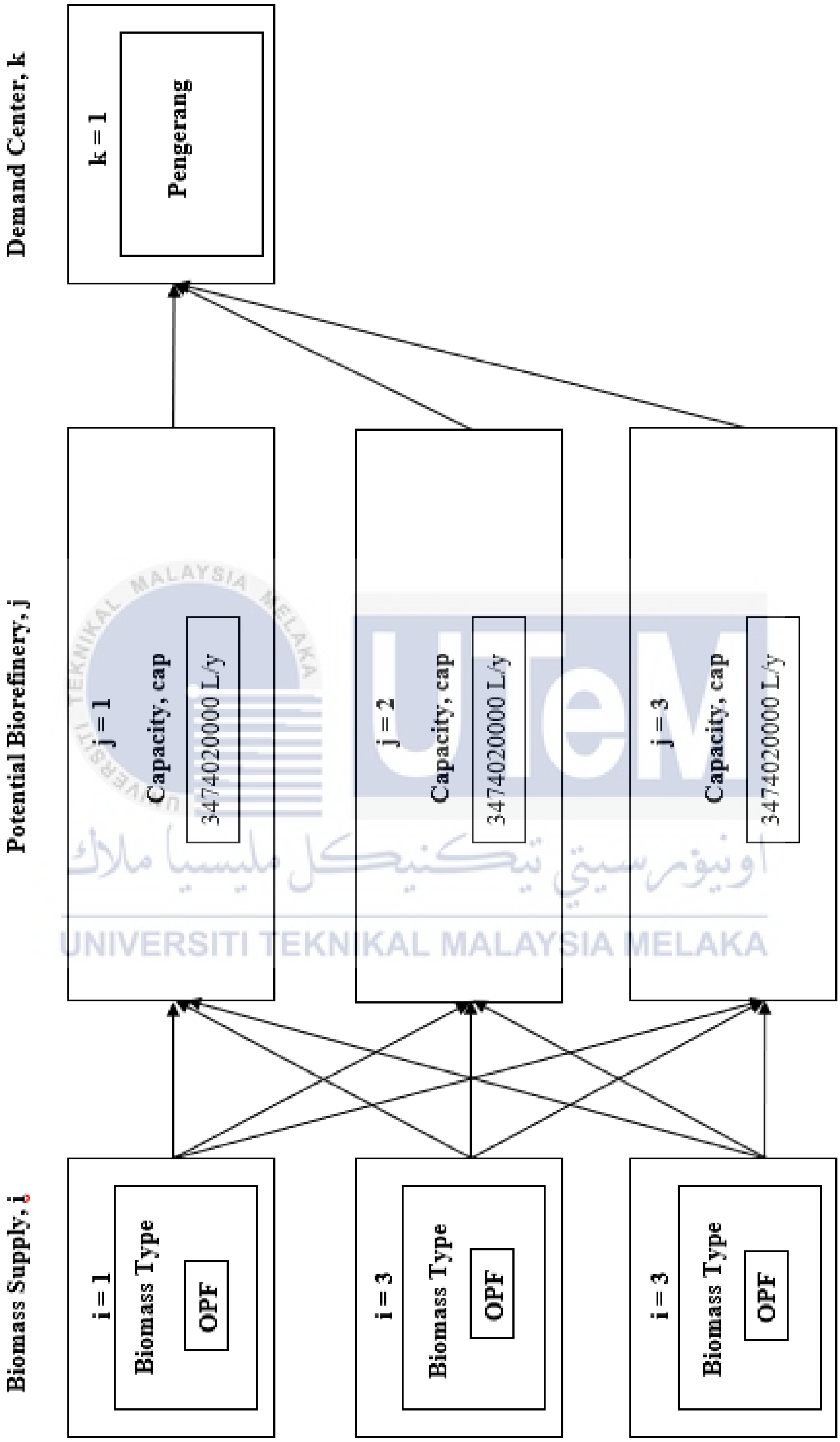


Figure 20: Superstructure of the transportation network of biomass.

4.6 Model Formulation

An optimization model for spatial biomass of biofuels supply chain planning is developed to assist in assessing the oil palm biomass economic and environmental performance of an existing biorefinery based on several scenarios. The design minimizes the overall cost and emission of the supply chain process while at the same time assessing the most suitable sites for the construction of the potential facilities. Overall, the potential facilities of oil palm biomass consisted of 78 locations. In table 10, all the environment, economic and technical parameters needed for the MILP model as input data were summarized.

Table 10: Economic, environment, and technical parameters.

PARAMETER	UNIT	VALUE	REFERENCES
ECONOMIC PARAMETER			
CAPEX (Biorefinery)	USD	51690000	(Do and Lim 2016)
OPEX (Biorefinery)	USD/y	13510000	(Do and Lim 2016)
Transportation (Truck)	USD/t.km	0.20	(Lam et al. 2013)
Transportation (Oil Tanker)	USD/L.km	0.00015	(Kang et al. 2010)
Biomass (OPT)	USD/t	15.00	(Ahmad et al. 2016)
Biomass (OPF)	USD/t	9.00	(Gabdo and 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)	Kg/CO_2t.km	0.595	(Paolucci, Bezzo, and Tugnoli 2016)
Emissions (Oil Tanker)	Kg/CO_2L.km	0.00015	(Syafiie and Valizadeh 2016)
Emissions (Cultivation (OPT))	Kg/CO_2t	20.5	(Loh 2017; Rivera-Méndez, Rodríguez, and Romero 2017)
Emissions (Cultivation (OPF))	Kg/CO_2t	105.5	(Loh 2017; Rivera-Méndez et al. 2017)
Emissions (Harvesting (OPT))	Kg/CO_2t	4.3	(Loh 2017; Rivera-Méndez et al. 2017)
Emissions (Harvesting (OPF))	Kg/CO_2t	22.2	(Loh 2017; Rivera-Méndez et al. 2017)

TECHNICAL PARAMETER			
Petrol Demands	L	15791000000 (2018)	J. Müller (2019)
Percentage Bioethanol Blend with Petrol	%	20	(Al-Hasan 2003)
Production scale efficiency	L/year	33900000	(Abdullah et al. 2016)
Bioethanol Capacity in Biorefinery	L/year	57600000	(Abdullah et al. 2016)
Conversion Factor of Biomass	%	0.76	(Li et al. 2016)
Conversion Factor of Emissions	kg CO2/L biofuel	0.58	(Syafiie and Valizadeh 2016)
Capital Recovery Factor		R= 7% N= 20 years Crf=0.09439	(Vlysidis et al. 2011)

4.6.1 Material Balance

In this study, set i represents the oil palm plantation location, set j represents the potential biorefinery location, set k represents the Pengerang Integrated Complex (PIC) location. Different notations of flowrates are used to indicate the mass flow in or out of the system. These include OPF biomass from oil palm plantation to potential biorefinery ($Fbiomass_{i,j}$), and bioethanol produced at biorefinery to the demand center of Pengerang Integrated Complex (PIC) ($Fethanol_{j,k}$).

4.6.2 Economic

The economic objective function in this study is to achieve optimal cost of biofuel supply chain by minimizing the total cost (C^{total}) of the system. The total cost is made up of OPF biomass cost (C^{OPF}), transportation cost from oil palm plantation to demand center (C^{transp}), capital expenditure or CAPEX of biorefinery(C^{capex}) and operating expenditure or OPEX of biorefinery(C^{opex}) as described in the Equation (1):

$$Min\ C^{total} = C^{OPF} + C^{transp} + C^{Capex} + C^{Opex} \tag{1}$$

OPF biomass cost (C^{OPF}) is described by the multiplication of biomass's flow rate ($Fbiomass_{i,j}$) with the respective price of OPF biomass (C_{opf}) as given in the:

$$C^{OPF} \quad = \sum\nolimits_{i,j}(Fbiomass_{i,j} \times C_{opf}) \tag{2}$$

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

$$\begin{aligned} C^{transp} \quad = & \sum_{i,j}(Fbiomass_{i,j} \times C_{truck} \times Dist_{i,j}) + \\ & \sum_{j,k}(Fethanol_{j,k} \times C_{tanker} \times Dist_{j,k}) \end{aligned} \tag{3}$$

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 biorefinery (T_{capex}), with the capacity unit of machine that is used to produce bio-alcohol ($CapUnit_j$). So, (C^{capex}) can be described as:

$$C^{capex} \quad = \sum_{j}(T_{capex} \times CapUnit_j) \tag{4}$$

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

$$C^{opex} = \sum_{j} (ethanol_{j,k} \times T_{opex}) \quad (5)$$

4.6.3 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 result 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:

$$Min\ E^{total} = E^{cultiv} + E^{harvest} + E^{transp} + E^{technology} \quad (6)$$

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:

$$E^{cultiv} = \sum_{i,j} (Ebiomass_{i,j} \times E_{copf}) \quad (7)$$

$$E^{harvest} = \sum_{i,j} (Ebiomass_{i,j} \times E_{hopf}) \quad (8)$$

There are two means of transportation involved in this supply chain system which is 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 ($E^{oil\ tanker}$).

$$E^{transp} = E^{truck} + E^{oil\ tanker} \tag{9}$$

$$E^{truck} = \sum_{i,j} (Ebiomass_{i,j} \times E_{truck} \times Dist_{i,j}) \tag{10}$$

$$E^{oil\ tanker} = \sum_{j,k} (Eethanol_{j,k} \times E_{tanker} \times Dist_{j,k}) \tag{11}$$

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}).

$$E^{technology} = \sum_{j,k} (Eethanol_{j,k} \times E_{cf}) \tag{12}$$

4.6.4 Constraints

The constraints take into account the major features of the biofuel supply chain, such as biomass availability, biorefinery capacities, and biofuel demand. Since it is not possible to harvest biomass feedstock above the available quantity, the flowrate of OPF biomass that is collected from oil palm plantation to the potential biorefinery ($\sum_j Fbiomass_{i,j}$) cannot exceed its biomass availability in oil palm plantation (A_i).

$$A_i \geq \sum_j Fbiomass_{i,j} \qquad \forall\ \mathrm{I} \tag{13}$$

The flowrate of bioethanol produced from OPF biomass at biorefinery ($\sum_k Fethanol_{j,k}$), should not exceed the maximum refinery capacity. The multiplication of (Cap and $Capunit_j$) is the capacity of biorefinery.

$$Cap \times Capunit_j > \sum_k Fethanol_{j,k} \qquad \forall\ \mathrm{j} \tag{14}$$

The flowrate of bioethanol produced from OPF biomass at biorefinery ($\sum_k Fethanol_{j,k}$), should fulfill the demand. $demandPIC$ represents the demand at Pengerang Integrated Complex (PIC).

$$demandPIC \quad \geq \quad \sum_j Fethanol_{j,k} \qquad \forall\, k \tag{15}$$

4.7 Results and Discussions

4.7.1 AHP for The Potential Biorefinery Selection

Figure 19 and 20 shows a summary of the performance for the selection of the potential biorefinery location under the two assessment areas (**performance and dynamic sensitivity-graph**). Although Pantai Timor performs the best as shown in Figure 21, this does not imply that Pantai Timor performs the best on all criteria. In Figure 22, it can be observed that Pantai Timor performs the best in only three criteria which are "Cost", "Distance", and "Emission" under the performance assessment area, while it ranks third and seventh on the other two areas—"Supply" and "Social". Hence, there is potential for Pantai Timor to improve in those two areas.

The important criteria for choosing the optimal potential biorefinery, Figure 21 shows that under the category of performance assessment area, the criteria percentage of assurance of cost, distance, supply, social, and emission are 29.4%, 22.1%, 16.7%, 15.2%, and 16.6%, respectively. According to these results, we can conclude that "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 10 possible locations.

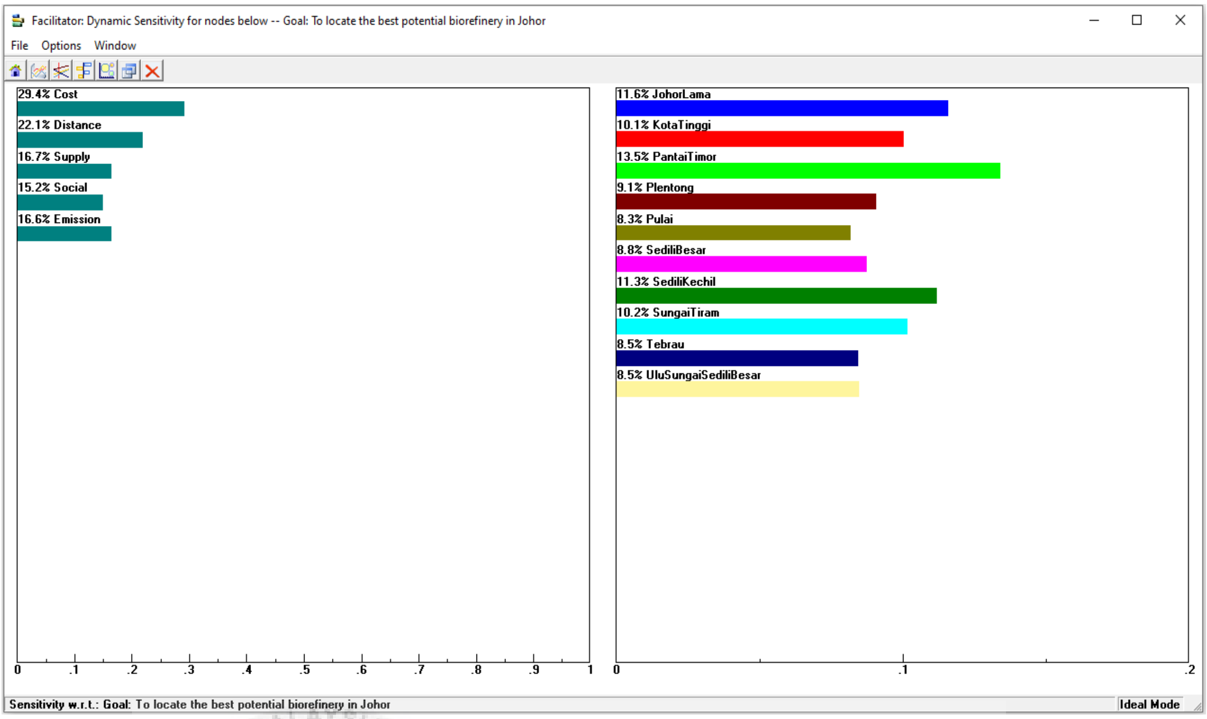


Figure 21: Dynamic sensitivity-graph for derived local priorities of alternatives.

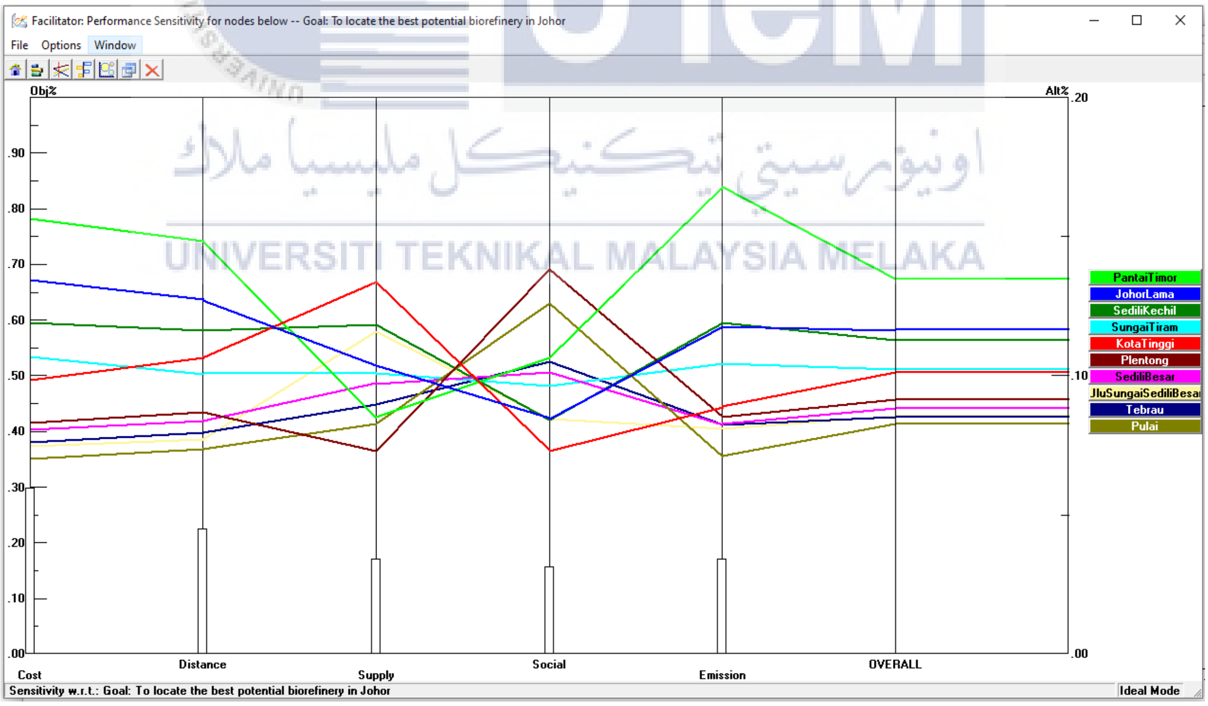


Figure 22: Performance sensitivity-graph for derived local priorities of alternatives.

4.7.2 Spatial Optimization of Biofuel Supply Chain

The spatial modeling model developed is used in the Johor case study to reduce the total cost and emissions of supply chain systems for biofuels. The issues facing the biofuel supply chain planning network are biorefinery facilities management to supply bioethanol on request. Johor has a wide area of the Pengerang Integrated Complex (PIC) which is a megaproject construction in Pengerang, Kota Tinggi District, Johor, Malaysia. This occupies an area of 80 km^2 and will host oil refineries, naphtha crackers, petrochemical facilities, liquefied natural gas (LNG) terminals, and a regasification plant upon construction. To make the biofuels in this PIC, a substantial amount of bioethanol is required. As shown in Figure 19, only one biorefinery is needed to supply bioethanol to the demand center at Pengerang Integrated Complex (PIC)

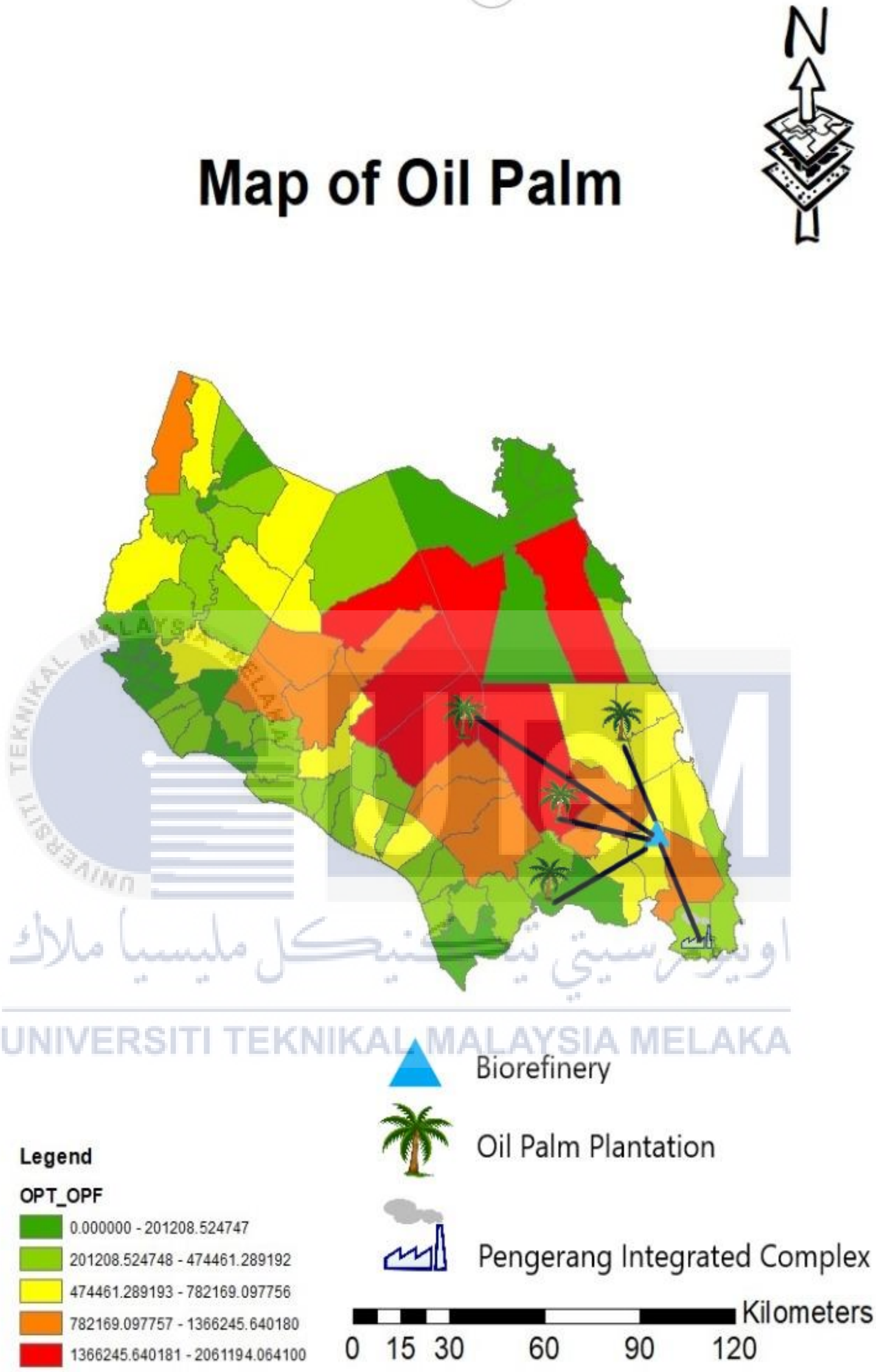


Figure 23: The optimal potential biorefinery in Johor, Malaysia.

In the cost minimization, the total cost of the biofuels supply chain obtained is 16,094,327,790 USD per year. The result is obtained by using the CPLEX solver in the software GAMS. The coding cost optimization model in the GAMS is made based on Equation 1 to Equation 5 as defined in the section of material balance. Besides, the total demand capacity of bioethanol needed in the blending process to make biofuels is 3.4-gallon liter per year. So, five optimal locations are chosen because of the lowest result in cost optimization as shown in Table 11. Table 12 portrays the total cost and emissions minimization of every 78 locations oil palm plantation to the potential biorefinery based on the optimization results in GAMS.

Table 11: The optimal cost and emissions of oil palm plantations in Johor, Malaysia for the biofuels supply chain.

i	***j***	**Lowest cost from (*i* to *j*) (Million USD/year)**	**Lowest Emissions from (*i* to *j*) (Ton CO_2/year)**	**Biomass (Ton/year)**
JohorLama	PantaiTimor	14.600	0.144	110384.247
KotaTinggi	PantaiTimor	17.800	0.154	149769.533
PantaiTimor	PantaiTimor	9.000	0.128	67493.312
SediliKechil	PantaiTimor	14.400	0.144	118790.402
SungaiTiram	PantaiTimor	16.200	0.149	91760.497
Plentong	PantaiTimor	20.337	0.161	164027.538
Pulai	PantaiTimor	24.314	0.173	270586.340
SediliBesar	PantaiTimor	20.782	0.163	522622.141
Tebrau	PantaiTimor	22.206	0.167	439100.951
UluSungaiSediliBesar	PantaiTimor	22.732	0.169	748742.957
		Total Biomass		5553667.203

Figure 24 shows the 10 optimal oil palm plantations that supplied the bioethanol to the Pengerang Integrated Complex (PIC) through the potential biorefinery in Pantai Timor. Furthermore, the figure was shown to give a clear insight into this biofuels supply chain. The AHP was carried out by using software Expert Choice and resulted that Pantai Timor has been determined as the optimal potential biorefinery among 78 locations in Johor.

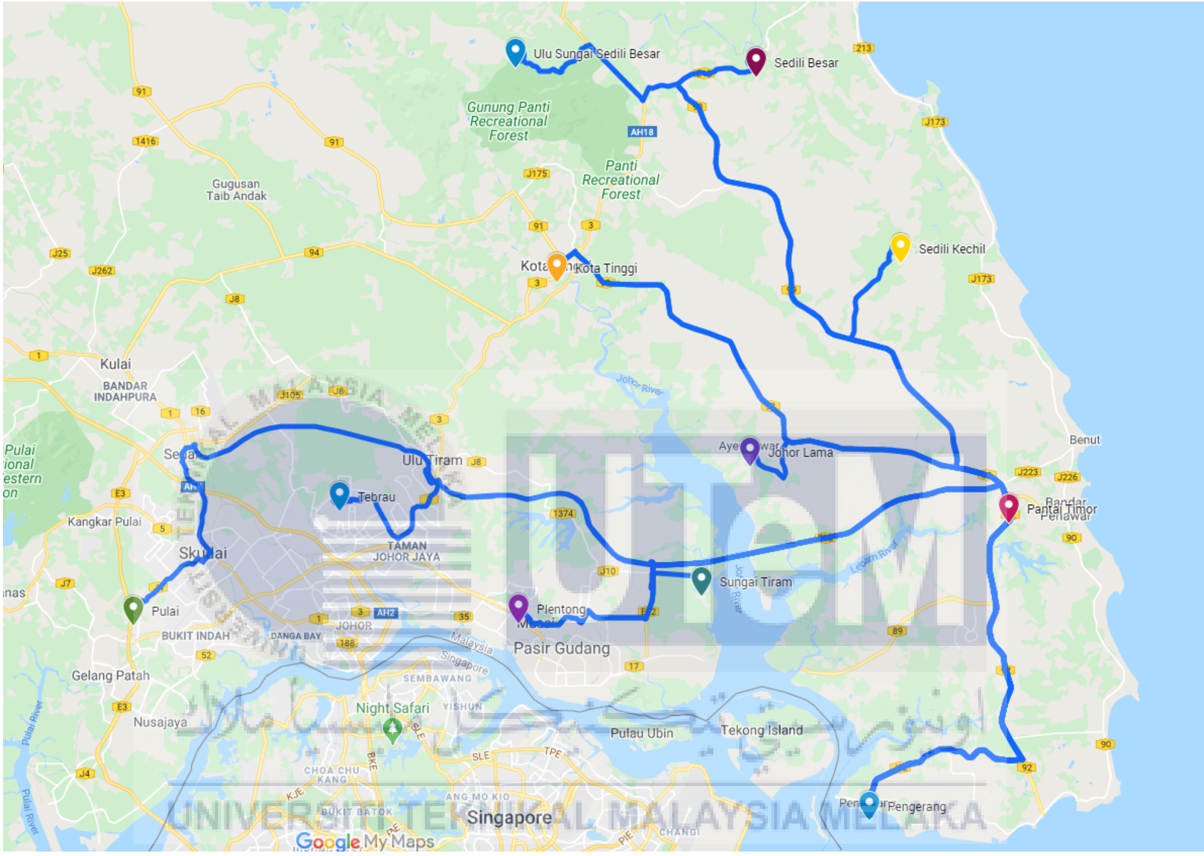


Figure 24: The overview of biofuels supply chain in Johor

Table 12: the total cost and emissions minimization of every 78 locations oil palm plantation to the potential biorefinery.

i	*j*	Cost (Million USD/year)	Emissions (Ton CO_2/year)
ApiApi	PantaiTimor	29.6024	0.1890
AyerBaloi	PantaiTimor	30.2453	0.1909
AyerHitam	PantaiTimor	41.6884	0.2249
AyerMasin	PantaiTimor	29.6279	0.1891
Bagan	PantaiTimor	40.1240	0.2203
Bandar	PantaiTimor	45.7011	0.2369
Benut	PantaiTimor	32.5343	0.1977
BukitSerampang	PantaiTimor	47.9605	0.2436
BulohKasap	PantaiTimor	50.3863	0.2508
Chaah	PantaiTimor	40.3341	0.2209
ChaahBahru	PantaiTimor	38.1845	0.2145
Gemereh	PantaiTimor	48.4113	0.2449
Gerisek	PantaiTimor	45.1900	0.2354
Jabi	PantaiTimor	50.9797	0.2526
JalanBakri	PantaiTimor	44.4664	0.2332
Jelutong	PantaiTimor	25.4048	0.1765
Jemaluang	PantaiTimor	30.9100	0.1929
Jementah	PantaiTimor	49.7337	0.2489
JeramBatu	PantaiTimor	26.8692	0.1809
JohorLama	PantaiTimor	14.6000	0.1444
Jorak	PantaiTimor	42.9572	0.2287
Kahang	PantaiTimor	36.0596	0.2082
KampungBaharu	PantaiTimor	36.2878	0.2089
Kluang	PantaiTimor	33.0421	0.1992
KotaTinggi	PantaiTimor	17.8000	0.1539
Kundang	PantaiTimor	47.8173	0.2432
Labis	PantaiTimor	44.2043	0.2324
Layang-Layang	PantaiTimor	30.3676	0.1913

Lenga	PantaiTimor	44.4707	0.2332
Linau	PantaiTimor	38.1820	0.2145
Lubok	PantaiTimor	40.9698	0.2228
Machap	PantaiTimor	32.7614	0.1984
Mersing	PantaiTimor	29.5035	0.1887
MinyakBeku	PantaiTimor	37.4931	0.2125
Niyor	PantaiTimor	35.0987	0.2053
Pagoh	PantaiTimor	46.9542	0.2406
Paloh	PantaiTimor	36.4293	0.2093
PantaiTimor	PantaiTimor	9.0000	0.1277
ParitBakar	PantaiTimor	45.3022	0.2357
ParitJawa	PantaiTimor	43.9306	0.2316
PengkalanRaja	PantaiTimor	27.3695	0.1823
Penyabong	PantaiTimor	34.3676	0.2032
Peserai	PantaiTimor	39.1571	0.2174
Plentong	PantaiTimor	20.3370	0.1614
Pontian	PantaiTimor	28.7897	0.1866
Pulai	PantaiTimor	24.3140	0.1733
Renggam	PantaiTimor	30.2544	0.1909
RimbaTerjun	PantaiTimor	28.5362	0.1858
Sedenak	PantaiTimor	27.7940	0.1836
SediliBesar	PantaiTimor	20.7825	0.1628
SediliKechil	PantaiTimor	14.4000	0.1438
Sembrong	PantaiTimor	40.9426	0.2227
SenaiKulai	PantaiTimor	25.1097	0.1756
Serkat	PantaiTimor	30.8317	0.1926
Sermin	PantaiTimor	50.2559	0.2504
Serom	PantaiTimor	46.0456	0.2379
SimpangKanan	PantaiTimor	37.8787	0.2136
SimpangKiri	PantaiTimor	40.8935	0.2226
SriGading	PantaiTimor	34.8322	0.2046
SriMenanti	PantaiTimor	44.0867	0.2321

SungaiBalang	PantaiTimor	42.0966	0.2262
SungaiKarang	PantaiTimor	29.1562	0.1877
SungaiKluang	PantaiTimor	33.4766	0.2005
SungaiPinggan	PantaiTimor	31.4445	0.1945
SungaiPunggor	PantaiTimor	34.2046	0.2027
SungaiRaya	PantaiTimor	44.9843	0.2348
SungaiSegamat	PantaiTimor	46.3447	0.2388
SungaiTerap	PantaiTimor	45.8276	0.2373
SungaiTiram	PantaiTimor	16.2000	0.1491
Tangkak	PantaiTimor	49.0040	0.2467
TanjungKupang	PantaiTimor	25.9549	0.1781
TanjungSemberong	PantaiTimor	35.4365	0.2063
Tebrau	PantaiTimor	22.2060	0.1670
Tenggaron	PantaiTimor	32.5584	0.1978
Teriang	PantaiTimor	35.6593	0.2070
UluBenut	PantaiTimor	30.8844	0.1928
UluSungaiJohor	PantaiTimor	24.5216	0.1739
UluSungaiSediliBesar	PantaiTimor	22.7317	0.1686

CHAPTER 5

CONCLUSIONS AND FUTURE WORKS

5.1 Introduction

This chapter presents the conclusion of this study about the 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 Conclusions

The spatial optimization model framework for the design of biofuel supply chains has been developed using ArcGIS in this research, taking into account the spatially explicit availability of biomass and transport data. The implementation of well-known MILP mathematical programming techniques for GAMS and AHP applications is discussed in this study. Specifically, AHP was used in this study as a specific reason for the determination of biorefinery locations, while MILP is used to optimize entire biofuel supply chain layers from feedstock centers to biofuel demand centers. Some managerial implications may be taken from this study as follows: i) Replacing fossil fuels with biofuels in the transport sector would minimize environmental emissions and enhance energy efficiency. ii) supply chains of biofuels should be completely integrated in order to maximize the commerciality of biofuels. iii) Mathematical programming models are the most effective methods for managing the supply chain of biofuels.

Based on the findings in this study, 10 potential oil palm plantations for the supply of OPF biomass have been identified through the optimization software where the implementation of the MILP method by using CPLEX solver in GAMS. The demand for biofuels in Pengerang Integrated Complex (PIC) is 3,158,200,000 million liters per year with 20% of ethanol blended with gasoline. On top of that, the 10 potential oil palm plantations can supply a total of 5,553,667.20 tons per year of OPF biomass to the biorefinery with the demanded oil palm biomass is 5,366,160.33 ton per year which is enough to fulfill the demand at PIC. The results produced in Expert Choice for the selection of potential biorefinery determined that Pantai Timor was the optimal location through five criteria such as cost, distance, supply, social, and emission. Despite the uncertainty, the three objectives of this study are achieved. The first objective is to analyze the model that integrates comprehensive spatial modeling techniques with the strategic biofuels supply chain optimization network design. Then, the second objective is to select the optimal potential biorefinery by using AHP through five criteria which are cost, distance, supply, social, and emission. Lastly, the third objective is to optimize the supply chain using Computer-aided tools such as GAMS and ArcGIS.

5.3 Future Works

While the introduction of biofuels blends in the transport sector will be more imminent in the future, sufficient planning must be made in advance in order to avoid more barriers from disrupting supply chain management. Over-pressure for the introduction of biofuels blends (ethanol) 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 research on the biofuel supply chain model is expected, such as consideration of external supply chain constraints and parameters. For example, the concept of geographical knowledge, weather, and seasonal resources are some of the core variables in the management of the supply chain.

ii. Key element identification for biomass technology is also important in order to ensure that all the characteristics of the biomass element are recognized. Experimental work on the spectrum of element acceptance for the respective biomass technologies is important in order to ensure consistency in process performance. This opens up a new path for researchers to further study the relationship between the characteristics of the biomass product and the process efficiency of growing biomass technology.

iii. Enhance the model by taking into account a centralized and decentralized approach, taking into account the distribution point and schedule. It would create a more robust paradigm to be adapted to the real-life circumstances of the industry.

iv. Consideration of uncertainty in the supply and efficiency of services, administrative problems, interruption of systems, and demand volatility. There is no question that the biomass sector is still in a fluid situation with several unpredictable possibilities. The optimization model should then be enhanced to cope with these unforeseen differences and to provide a reliable decision-making tool.

APPENDIX A

Coding Programming: Cost Optimization Model for Biofuel Supply Chain

```
$Title Cost Optimization Model for Biofuel Supply Chain
$EolCom //
$set it TEST
$onEchoS   > Introduction.txt

  The objective of this model is to allocate the optimal
  biofuel supply chain. The problem is to find the cheapest cost and lowest
  emission for the transportation of biomass and biofuel from supply to
  demand that meets requirements at markets and supplies at plantations.

  Supervisor : Mrs. Nurul Hanim Binti Haji Razak

  Muhammad Hilmi Bin Mohd Nasir
  B041610099
  Faculty of Mechanical Engineering
  Universiti Teknikal Malaysia Melaka

$offEcho

  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
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,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 bioethanol 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)'

      Fethanol(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   /    // DOI: 10.1016/j.energy.2011.04.046

      n              'Plant lifetime for capital recovery factor (years)    '   / 20     /    // DOI: 10.1016/j.energy.2011.04.046

      Ccf            'Conversion factor of biomass OPF to bioethanol (Liters per ton)    '   / 588.54 /    //adapted 
```

```
from DOI: 10.1002/bbb.1431 // demand 20% of petrol demand (L/ye»
ar)

      Ecf           'Conversion emission factor of biomass O»
PF to bioethanol (ton CO2 per ton) ' / 0.58   /  ;  // DOI: 10»
.1504/IJPSE.2016.081205



 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 Best5c                »
                  '

      Bestc         'Lowest cost from oil palm plantation it»
h to biorefinery jth     '

      Bestd         'Lowest distance from oil palm plantatio»
n 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         /                         »
 // DOI: 10.5539/jas.v5n12p47

      Ctruck        'Price of truck for biomass OPF transpor»
tation (USD per ton.km)    ' / 0.2        /                 »
 // DOI: 10.1016/j.energy.2013.01.032

      Ctanker       'Price of oil tanker for bioethanol tran»
sportation (USD per L.km) ' / 0.15       /                  »
 // DOI: 10.1007/978-1-4419-0369-3_10

      Ccapex        'Capital expenditure (USD)              »
                  '   / 2567744847  /                       »
 // Adapted DOI: 10.1016/j.renene.2016.01.030
```

```
        Copex           'Operating  expenditure  (USD  per  year)   »
                         '    / 1549567569  /                       »
 //  Adapted  DOI:  10.1016/j.renene.2016.01.030

        Cap             'Biorefinery  production  capacity  of  bioe»
thanol (L per year)                         '  / 3474020000  /      »
 // Assumption 10% increment in 10years (2009-2019) Link: https»
://www.statista.com/statistics/1078403/malaysia-fuel-use-by-typ     »
e-of-fuel/#statisticContainer
                                                                    »
                                                                    »
 // 110% * 3 158 200 000   = 3 474 020 000 L ethanol/year
        demandPIC       'Total bioethanol demand in Pengerang In»
tegrated Complex, Malaysia (L per year)  '  / 3158200000 / ;       »
 // %ethanol Blend            = 20% , DOI : 10.1016/S0196-8904(02)0»
0166-8
                                                                    »
                                                                    »
 // Petrol demand (2018)   = 15 791 000 000 , Link: https://www.»
statista.com/statistics/1078403/malaysia-fuel-use-by-type-of-fu     »
el/#statisticContainer

  Crf       = [r*power((1+r),n)]  / [power((1+r),n)  -1]  ;    // »
Crf  (1 per year)
  Tcapex     = (Crf*Ccapex)                              ;    // »
Tcapex (USD per year)          = Crf (1 per year)             * Cca»
pex  (USD)
  Topex      = Copex                                     ;    // »
Topex (USD per L)               = Copex (USD per year)       / Cap»
 (Liters per year)
  demandbio  = demandPIC  / Ccf                          ;    // »
demandbio (ton OPF per year) = demandPIC (L ethanol/year)  / CF »
(L ethanol/ton OPF)

  Display Crf, Tcapex, Topex, demandbio  ;


Parameter  A(i)              'Biomass availability (OPF) in palm»
oil plantation itj (ton per year)' /
       ApiApi                 324241.8041
       AyerBaloi              567616.8676
       AyerHitam              134196.0273
       AyerMasin              133828.1229
       Bagan                  164330.0969
       Bandar                 5232.271936
       Benut                  546139.9586
       BukitSerampang         443130.3399
       BulohKasap             734610.6192
       Chaah                  707719.0842
```

```
ChaahBahru	1153058.187
Gemereh	131.4309833
Gerisek	354487.9382
Jabi	183505.8225
JalanBakri	82116.94182
Jelutong	7865.676642
Jemaluang	14522.41859
Jementah	283463.9511
JeramBatu	249311.6316
JohorLama	699100.232
Jorak	693266.2141
Kahang	1784555.022
KampungBaharu	304361.6758
Kluang	2061194.064
KotaTinggi	948540.3729
Kundang	78990.48352
Labis	782169.0978
Layang-Layang	1020164.58
Lenga	331926.9734
Linau	437793.7374
Lubok	106243.928
Machap	356871.45
Mersing	1864943.802
MinyakBeku	463224.7445
Niyor	1132273.988
Pagoh	396449.5987
Paloh	1827199.676
PantaiTimor	427457.6452
ParitBakar	31770.57696
ParitJawa	234768.9046
//	Pengerang	380722.1423
PengkalanRaja	40750.98138
Penyabong	20678.70234
Peserai	83072.88833
Plentong	164027.5385
Pontian	474461.2892
Pulai	270586.3403
Renggam	1908934.51
RimbaTerjun	289853.4709
Sedenak	1242912.5
SediliBesar	522622.1407
SediliKechil	752339.2145
Sembrong	139593.846
SenaiKulai	1242814.939
Serkat	151316.2075
Sermin	371772.4632
Serom	132584.4629
SimpangKanan	298131.5864
SimpangKiri	461032.9139
SriGading	734470.0384
```

```
        SriMenanti              318775.487
        SungaiBalang            328176.0816
        SungaiKarang            129114.0784
        SungaiKluang            384573.2528
        SungaiPinggan           293334.9093
        SungaiPunggor           374681.9691
        SungaiRaya              96740.55046
        SungaiSegamat           279264.6728
        SungaiTerap             21143.52357
        SungaiTiram             581149.8117
        Tangkak                 615851.5242
        TanjungKupang           86916.36924
        TanjungSemberong        1366245.64
        Tebrau                  439100.951
        Tenggaron               433877.7934
        Teriang                 141893.7986
        UluBenut                419555.1979
        UluSungaiJohor          1933012.279
        UluSungaiSediliBesar   748742.9566   / ;

  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
//    Pengerang              12.25387932
PengkalanRaja          91.84763463
Penyabong              126.8380604
Peserai                150.7855548
Plentong               56.68490626
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                 66.03018776
Tenggaron              117.7917561
Teriang                133.2963801
UluBenut               109.4219138
```

```
        UluSungaiJohor          77.60816512
        UluSungaiSediliBesar    68.65852936   ;

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           '
//         Conver(j)       'Conversion constraint                   '
        cost            'Objective for minimizing cost           '
        emissions       'Objective for minimizing CO2 emissions'  ;

  supply(i)..        sum(j,Fbiomass(i,j))         =L= A(i)        ; // Fbiomass(i,j) (ton/yr) =L= Availabilty (ton/year)

  capacity(j)..      sum(k,Fethanol(j,k))         =L= Cap*CapUnit(j)        ; // Fethanol(j,k) (L/yr)    =L= Cap (L/year)

  demand(k)..        sum(j,Fethanol(j,k))         =G= demandPIC        ; // Fethanol(j,k) (L/yr)    =G= Cap (L ethanol/year)
                                                                            // Greater because have to reserve bioethanol in case something happen
// conver(j)..         sum(i ,Fbiomass(i,j)*Ccf)   =E= sum(k,Fethanol(j,k)) ;

  cost..             Ctotal =E=              // Ctotal (USD/yr)

                   [sum((i,j),Fbiomass(i,j)*Copf)              // Ctotal (USD/yr) = Fbiomass(i,j) (ton/yr)* Copf (USD/ton)

                 + sum((i,j),Fbiomass(i,j)*dist(i,j)*Ctruck)]        // Ctotal (USD/yr) = Fbiomass(i,j) (ton/yr)* dist(i,j) (km) * Ctruck (USD/ton.km)

                 + [sum((j,k),Fethanol(j,k)*Bdist(j,k)*Ctanker)        // Ctotal (USD/yr) = Fethanol(j,k) (L/yr)* Bdist(i,j) (km)  * Ctanker (USD/L.km)

                 + sum((j),Tcapex*CapUnit(j))                  // Ctotal (USD/yr) = Fethanol(j,k) (L/yr)* Tcapex (
```

```
USD/L)

                  +  sum((j,k),Fethanol(j,k)*Topex)]                        »
         ;  // Ctotal  (USD/yr)  =   Fethanol(j,k)  (L/yr)*  Topex  (U»
SD/L)

 Model COM 'transport' / supply,  capacity,  demand,  cost  /               »
         ;  // COM  =  Cost  Optimization  Model

 Option MIP = 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)$(dist(i,j)   <= 76.76)  ;
 Best5a(i,j)    = A(i)$Best5c(i,j)               ;
 Tbiomass       = sum((i,j),A(i)$Best5c(i,j))    ;

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

 Report2(j,k, "Cost")        = Fethanol.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,  Tb»
iomass,  CapUnit.l  ;

 execute_unload  'SCO_CostResults.gdx'  ,  Ctotal.l  Fbiomass.m  Fet»
hanol.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=Fethanol.l    rng=Fethanol.l!a1'



                                                                            »
                                                                            »
```

APPENDIX B

Coding Programming: Emissions Optimization Model for Biofuel Supply Chain

```
$Title Emissions Optimization Model for Biofuel Supply Chain
$EolCom //
$set it TEST
$onEchoS   > Introduction.txt

  The objective of this model is to allocate the potential biorefinery for
  biofuel supply chain. The problem is to find the cheapest cost and lowest
  emission for the transportation of biomass and biofuel from supply to
  demand that meets requirements at markets and supplies at plantations.

  Supervisor : Mrs. Nurul Hanim Binti Haji Razak

  Muhammad Hilmi Bin Mohd Nasir
  B041610099
  Faculty of Mechanical Engineering
  Universiti Teknikal Malaysia Melaka

$offEcho

  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  plant»
ations

       j                 'Potential  Biorefinery  (Process)          '»
 /  PantaiTimor  /

       k                 'Pengerang  Integrated  Complex  (Demand)  '»
 /  Pengerang    /   ;


 Free  variable

       Etotal            'Total  emissions  of  bioethanol  supply  ch»
ain  (ton  CO2  per  year)'  ;


 Positive  variable

       Ebiomass(i,j)     'Flowrate  of  emissions  from  oil  palm  pla»
ntation  ith  to  biorefinery  jth  (ton  per  year)  '

       Eethanol(j,k)     'Flowrate  of  emissions  from  biorefinery »
jth to  demand  kth  (ton per  year)              '  ;

 Scalar

       E c f             'Conversion  emission  factor  of  biomass  O»
PF  to  bioethanol  (ton  CO2  per  ton)  '  /  0.58  /    ;  //  DOI:  10.»
1504/IJPSE.2016.081205

 Parameters

       Tbiomass          'Total  biomass  of  Best5e                     »
                                          '

       Beste             'Lowest  emission  from  oil  palm  plantatio»
n  ith  to  biorefinery  jth                  '

       Bestd             'Lowest  distance  from  oil  palm  plantatio»
n  ith  to  biorefinery  jth                  '

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

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

```
        Ecopf          'Emissions cultivation of biomass OPF (t»
on CO2 per ton)                          ' / 0.1055    /   // D»
OI:  10.1016/j.jclepro.2017.02.149  and  10.1016/j.enconman.2016.0»
8.081

        Ehopf          'Emissions harvesting of biomass OPF (to»
n CO2 per ton)                           ' / 0.0222    /   // N»
HR-consider only OPF emissions (included cultivation & harvesti»
ng  emissions)

        Etruck         'Emissions of truck for OPF transportati»
on (ton CO2 per ton.km)                  ' / 0.000595 /   // D»
OI:   10.1016/j.biombioe.2015.11.011

        Etanker        'Emissions of oil tanker for bioethanol »
transportation (ton CO2 per ton.km)      ' / 0.00015   / ; // D»
OI:   10.1504/IJPSE.2016.081205

   Parameter A(i)              'Biomass availability (OPF) in pa»
lm oil plantation itj (ton per year)     ' /
         ApiApi                324241.8041
         AyerBaloi             567616.8676
         AyerHitam             134196.0273
         AyerMasin             133828.1229
         Bagan                 164330.0969
         Bandar                5232.271936
         Benut                 546139.9586
         BukitSerampang        443130.3399
         BulohKasap            734610.6192
         Chaah                 707719.0842
         ChaahBahru            1153058.187
         Gemereh               131.4309833
         Gerisek               354487.9382
         Jabi                  183505.8225
         JalanBakri            82116.94182
         Jelutong              7865.676642
         Jemaluang             14522.41859
         Jementah              283463.9511
         JeramBatu             249311.6316
         JohorLama             699100.232
         Jorak                 693266.2141
         Kahang                1784555.022
         KampungBaharu         304361.6758
         Kluang                2061194.064
         KotaTinggi            948540.3729
         Kundang               78990.48352
         Labis                 782169.0978
         Layang-Layang         1020164.58
```

```
        Lenga               331926.9734
        Linau               437793.7374
        Lubok               106243.928
        Machap              356871.45
        Mersing             1864943.802
        MinyakBeku          463224.7445
        Niyor               1132273.988
        Pagoh               396449.5987
        Paloh               1827199.676
        PantaiTimor         427457.6452
        ParitBakar          31770.57696
        ParitJawa           234768.9046
//        Pengerang           380722.1423
        PengkalanRaja       40750.98138
        Penyabong           20678.70234
        Peserai             83072.88833
        Plentong            164027.5385
        Pontian             474461.2892
        Pulai               270586.3403
        Renggam             1908934.51
        RimbaTerjun         289853.4709
        Sedenak             1242912.5
        SediliBesar         522622.1407
        SediliKechil        752339.2145
        Sembrong            139593.846
        SenaiKulai          1242814.939
        Serkat              151316.2075
        Sermin              371772.4632
        Serom               132584.4629
        SimpangKanan        298131.5864
        SimpangKiri         461032.9139
        SriGading           734470.0384
        SriMenanti          318775.487
        SungaiBalang        328176.0816
        SungaiKarang        129114.0784
        SungaiKluang        384573.2528
        SungaiPinggan       293334.9093
        SungaiPunggor       374681.9691
        SungaiRaya          96740.55046
        SungaiSegamat       279264.6728
        SungaiTerap         21143.52357
        SungaiTiram         581149.8117
        Tangkak             615851.5242
        TanjungKupang       86916.36924
        TanjungSemberong    1366245.64
        Tebrau              439100.951
        Tenggaron           433877.7934
        Teriang             141893.7986
        UluBenut            419555.1979
        UluSungaiJohor      1933012.279
```

```
        UluSungaiSediliBesar   748742.9566   / ;

    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                   177.8537324
        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
//         Pengerang               12.25387932
        PengkalanRaja           91.84763463
        Penyabong               126.8380604
        Peserai                 150.7855548
        Plentong                56.68490626
```

```
        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                  66.03018776
        Tenggaron               117.7917561
        Teriang                 133.2963801
        UluBenut                109.4219138
        UluSungaiJohor          77.60816512
        UluSungaiSediliBesar    68.65852936   ;

  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=                          // Etotal (ton CO2/yr)

                  [sum((i,j),Ebiomass(i,j)*Ecopf)       // Etotal (ton CO2/yr) = Ebiomass(i,j) (ton/yr)* Ecopf (ton CO2/ton)

```

```
                    + sum((i,j),Ebiomass(i,j)*Ehopf)          // Etotal (ton CO2/yr) = Ebiomass(i,j) (ton/yr)* Ehopf (ton CO2/ton)

                    + sum((i,j),Ebiomass(i,j)*dist(i,j)*Etruck)]          // Etotal (ton CO2/yr) = Ebiomass(i,j) (ton/yr)* dist(i,j) (km) * Etruck (ton CO2/ton.km)

                    + [sum((j,k),Eethanol(j,k)*Bdist(j,k)*Etanker)          // Etotal (ton CO2/yr) = Eethanol(j,k) (ton/yr)* Bdist(i,j) (km) * Etanker (ton CO2/ton.km)

                    + sum((j,k),Eethanol(j,k)*Ecf)]  ;  // Etotal (ton CO2/yr) = Eethanol(j,k) (ton/yr)* Ecf (ton CO2/ton) = (ton CO2/yr)

 Model EOM 'transport' / emissions / ;  // EOM = Emissions Optimization Model

 Option MIP = 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)$(dist(i,j)  <= 76.76)  ;
 Best5a(i,j)    = A(i)$Best5e(i,j)               ;
 Tbiomass       = sum((i,j),A(i)$Best5e(i,j))    ;

 Report1(i,j, "Emission" )     = Ebiomass.m(i,j)   ;

 Report2(j,k, "Emission" )     = Eethanol.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  Eethanol.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=Eethanol.m  rng=Eethanol.m!a1'
```

APPENDIX C

Results: Cost Optimization Model for Biofuel Supply Chain

```
Cost Optimization Model for Biofuel Supply Chain
E x e c u t i o n


----      333 VARIABLE Ctotal.L                    =   4.89384E+18   Tota»
l cost of bioetha
                                                                     n o l »
supply chain (Lit
                                                                     e r s »
per year)

----      333 PARAMETER Report1    |    'Summary report'


                                          C o s t

ApiApi                  .PantaiTimor       29.602
AyerBaloi               .PantaiTimor       30.245
AyerHitam               .PantaiTimor       41.688
AyerMasin               .PantaiTimor       29.628
Bagan                   .PantaiTimor       40.124
Bandar                  .PantaiTimor       45.701
Benut                   .PantaiTimor       32.534
BukitSerampang          .PantaiTimor       47.960
BulohKasap              .PantaiTimor       50.386
Chaah                   .PantaiTimor       40.334
ChaahBahru              .PantaiTimor       38.184
Gemereh                 .PantaiTimor       48.411
Gerisek                 .PantaiTimor       45.190
Jabi                    .PantaiTimor       50.980
JalanBakri              .PantaiTimor       44.466
Jelutong                .PantaiTimor       25.405
Jemaluang               .PantaiTimor       30.910
Jementah                .PantaiTimor       49.734
JeramBatu               .PantaiTimor       26.869
JohorLama               .PantaiTimor       14.600
Jorak                   .PantaiTimor       42.957
Kahang                  .PantaiTimor       36.060
KampungBaharu           .PantaiTimor       36.288
Kluang                  .PantaiTimor       33.042
KotaTinggi              .PantaiTimor       17.800
Kundang                 .PantaiTimor       47.817
Labis                   .PantaiTimor       44.204
Layang-Layang           .PantaiTimor       30.368
Lenga                   .PantaiTimor       44.471
Linau                   .PantaiTimor       38.182
Lubok                   .PantaiTimor       40.970
Machap                  .PantaiTimor       32.761
Mersing                 .PantaiTimor       29.503
MinyakBeku              .PantaiTimor       37.493
Niyor                   .PantaiTimor       35.099
Pagoh                   .PantaiTimor       46.954
Paloh                   .PantaiTimor       36.429
PantaiTimor             .PantaiTimor        9.000
ParitBakar              .PantaiTimor       45.302
ParitJawa               .PantaiTimor       43.931
PengkalanRaja           .PantaiTimor       27.370
Penyabong               .PantaiTimor       34.368
Peserai                 .PantaiTimor       39.157
Plentong                .PantaiTimor       20.337
Pontian                 .PantaiTimor       28.790
Pulai                   .PantaiTimor       24.314
Renggam                 .PantaiTimor       30.254
RimbaTerjun             .PantaiTimor       28.536
Sedenak                 .PantaiTimor       27.794
SediliBesar             .PantaiTimor       20.782
SediliKechil            .PantaiTimor       14.400
Sembrong                .PantaiTimor       40.943
SenaiKulai              .PantaiTimor       25.110
```

```
----     333 PARAMETER Report2   |   'Summary report'

                                  Cost

PantaiTimor.Pengerang 3.158200E+9


----     333 PARAMETER Bestc                =         9.000  Lowest cost from oil
                                                             palm plantation ith t
                                                             o biorefinery jth
         PARAMETER Bestd                    =         0.000  Lowest distance from
                                                             oil palm plantation i
                                                             th to biorefinery jth

----     333 PARAMETER Report3   |   'Summary report'

                                        Best5c     Biomass

JohorLama           .PantaiTimor      14.600  699100.232
KotaTinggi          .PantaiTimor      17.800  948540.373
PantaiTimor         .PantaiTimor       9.000  427457.645
Plentong            .PantaiTimor      20.337  164027.538
Pulai               .PantaiTimor      24.314  270586.340
SediliBesar         .PantaiTimor      20.782  522622.141
SediliKechil        .PantaiTimor      14.400  752339.214
SungaiTiram         .PantaiTimor      16.200  581149.812
Tebrau              .PantaiTimor      22.206  439100.951
UluSungaiSediliBesar.PantaiTimor      22.732  748742.957


----     333 PARAMETER Tbiomass             =   5553667.203  Total biomass of Best
                                                             5c

----     333 VARIABLE CapUnit.L  unit of production area in biorefinery plant

PantaiTimor 1.000
```

APPENDIX D

Results: Emissions Optimization Model for Biofuel Supply Chain

```
----    282 PARAMETER Report1  |  'Summary report'

                                            Emission

ApiApi                  .PantaiTimor          0.189
AyerBaloi               .PantaiTimor          0.191
AyerHitam               .PantaiTimor          0.225
AyerMasin               .PantaiTimor          0.189
Bagan                   .PantaiTimor          0.220
Bandar                  .PantaiTimor          0.237
Benut                   .PantaiTimor          0.198
BukitSerampang          .PantaiTimor          0.244
BulohKasap              .PantaiTimor          0.251
Chaah                   .PantaiTimor          0.221
ChaahBahru              .PantaiTimor          0.215
Gemereh                 .PantaiTimor          0.245
Gerisek                 .PantaiTimor          0.235
Jabi                    .PantaiTimor          0.253
JalanBakri              .PantaiTimor          0.233
Jelutong                .PantaiTimor          0.177
Jemaluang               .PantaiTimor          0.193
Jementah                .PantaiTimor          0.249
JeramBatu               .PantaiTimor          0.181
JohorLama               .PantaiTimor          0.144
Jorak                   .PantaiTimor          0.229
Kahang                  .PantaiTimor          0.208
KampungBaharu           .PantaiTimor          0.209
Kluang                  .PantaiTimor          0.199
KotaTinggi              .PantaiTimor          0.154
Kundang                 .PantaiTimor          0.243
Labis                   .PantaiTimor          0.232
Layang-Layang           .PantaiTimor          0.191
Lenga                   .PantaiTimor          0.233
Linau                   .PantaiTimor          0.215
Lubok                   .PantaiTimor          0.223
Machap                  .PantaiTimor          0.198
Mersing                 .PantaiTimor          0.189
MinyakBeku              .PantaiTimor          0.212
Niyor                   .PantaiTimor          0.205
Pagoh                   .PantaiTimor          0.241
```

Paloh	.PantaiTimor	0.209
PantaiTimor	.PantaiTimor	0.128
ParitBakar	.PantaiTimor	0.236
ParitJawa	.PantaiTimor	0.232
PengkalanRaja	.PantaiTimor	0.182
Penyabong	.PantaiTimor	0.203
Peserai	.PantaiTimor	0.217
Plentong	.PantaiTimor	0.161
Pontian	.PantaiTimor	0.187
Pulai	.PantaiTimor	0.173
Renggam	.PantaiTimor	0.191
RimbaTerjun	.PantaiTimor	0.186
Sedenak	.PantaiTimor	0.184
SediliBesar	.PantaiTimor	0.163
SediliKechil	.PantaiTimor	0.144
Sembrong	.PantaiTimor	0.223
SenaiKulai	.PantaiTimor	0.176
Serkat	.PantaiTimor	0.193
Sermin	.PantaiTimor	0.250
Serom	.PantaiTimor	0.238
SimpangKanan	.PantaiTimor	0.214
SimpangKiri	.PantaiTimor	0.223
SriGading	.PantaiTimor	0.205
SriMenanti	.PantaiTimor	0.232
SungaiBalang	.PantaiTimor	0.226
SungaiKarang	.PantaiTimor	0.188
SungaiKluang	.PantaiTimor	0.201
SungaiPinggan	.PantaiTimor	0.194
SungaiPunggor	.PantaiTimor	0.203
SungaiRaya	.PantaiTimor	0.235
SungaiSegamat	.PantaiTimor	0.239
SungaiTerap	.PantaiTimor	0.237
SungaiTiram	.PantaiTimor	0.149
Tangkak	.PantaiTimor	0.247
TanjungKupang	.PantaiTimor	0.178
TanjungSemberong	.PantaiTimor	0.206
Tebrau	.PantaiTimor	0.167
Tenggaron	.PantaiTimor	0.198
Teriang	.PantaiTimor	0.207
UluBenut	.PantaiTimor	0.193
UluSungaiJohor	.PantaiTimor	0.174
UluSungaiSediliBesar	.PantaiTimor	0.169

```
----     282 PARAMETER Report2  |  'Summary report'

                         Emission

PantaiTimor.Pengerang       0.585


----     282 PARAMETER Beste                =        0.128  Lowest emission from
                                                            oil palm plantation i
                                                            th to biorefinery jth
            PARAMETER Bestd                =        0.000  Lowest distance from
                                                            oil palm plantation i
                                                            th to biorefinery jth

----     282 PARAMETER Report3  |  'Summary report'

                                      Best5e     Biomass

JohorLama           .PantaiTimor       0.144  699100.232
KotaTinggi          .PantaiTimor       0.154  948540.373
PantaiTimor         .PantaiTimor       0.128  427457.645
Plentong            .PantaiTimor       0.161  164027.538
Pulai               .PantaiTimor       0.173  270586.340
SediliBesar         .PantaiTimor       0.163  522622.141
SediliKechil        .PantaiTimor       0.144  752339.214
SungaiTiram         .PantaiTimor       0.149  581149.812
Tebrau              .PantaiTimor       0.167  439100.951
UluSungaiSediliBesar.PantaiTimor       0.169  748742.957


----     282 PARAMETER Tbiomass             =  5553667.203  Total biomass of Best
                                                            5e
```

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