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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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. $7.39\text{x}10^{1o}$ 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.

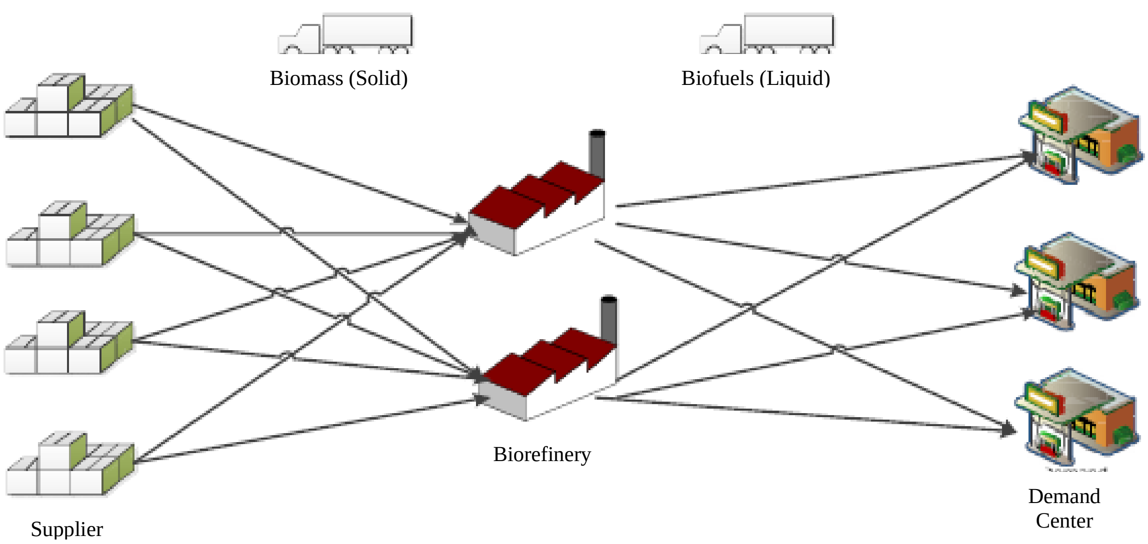

Figure 1: Centralized biofuel supply chain.

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.