ENVIRONMENTAL DEGRADATION ASSESSMENT OF BIODIESEL PRODUCTION USING LIFE CYCLE ANALYSIS

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To my beloved family

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ABSTRACT

The global transportation sector is one of the major fuel consumers and contributes directly to greenhouse gas emissions. In order to reduce the environmental burden of fuel usage, new diesel blending formulations that consist of biofuels were developed. The objective of the study is to assess the environmental performance of the new diesel blending formulations compared to the existing diesel blending formulation (B5). The life cycle assessment (LCA) methodology has been used to assess the environmental performance of the blending formulation. New weighting values are also developed by using an analytical hierarchy process to support the study within Malaysia's context. In term of LCA result within midpoint categories, Blending 5 has shown the most potential compared to other fuels including B5 blending due to better environmental performance in most categories except for ozone depletion and urban land occupation impacts. In the endpoint categories, for Malaysia's context; Blending 5 has shown better environmental performance as compared to B5 blending with each scoring 9.63E-5 point and 1.00E-4 point, respectively. The result is found to be consistent with other weighting methods. In developing new weighting values, this study suggests there is no consensus in term of importance between regional and global impact categories. This is visualized in the individualist perspective where both global and regional impacts were scored most importance but higher regional impact scored in egalitarian and hierarchist perspectives. In conclusion, Blending 5 has scored the least weighting values as compared to other diesel blending formulations including B5 thus indicating its potential as an alternative to the existing diesel blending formulation.

ABSTRAK

Di peringkat global, sektor pengangkutan merupakan salah satu pengguna bahan api fosil dan secara langsung menyumbang kepada pelepasan gas rumah hijau. Dalam usaha untuk mengurangkan pencemaran alam sekitar daripada penggunaan bahan api fosil, rumusan diesel campuran baru yang terdiri daripada biofuel telah dibangunkan. Objektif kajian ini adalah untuk menilai potensi pencemaran alam sekitar bagi formula baru diesel dan membandingkan dengan formulasi adunan diesel yang sedia ada (B5). Kaedah penilaian kitaran hayat (LCA) telah digunakan untuk menilai prestasi alam sekitar rumusan adunan formula tersebut. Nilai pemberat baru juga dibangunkan dengan menggunakan proses hierarki analisis untuk menyokong kajian dalam konteks Malaysia. Dari segi hasil LCA dalam kategori titik tengah, Adunan 5 telah menunjukkan potensi untuk diaplikasikan kerana prestasi alam sekitar yang lebih baik dalam setiap kategori kecuali impak pengurangan ozon dan kesan pendudukan tanah bandar termasuk B5. Dalam kategori titik akhir, untuk konteks Malaysia; Adunan 5 telah menunjukkan prestasi alam sekitar yang lebih baik berbanding dengan B5 dengan masing-masing menghasilkan 9.63E-5 dan 1.00E-4 markah. Hasil keputusan juga didapati konsisten dengan kaedah pemberat lain. Dalam membangunkan nilai-nilai pemberat baru, kajian ini menunjukkan tidak ada kesepakatan dari segi kepentingan antara kategori kesan serantau dan global. Ini digambarkan dalam perspektif individualis di mana kedua-dua kesan global dan serantau menghasilkan pemberat yang sama penting tetapi pemberat yang lebih tinggi pada kesan serantau pada perspektif egalitarian dan hierarkis. Kesimpulannya, Adunan 5 menghasilkan nilai pemberat yang kurang berbanding dengan formula campuran diesel lain termasuk B5 dan menunjukkan potensinya sebagai alternatif untuk formulasi campuran diesel yang sedia ada.

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LIST OF ABBREVIATIONS

ADP	-	Abiotic Depletion Potential
AHP	-	Analytical Hierarchy Process
B5	-	Diesel Blending (5% Biodiesel, 95% Diesel)
B20	-	Diesel Blending (20% Biodiesel, 80% Diesel)
B100	-	Diesel Blending (100% Biodiesel)
BR	-	Brazil
C	-	Cellulose
CFC-11 EQ	-	Chlorofluorocarbon Equivalent
CH	-	Switzerland
CI	-	Consistency Index
CN	-	China
CO_2E	-	Carbon Dioxide equivalent
CPO	-	Crude Palm Oil
CR	-	Consistency Ratio
DB EQ.	-	Diethyl Benzene Equivalent
DOE	-	Department of Environmental
EFB	-	Empty Fruit Bunch
EtOH	-	Ethanol
FE EQ	-	Ferum Equivalent
FFA	-	Free Fatty Acid
FR	-	France
G	-	Glucose

GHG	-	Greenhouse Gas
GLO	-	Global
GMM	-	Geometric Means
GWP	-	Global Warming Potential
H	-	Hemicellulose
HC	-	Hydrocarbon
I	-	Inhibitors
ILCD	-	The International Reference Life Cycle Data System
ISO	-	International Organization for Standardization
L	-	Lignin
KETTHA	-	Kementerian Tenaga, Teknologi Hijau dan Air
LCA	-	Life Cycle Assessment
LCI	-	Life Cycle Inventory
LCIA	-	Life Cycle Impact Assessment
MNRE	-	Ministry of New and Renewable Energy
MY	-	Malaysia
N-EQUIV.	-	Nitrogen Equivalent
NG	-	Natural Gas
NMVOC	-	Non-methane volatile organic compound
NO_x	-	Nitrogen Oxide
ODP	-	Ozone Depletion Potential
P	-	Pentose
P EQ.	-	Phosphorus Equivalent
PAHs	-	Polycyclic Aromatic Hydrocarbons
PM	-	Particulate Matter
POCP	-	Photochemical Oxidation Potential
POF	-	Photochemical Oxidation Formation
POME	-	Palm Oil Mill Effluent
PPF	-	Palm Press Fiber
RC	-	Random Consistency
RER	-	Europe
RPO	-	Refined Palm Oil
SO_2 eq.	-	Sulfur Dioxide Equivalent
SSCF	-	Simultaneous Saccharification and Cofermentation

SSF	-	Simultaneous Saccharification and Fermentation
U235 eq-	-	Uranium-235 Equivalent
UIAM -	-	Universiti Islam Antarabangsa Malaysia
UKM -	-	Universiti Kebangsaan Malaysia
UM -	-	Universiti Malaya
UPM -	-	Universiti Pertanian Malaysia
US	-	United States of America
UTM -	-	Universiti Teknologi Malaysia
UTP -	-	Universiti Teknologi Petronas
UV	-	Ultra Violet
VOC	-	Volatile Organic Compounds
WAMM	-	Weighted Arithmetic Means
WHO	-	World Health Organizations
WWTP	-	Waste Water Treatment Plant
WHO	-	World Health Organization

LIST OF SYMBOLS

P_j	-	Root of number of element
n	-	Number of element
a_i	-	Element i
a_j	-	Element j
$EI\ (a_j)$	-	Environmental impact of an alternative aj
R_i	-	Indicator result of impact category i of the reference area
W_i	-	Weighting factor of impact category i
$I_i(a_j)$	-	Impact category indicator result of impact category i caused by alternative aj
W_{Di}	-	Weighting factor for damage of category i
W_{SDi}	-	Weighting factor for sub damage of category i

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The world is currently moving towards sustainable development due to environmental crisis. Sustainability is observed as the main objective of most countries developments and researches. Even the definition of sustainability term give different context in which the word is applied, the main idea is to maintain the resource without neglecting the development. In energy concept, sustainability has been well discussed, mostly agreed with replacement of current shrinking sources of energy with new unlimited sources (Brown et al., 1987). However, this sustainability concept is seem impossible with the current situation in which fossil fuel remains the major source and projected to meet 84% of energy demand in 2030 (The World Energy Outlook (WEO) 2007). Current state of fuel consumption have seen the utilization of fossil fuel alone or blending with other renewable fuel.

The most energy use nowadays comes from fossil fuel including diesel, natural gas, coal and gasoline. Many researches and field engineers believe that the depletion of the original world fossil petroleum has arrived and the exhaustion of the natural resource is already happening. The logic from this theory is based on the current situation that shows depletion of crude oil storage and slow discovery of new fields. There are also contrasting opinions that the peak of oil production is still not occurring for years or maybe decades due to giant oil reservoirs that are waiting to be discovered (Speight, 2010). Another important issue of energy sustainability related to fossil fuel is the fuel price movement. Several incidents such as Iran/Iraq war and 9/11 tragedy are affecting the fuel price especially oil (Economics WTRG, 2008). This arise the concern that forecasting fossil fuel price are difficult due to uncertainty in the future (Shafiee and Topal, 2009). In term of environmental impact, the burning of fossil fuel produces acid solution that generates acid rain which affects both natural and develop areas. Combustion of fossil fuel also generates carbon dioxide and other gases which lead to global warming (Yee *et al.* 2009).

In order to reduce the reliant on the fossil fuel, diesel is utilized align with other fuel such as biodiesel. International standard has been applied for describing the concentration of biodiesel in the blend, known as the BXX nomenclature, where XX denotes the percentage in the biodiesel volume in the diesel/biodiesel blends. Nowadays, nomenclatures such as B2, B5, B20 and B100 are being used with 2%, 5%, 20% and 100% of biodiesel content respectively. The most common blending utilized today is B100, blend B20-B30, additive B5 and lubricity-additive B2 (Yusuf *et al.* 2011). In Malaysia, the implementation of B5 usage, which constitutes of 5% biodiesel and 95% petroleum diesel, was started in February 2009. The utilization of biofuel in Malaysia, especially biodiesel, has been known since the introduction of the National Biofuel Policy on August 10, 2005. The policy is later changed into National Biodiesel Policy and was developed after many consultations with all stakeholders and extensive research by Malaysian Palm Oil Board (MPOB) since 1982. Although the B5 programme can help to reduce emission of harmful substance into the environment, as for industrial purposes, the policy should target a higher blend of biodiesel in the future to ensure the success of the policy (Abdullah *et al.* 2009).

One of the potential fuel that have been used extensively as a blending component is biodiesel. Biodiesel has many advantages compared to fossil fuel in terms of GHG emissions and also as renewable sources (Yee et al. 2009). Biodiesel is extracted from vegetable oils and fats that contain triglycerols, thus entitle the fuel as a renewable source (Sharma et al. 2011). There are several vegetable oils that have been experimented to produce biodiesel based on their availability of the oils in the respective country. Palm oil is commonly utilized as raw materials for biodiesel in Malaysia due to its superior annual yield compared to other crops (Yee et al. 2009). Meanwhile, soybean oil is widely applied in United States and rapeseed oil is used in many European countries (Knothe, 2010).

Another blending component, bioethanol can be extracted through traditional methods such as fermentation. Its potential is already known as replacement of petrol usage in transportation systems. The key in converting biomass into bioethanol are based on two significant reactions which are hydrolysis and fermentation. Hydrolysis is a process of converting complex polysaccharides in raw feedstocks into simple sugars. The fermentation reaction is aided by yeast or bacteria that feed on the simple sugars. The products from this process are bioethanol and carbon dioxide (Cheng et al. 2007). Bioethanol is believed to be one of the best alternatives fuel due to its renewable and environmentally properties. In addition, ethanol has been labelled as a cleaner fuel than gasoline with regard to the reduction of tailpipe emissions of certain pollutions such as CO_2, CH_4, CO and NO_x. Furthermore, the mixture of ethanol in gasoline can improve the quality of gasoline in the sense of increasing the fuel octane number. Despite the advantages, the concern of using ethanol in the main market arises due to its relatively high price over gasoline, either in pure or blended form (Nguyen and Gheewala, 2008).

Lower diesel component within the diesel blending, a greener and sustainable fuel is expected. However, the sustainability of these blending formulation is still questioned due to the increasing of other environmental impacts related to agricultural effect coming from biofuel components. Study on biodiesel consumption as transportation fuel shown, despite of lower carbon dioxide concentration in pipe tail, other pollutants such as particulate matter (PM_{10}) and nitrous oxide have been claimed much higher compared to diesel. The increasing impact of eutrophication due to high utilization of nitrogen and phosphorus in biodiesel are also been reported (Nanaki and Koroneos, 2012). Therefore, the environmental impacts of new diesel blending were discussed in this study. The new diesel blending formulation are developed by other research teams. The blending consists of diesel and blended with biofuel, and other fuel.

In order to fully understand the sustainability of new diesel blending formulation in Malaysia, Life cycle assessment (LCA) appears to be a valuable tool. Life cycle assessment is a method for assessing the potential environmental impact of a product or process throughout its entire life cycle. Life cycle impact assessment (LCIA), an analytical step within LCA methodology, consists of classification, characterization, normalization and weighting steps. ISO 14000 series were used as reference to the LCA studies. In term of life cycle inventory (LCI), the data were collected through industrial data, literatures and ecoinvent database version 2.2. All the inventories data involves were analysed and modelled using LCA software (Gabi5).

For environmental impact interpretation, presently, majority of life cycle impact assessment (LCIA) analyses were performed using European database that may not precise in term of regional context. The study that comprehend Malaysia's context using Eco-Indicator was conducted by Onn and Yusoff (2010). This however only covers one LCIA methodology, which is Eco-Indicator. The weighting values for others method such as in ReCiPe, CML and Impact 2002+ are still open for reconsideration. Consequently, improvement on LCIA method with emphasizing on new weighting values is suggested in order to characterize the Malaysia's condition. Thus the new weighting values formulated based on ReCiPe methodology is one of the major contribution of the thesis. ReCiPe LCIA methodology was used as this method compromises 18 impact categories within midpoint analysis thus give large coverage on the environment (Goedkoop et al., 2009). Furthermore the method covers both midpoint and endpoint categories. This value not only contributes in precision result of regional LCA studies, but also to contribute the national life cycle assessment (LCA) inventory by LCA Malaysia.

1.2 Problem Statement

Awareness on the significance of environmental issue on the usage of fossil fuel has motivated the society towards utilization of greener fuel that more sustainable to the environment. The utilization of fossil fuel produces numerous amounts of greenhouse gases (GHG) emissions which contribute to global warming. Diesel utilization in diesel engine also emit significant air pollutants such as particulate matter (PM) and nitrogen oxides (NOx) (Lloyd & Cackette, 2001). The depletion of the original world fossil petroleum and the exhaustion of the natural resource are also arise concern among the society. This is based on slow discovery of new oil fields to fulfil the demand. There are also contrasting opinions that the peak of oil production is still not occurring for years or maybe decades due to giant oil reservoirs that are waiting to be discovered (Speight, 2010) which increase the uncertainty of the fuel utilization.

Diesel blending has been introduced to reduce the reliant of fossil diesel in the transportation sector. Fossil diesel is blending with others fuel such as biodiesel. The most common blending utilized today is B100, blend B20-B30, additive B5 and lubricity-additive B2 (Yusuf *et al.* 2011). In Malaysia, the implementation of B5, which constitutes 5% biodiesel and 95% petroleum diesel in Malaysia, was started in February 2009. Although the B5 programme can help to reduce emission into the environment, for industrial purposes, the policy should target a higher blend of biodiesel in the future to ensure the success of the policy (Abdullah *et al.* 2009).

Thus new blending formulations were developed with intentions to have a minimum potential environmental impact. With the reduction of fossil diesel, lower GHG emissions are expected. Study on biodiesel consumption as transportation fuel shown, despite lower carbon dioxide concentration in pipe tail, other pollutants such as particulate matter (PM10) and nitrous oxide have been claimed much higher compared to diesel. The increasing impact of eutrophication due to high utilization of nitrogen and phosphorus are also been reported (Nanaki and Koroneos, 2012). Thus it is crucial to identify the potential environmental impact from the new diesel blending formulation.

In term of life cycle assessment (LCA) method, life cycle impact assessment (LCIA) was used to evaluate the data from process inventory is a combination of classification, characterization, normalization and weighting. This procedure is well known and applied worldwide, however, currently most LCIA analyses were performed using European database thus making the analysis less precise from regional perspective. This is because the European pollution emission rates being used as a basis for European database might not be suitable and accurate for LCA study of Malaysia scenario. Thus, in order to represent Malaysia's environmental condition, it is crucial to establish a Malaysia version of normalization and weighting values based on Malaysia own data. The weighting value will provide more accurate represent value in term of local perspectives.

1.3 Objectives

The main aim of the research is to assess and quantify the environmental performance of the new diesel blending formulation consisting of five type of fuels namely diesel, biodiesel, bioethanol, butanol and butyl levulinate using LCA methodology. New weighting values are also developed to support the LCA study by using AHP approach. The objectives of this study are:

I. To conduct inventory of inputs and outputs (based on several different blending and formulation) of new diesel blending production.
II. To quantify the potential environmental degradation of the different diesel blending formulation using life cycle assessment approach.
III. To develop new LCA weighting value that represents Malaysia condition.
IV. To compare the environmental impacts of new and current diesel blending based on the new weighting value.

1.4 Scope

The blending formulation consists of biodiesel, diesel, bioethanol, butanol and butyl levulinate. For data inventory, input and output of each blending composition were collected through literature, industrial data and software database. An electricity component which is natural gas power plant also included to represent Malaysia's context. The raw material for biodiesel is refined palm oil and for bioethanol is empty fruit bunch (EFB) and press palm fiber (PPF). Ecoinvent database was used as inventory data for diesel, butanol and butyl levulinate. The data is assumed based on current technology and also represent Malaysia condition. The boundaries have been setup based on cradle-to-gate for each diesel blending composition.

In order to quantify the potential environmental degradation of different diesel blending formulation, eighteen potential impact included in ReCiPe LCIA methodology were used. The collected inventory data were modeled using LCA software (Gabi 6). Initially, the individual LCIA result of two new diesel blending formulation which is biodiesel and bioethanol; and one electricity mix which is natural gas power plant were presented. The LCIA results of five different blending formulations and comparison with pure fossil diesel were later applied.

New weightage values were developed to represents Malaysia condition in the weighting stage in LCA methodology. Three main criteria which is human health, ecosystem quality and resource consumption of eighteen environmental impact categories listed in ReCiPe LCIA methodology were used as sub-criteria. A questionnaire based on important criterion and sub criterion of environmental impact categories in Malaysia was developed and answered by experts, scientist and LCA practitioners. The responds from the questionnaires were analyzed using AHP methodology in sequence of three steps, namely pairwise comparison, AHP matrix and consistency index (CI). The new weighting values are then used to support the environmental performance of the new diesel blending formulation.

The environmental impacts of diesel blending formulation were further investigated using the new weighting values. The environmental performance of each formulation was later compared to current diesel to ensure the sustainability of the new formulation.

1.5 Significance of the Study

Globally, transportation sector has become one of the major sectors for each country. The increasing number of automobiles each year directly consume a lot of energy and indirectly create negative impact to the environment. The adverse impact caused by transportation sector such as emission of CO_2 and NO_x has changed the world towards sustainability. Renewable fuel such as biodiesel and bioethanol have become an attractive fuel to replace the current fossil fuel due to their environmental impact potential. In Malaysia, biodiesel is produce from palm oil and blended with fossil diesel (B5) (Abdullah *et. al.*, 2009). In this study, several blending formulations consist of diesel, biodiesel, bioethanol, butanol and butyl levulinate have been developed by others research group (Mohidin, 2014) which have matched their target properties. However, the environmental performance of these new diesel blending is yet to be assessed. LCA, which is one of environmental assessment tool, appears to be an important tool due to comprehensive assessment on product life cycle (Seppala, 2003). The significance of this thesis is to present the environmental performance of new diesel blending formulation and later identified the best formulation in term of environmental impact based on LCA methodology. Furthermore, comparison between the new diesel formulation and the current diesel blending is also presented.

The thesis also intends to highlight the importance of weighting steps that incorporated in LCA methodology that highly preference to regional condition. Without the weightage value of Malaysia's context, the final finding of LCA study may less precise due to different background condition. The weighting values are intended to be used in the LCA study for the diesel blending as well as for other local LCA study application.

1.6 Thesis Layout

The thesis layout of this dissertation is presented as follows:

Chapter 1 comprises the introduction, problem statement, objectives, scope of study, significance of the study and lastly thesis layout. This chapter presents general information of diesel utilization globally and in Malaysia. This chapter also includes issues related to new diesel blending components and LCA weighting procedure to be applied in Malaysia that contribute to the problem statement, objectives and scope of study.

Chapter 2 discusses the related studies of diesel, palm biodiesel, bioethanol and Life Cycle Assessment (LCA) that was used as method for environmental impact assessment. The related topic regarding AHP and its applications are also been discussed.

Chapter 3 describes the methodology utilized in this research. This chapter initially discussed on the gathering of information and then on the environmental potential impact analysis using LCA. Followed the process, AHP methodology adopted in the development of Malaysia new weighting is explain in detail. Lastly, the inclusion of the new weighting values in the LCA methodology is described.

Chapter 4 presents evaluation on the result and findings from the assessment of the new green diesel formulations. The result from the LCA is illustrated in tables and graphs. The best formulation based on environmental performance was later identified.

Chapter 5 involves results and discussion of the AHP section. The chapter consists of the AHP modelling and the weighting values generated from the questionnaires. Based on the results, the details of the weighting values are discussed. The implications of the weightings value in the LCA study are also deliberated.

Chapter 6 shows the result and findings from the assessment of the new green diesel formulation with the application of the new weighting formulations. The implication of weighting in the life cycle assessment study is discussed.

Chapter 7 presents conclusions and recommendation based on the findings of the thesis. The sustainability of the diesel blending formulation is reviewed based on the finding. The best formulation which has least environmental impact are determined.

The outcomes from the applications of AHP methodology in the LCA weighting are concluded.

10. In sensitivity analysis within impact category, in midpoint impact category the sensitivity analysis was based on specific impact category; while endpoint approach was majorly based on the in normalization and weighting value.
11. In term of value, significant different in number was observed among weighting methods since different values were used in weighting step.
12. The new weighting formulation has also found to follow criteria that listed in literature.

7.2 Limitation and Recommendation

In this study, few limitations are observed. The limitations are as follows:

1. In data collection for the life cycle assessment study, major of the data collected were based on secondary data (literature and database) thus it is recommended that the data collection were mainly collected through primary data.
2. In the life cycle impact assessment methodology, only one method was used which is ReCiPe LCIA methodology. Hence, it is recommended that more LCIA methods were applied such as CML, Impact 2002+ and Eco Indicator 99.
3. In term of the boundary of life cycle study, it is suggest for the assessment to be done from cradle-to-grave to have the full diesel blending life cycle evaluation.
4. The size of the respondents can be improved by using a bigger sample size with a broader panel of respondents and specified the scope to few sector such as sustainability purchasing and green constructions.

As for improvement, different methods can be used to develop the weighting value based on multi criteria decision making such as PROMETHEE since different methods may induce different values.

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