UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A MATHEMATICAL MODEL FOR OPTIMAL PLANNING OF BIOFUEL SUPPLY CHAIN

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DEVELOPMENT OF A MATHEMATICAL MODEL FOR OPTIMAL PLANNING OF BIOFUEL SUPPLY CHAIN

By

MARYAM VALIZADEH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

October 2014

DEDICATION

I would like to dedicate this thesis to my adorable parents whose affection, love, encouragement and support have sustained me throughout the challenges of my life. I also dedicate this thesis to my beloved brothers, Ali and Amin, for their patience and encouragement. I am truly thankful for having you in my life.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

DEVELOPMENT OF A MATHEMATICAL MODEL FOR OPTIMAL PLANNING OF BIOFUEL SUPPLY CHAIN

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October 2014

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Biofuels have attracted the attention of researchers, due to their potential to mitigate climate changes. Biodiesel is a type of biofuel that can be used as an alternative fuel for diesel engines. The three main problems with biodiesel production are, high production costs, environmental, and social impact over the entire supply chain.

The main objective of this thesis is to propose a method for optimal planning and operation of biodiesel supply chain. An additional objective is to understand the capability of a modern heuristic method for optimal planning of the chain.

In this study, a methodology is presented to optimize the full supply chain for producing biodiesel. A Multi-Objective Linear Programming (MOLP) model is developed, which takes into account the economic, environmental and social concerns that are related to the biodiesel supply chain. The model aims to minimize total operational cost, greenhouse gas (GHG) emission, and edible feedstock consumption. The proposed model is solved using a simple Multi-Objective Particle Swarm Optimization (MOPSO) method, to overcome the difficulties related to classical methods for solving multi-objective optimization problems. The performance of this method is compared with a well-known classical method, Ɛ-constraint, to study the capability of the MOPSO method.

The proposed model and solving strategy was used to evaluate biodiesel production from palm oil and jatropha, based on existing biodiesel plants in Malaysia. The results show that the MOPSO method has a good ability for finding the approximation of optimal solutions. The model determined the optimal annual operational cost, GHG emission, edible feedstock consumption, quantity of feedstock to be harvested, transportation schedules, and quantity of biodiesel to be produced at bio-refineries, for the selected case study in Malaysia. The model was also compared with an economic and environmental-economic optimization models.

The results show the effectiveness of the proposed MOLP model at providing decisions with better economic, environmental, and social performances. Furthermore, a sensitivity analysis, based on the availability of jatropha, demonstrated the impact of a reduction of jatropha availability, on total emission and edible feedstock consumption.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan Ijazah Master Sains

PERKEMBANGAN MODEL MATEMATIK UNTUK PERANCANGAN OPTIMUM RANTAIAN BEKALAN BIOFUEL

Oleh

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Biofuel telah menarik perhatian penyelidik kerana potensinya untuk mengurangkan kesan perubahan iklim. Biodiesel adalah sejenis biofuel yang boleh digunakan sebagai bahan api alternatif untuk enjin diesel. Tiga masalah utama dengan pengeluaran biodiesel adalah kos pengeluaran yang tinggi, dan kesan alam sekitar dan sosial ke atas rantaian bekalan keseluruhannya.

Objektif utama projek ini adalah untuk mencadangkan suatu kaedah untuk perancangan dan operasi optimum rantaian bekalan biodiesel. Objektif tambahannya adalah untuk memahami keupayaan kaedah heuristik moden untuk perancangan optimum rantai tersebut.

Kajian ini membentangkan kaedah untuk mengoptimumkan rantaian bekalan sepenuhnya untuk menghasilkan biodiesel. Suatu model Pengaturcaraan Linear Pelbagai Objektif (MOLP) dibangunkan, dengan mengambil kira aspek-aspek ekonomi, alam sekitar dan sosial yang berkaitan dengan rantaian bekalan biodiesel. Model ini bertujuan untuk mengurangkan jumlah kos operasi, pelepasan gas rumah hijau (GHG), dan penggunaan bahan mentah yang boleh dimakan. Model yang dicadangkan itu diselesaikan dengan menggunakan kaedah Pengoptimuman Partikel Swarm Pelbagai Objektif (MOPSO) yang mudah, untuk mengatasi kesukaran yang berkaitan dengan kaedah-kaedah klasik untuk menyelesaikan masalah pengoptimuman pelbagai objektif. Prestasi kaedah ini dibandingkan dengan kaedah klasik terkenal, kekangan-ϵ, untuk mengkaji keupayaan kaedah MOPSO itu.

Model dan strategi penyelesaian yang dicadangkan ini telah digunakan untuk menilai pengeluaran biodiesel daripada minyak kelapa sawit dan jarak berdasarkan kilang biodiesel yang sedia ada di Malaysia. Hasil kajian menunjukkan bahawa kaedah MOPSO mempunyai keupayaan yang baik untuk mencari penghampiran penyelesaian yang optimum. Model ini menentukan kos operasi tahunan yang optimum, pelepasan GHG, penggunaan bahan mentah yang boleh dimakan, kuantiti bahan mentah untuk dituai, jadual pengangkutan, dan kuantiti biodiesel yang harus dikeluarkan oleh kilang penapis bio, untuk kajian kes yang dipilih di Malaysia. Model ini juga dibandingkan dengan model-model pengoptimuman ekonomi dan ekonomi alam sekitar.

Hasil kajian menunjukkan keberkesanan model MOLP yang dicadangkan untuk menyediakan keputusan dengan prestasi ekonomi, alam sekitar, dan sosial yang lebih baik. Tambahan pula, analisis sensitiviti berdasarkan ketersediaan jarak menunjukkan kesan pengurangan ketersediaan jarak ke atas jumlah pengeluaran dan penggunaan bahan mentah yang boleh dimakan.

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I would also like to express my wholehearted thanks to my family for their generous support provided me throughout my life.

I certify that a Thesis Examination Committee has met on 30 October 2014 to conduct the final examination of Maryam Valizadeh on her thesis entitled "Development of a Mathemtical Model for Optimal Planning of Biofuel Supply Chain" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

NPC	National Petroleum Council
GHG	Greenhouse gas
MOPSO	Multi- Objective Particle Swarm Optimization
MOLP	Multi-Objective Linear Programming
PSO	Particle Swarm Optimization
MINLP	Mixed Integer Non-Linear Programming
MILP	Mixed Integer Linear Programming
CBGTL	Coal, Biomass and Natural Gas to Liquids
LCA	Life Cycle Assessment
UK-RFA	UK Renewable Fuels Agency
EIA	United States Energy Information Administration
APEC	Asia-Pacific Economic Cooperation
FAO	Food and Agriculture Organization of the United Nations
JO	Jatropha Oil
FFB	Fresh Fruit Bunches
MPOB	Malaysia Palm Oil Board
CPO	Crude Palm Oil
APOC	American Palm Oil Council
PPI	Producer Price Index
MEIH	Malaysia Energy Information Hub
MYR	Malaysian Ringgit

NOTATIONS

Indices

i	Type of feedstock
l	Feedstock resource
w	Biorefinery
n	Demand zone

Parameters

$C_{i,l}^{har}$	Production and harvesting cost of feedstock type *i* from resource *l*
C_i^{pre}	Pre-processing cost of feedstock type *i*
$T1_i^r$	Transportation cost of feedstock type *i* via road
$D_{l,w}$	Road distance between resource *l* and biorefinery *w*
$T1_i^S$	Transportation cost of feedstock type *i* via ocean
	Production cost of biodiesel from feedstock *i* at biorefinery *w*
$T2_i^r$	Transportation cost of biodiesel via road
$D'_{w,n}$	Road distance between biorefinery *w* and demand zone *n*
$T2_i^S$	Transportation cost of biodiesel via ocean

η_i	Conversion factor for pre-processing of feedstock type *i*
E_i^p	Emission factor for production and harvesting of feedstock type *i*
E_i^{pre}	Emission factor for pre-processing of feedstock type *i*
Et_i^r	Emission factor for transportation of feedstock type *i* via road
Et_i^S	Emission factor for transportation of feedstock type *i* via ocean
$Ds_{l,w}$	Ocean distance between resource *l* and biorefinery *w*
E_i^c	Emission factor for conversion of feedstock *i* to biodiesel
Ed_i^r	Emission factor for distribution of biodiesel via road
Ed_i^S	Emission factor for distribution of biodiesel via ocean
$D's_{w,n}$	Ocean distance between biorefinery *w* and demand zone *n*
β_i	Binary variable which is equal to 1 if feedstock is edible, otherwise equals 0
$Y_{i,l}$	Maximum availability of feedstock type *i* at resource *l*
α_i	Conversion factor for biodiesel production from feedstock type *i*
Ref_w	Capacity of biorefinery *w*
D_n	Biodiesel demand at demand zone *n*

Decision variables

$Q_{i,l}$	Quantity of feedstock type *i* to be harvested from resource *l*
$X_{i,l,w}$	Quantity of pre-processed feedstock type i shipped from resource *l* to biorefinery *w*
$X_{i,w}^f$	Amount of biodiesel produced from feedstock *i* at biorefinery *w*
$Q_{i,w,n}^f$	Quantity of biodiesel which is produced from feedstock *i* and shipped from biorefinery *w* to demand zone *n*

CHAPTER 1

INTRODUCTION

Recently, issues such as energy demand growth, interest in cutting down energy consumption as well as the related emissions, have led to the use of renewable energy resources. It has been predicted that the world's demand for energy will increase by 50% to 60% until 2030, as a result of population growth and the pursuit of higher living standards. Additionally, biomass has been considered as a good substitute for meeting the demands, due to the increasing prices of petroleum and the uncertainty of its availability (Santibañez-Aguilar et al., 2011; National Petroleum Council [NPC], 2007; Rosegrant et al., 2006).

To satisfy future energy demands, renewable energy generated from wind, biomass, and solar resources has great potential for growing (Drapcho et al., 2008). Biofuel energy is considered as a type of renewable energy produced from biomass resources.

Biofuels such as bioethanol, biodiesel, biogas, and syngas are produced from variety of sources and are classified into three categories (An et al., 2011):

Sugar, oil crops, starch crops and animal fats are sources of the first generation biofuels. Edible feedstocks are the main source of the first generation biofuels, which could affect the global food crisis (Rosegrant et al., 2006).
Non-edible crops, residues of crops and other lignocellulosic materials, are sources of the second generation biofuels.
Algae are considered as the source of the third generation biofuels.

Biofuels are capable of reducing greenhouse gas (GHG) emissions. However, biofuels' potential for reducing climate changes depends on feedstock type and the way it is produced and the technologies used for processing of biomass and biofuels as well (Santibañez-Aguilar et al., 2011; Timilsina & Shrestha, 2011).

From an economic point of view, the production cost of biofuels in large scale is high comparing to fossil fuels (United Nations, 2006). Production cost of biofuels varies based on factors such as feedstock type, process, plant size, and region. The price of feedstock is the major factor in overall costs (Demirbas, 2009; Timilsina & Shrestha, 2011).
Another challenge lies in the issue that some of biofuel's feedstocks, such as soybean, oil palm, and corn are food sources for humans or animals. Growing demand for agricultural crops, which are sources of food, to produce biofuel has been one of the factors in increasing food prices. Furthermore, increase in

demand for these crops may lead to deforestation due to the area required for cultivation of energy crops, which will result in GHG emissions (FAO, 2008). Management of plant, production and transportation and optimization of biofuel supply chain could improve the biofuel production.

Among all the biofuels, biodiesel has received considerable attention due to the similarities to petroleum diesel (Lam et al., 2009).

1.1 Problem Definition

Biodiesel is considered as renewable energy and has the potential to reduce GHG emissions (Panwar et al., 2011). However, climate change mitigation potential of biodiesel depends on other factors such as biomass cultivation process as well as feedstock to biodiesel processing technologies (Timilsina & Shrestha, 2011). In addition, production costs of biodiesel are high compared to petroleum diesel. Another issue is management of crops used for production of biodiesel, as more than 95% of biodiesel is made from edible oil derived from agricultural crops. This issue is along with the reduction of food resources which can bring global imbalance to the food supply and the market demand. Furthermore, deforestation and destruction of ecosystems are among the negative impacts of biodiesel derived from edible oils (Yusuf et al., 2011).

According to the previous descriptions, an effective strategy is needed for production of sustainable biodiesel. Planning of biodiesel supply chain is one of the most important aspects of biodiesel production, since the methods of production and consumption of energy as well as the way it is supplied influence the environment (Tran et al., 2011). An optimal biofuel supply chain will lead to the efficient delivery of biofuel to the end users (Hamelinck et al., 2005).

Optimization problems in biofuel supply chains are formulated in form of mathematical models. Some of the optimization problems, like the problem in hand, deal with multiple objectives. Depending on complexity of supply chain, the optimization of chain could become difficult to handle with classical methods (Silva & Coelho, 2007). Therefore, a proficient method is required for solving the biodiesel supply chain optimization problem.

The aim of this contribution is improvement of biodiesel production by taking into account economic, environmental, and social criteria through the development of a mathematical model. Subsequently, a heuristic method will be used to study the capability of the heuristic method for solving the optimization problem in hand.

1.2 Research Questions

In order to improve biodiesel production, a series of questions need to be addressed.How to reach a solution for optimal planning of biodiesel supply chain considering economic, environmental and social concerns?

- How to overcome difficulties associated with classical methods for solving multi-objective optimization problems?
- What are the optimal quantity of feedstock to be harvested, feedstock and biodiesel transportation schedules, and quantity of biodiesel produced at biorefineries?
- What are the optimal operational cost, GHG emissions, and edible feedstock consumption for production of biodiesel over the specified planning horizon?

1.3 Research Objectives

Based on the research questions, the research objectives are:

- To develop a mathematical model for optimal planning of biodiesel supply chain under the economic, environmental, and social criteria
- To evaluate the capability of a heuristic method for solving the multi-objective optimization problem in biodiesel supply chain
- To specify the optimal quantity of feedstock to be harvested, feedstock and biodiesel transportation schedules, and quantity of biodiesel produced at biorefineries based on the proposed model
- To determine the optimal operational cost, GHG emissions, and quantity of edible feedstock consumption for production of biodiesel over the planning horizon based on the proposed optimization model.

1.4 Research Scope

This study focuses on optimal planning of biodiesel supply chain based on available resources and facilities through development a mathematical model. It considers the minimization of annual operational cost, GHG emissions in form of CO2 equivalent, and quantity of edible feedstock consumption for production of biodiesel over the entire supply chain. It should be noted that capital costs are not included in this study. The model also takes into account optimal selection of feedstock, harvesting and transportation schedules as well as biodiesel production at biorefineries.

The proposed model is applied to a case study for production of biodiesel from palm oil and jatropha in Malaysia. The planning horizon has been set to one year. The simple multi-objective particle swarm optimization (MOPSO) method is applied to solve the optimization problem and it is compared with the ε-constraint method. These methods are implemented in MATLAB software.

1.5 Methodology Framework

To obtain an optimal plan for operation of biodiesel supply chain, a five-step methodology has been proposed. This methodology has been briefly presented in Figure 1.1. Identifying the decision variables and parameters that should be used in the model is the first step. The decision variables are shown in Figure 1.2.

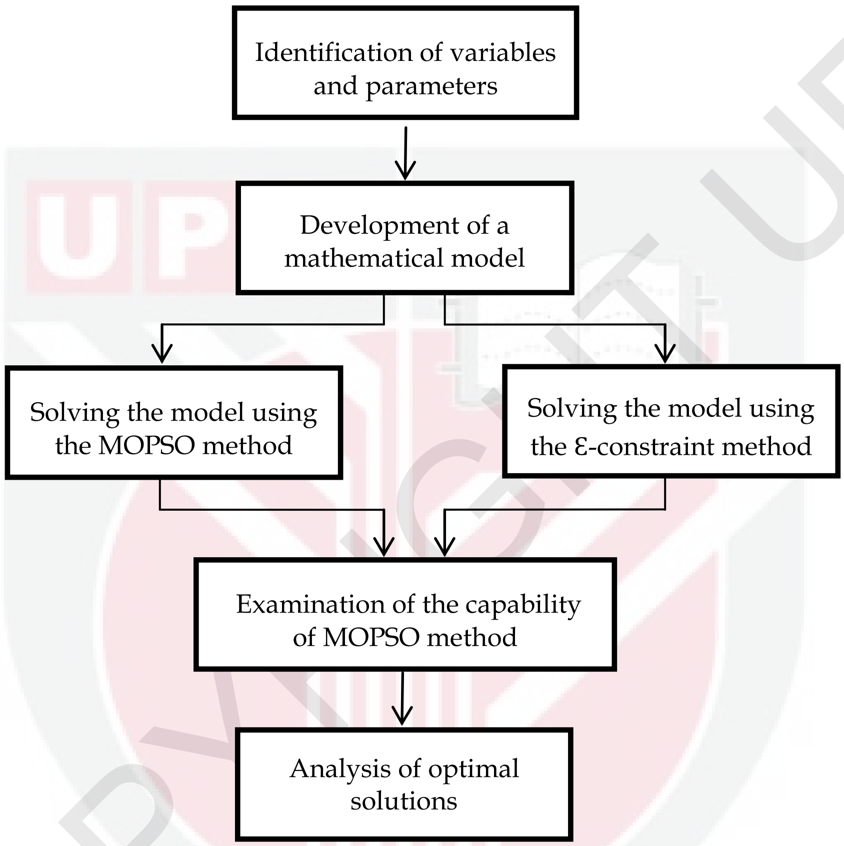

Figure 1.1.Steps of methodology

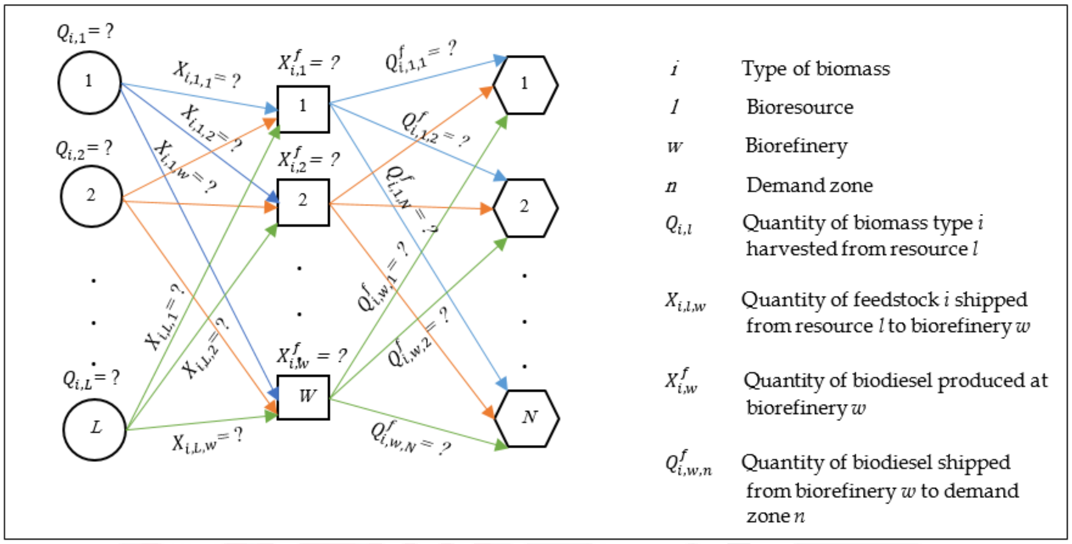

Figure 1.2.Structure of biodiesel supply chain and optimization decision variables

A mathematical model will be developed in the next step. The model is linear and considers the economic, environmental, and social objectives related to biodiesel supply chain. Therefore, the proposed model is a multi-objective linear programming (MOLP) model. The economic objective represents the total operational cost. GHG emissions (CO_2 equivalent) over the entire supply chain are used to measure the environmental objective. Likewise, quantity of edible feedstock consumption for production of biodiesel is measured as the social objective.

In the third step, the MOPSO method, which is improved form of particle swarm optimization (PSO) approach for handling multi-objective problems, is applied to solve the optimization problem. PSO approach is a modern heuristic method which has been successfully applied to several supply chain problems (Izquierdo et al., 2008; Sinha et al., 2009; Wei, 2011; Song et al., 2011). The Ɛ-constraint method, a well-known classical method that is usually used for solving the multi-objective optimization problems, is applied to the proposed model as well.

In the next step, the MOPSO method and the Ɛ-constraint method are compared in order to investigate the capability of the heuristic method (MOPSO) for solving the multi-objective optimization problem in biodiesel supply chain.

In the last step, optimal solutions resulting from optimization process are analyzed in order to select an appropriate solution.

1.6 Thesis Structure

After the introduction provided in this chapter, Chapter 2 reveals a literature review of relevant works, including the mathematical modeling of biofuel supply chain and multi-objective optimization solving methods. A detailed description of the methodology for optimal planning of biodiesel_supply chain is given in Chapter 3. Chapter 4 presents the results through the illustration of proposed model in a case study for the optimal planning of biodiesel supply chain in Malaysia. Chapter 5 draws the conclusion and provides the discussion of potential research extensions.

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