TECHNO-ECONOMIC ANALYSIS OF BIODIESEL PRODUCTION FROM PALM, JATROPHA CURCAS AND CALOPHYLLUM INOPHYLLUM FOR ROAD TRANSPORT IN MALAYSIA

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ABSTRACT

Transportation sector has a dominant role in global fuel consumption and greenhouse gas emissions. Due to the dramatic increase in greenhouse gas emission, sustainable development of this sector has raised the concern in many countries including Malaysia. Biodiesel is a renewable energy that has great potential to serve as an alternative fuel to fossil diesel in the compression ignition (CI) engine. Although Malaysia is one of the biggest biodiesel fuel producers, the commercialization of biodiesel has not been fully undertaken in a large scale. Besides the technical barriers, there are several nontechnical limiting factors, which impede the development of biodiesel. A wide variety of biodiesel research on transesterification, performance and emission analysis is currently available worldwide. However, the study on techno-economic and feasibility of biodiesel fuel for Malaysian condition is limited. Therefore, this study is focused on biodiesel production and techno-economic comparison among palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel as transportation fuel in Malaysia. Moreover, the present study attempts to find out the impact of biodiesel implementation towards the energy scenario, environmental and economy. The total CO_2 equivalent emissions for road transport are 59,383 million kg. Therefore, alkaline catalyst transesterification process is used to produce palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel as biofuel for road transport vehicles. It was found that the life cycle cost for 50 ktoe palm, *jatropha curcas* and *calophyllum inophyllum* biodiesel production plant with an operating period of 20 years is $764, $583 and $604 million respectively. The largest economic factor for biodiesel production is feedstock cost. Furthermore, replacing 5% of diesel with biodiesel in road transport vehicles can reduce the CO_2 emission up to 1200 million kg in year 2031.

In order to repay the carbon debt from land converting to feedstock cropland, *calophyllum inophyllum* biodiesel requires the lowest cropland and ecosystem carbon

payback period compared to palm and *jatropha curcas* biodiesel due to the high oil yield which is 4680 kg/ha. When the subsidy policy and tax exemption are implemented, biodiesel fuel is more competitive than fossil diesel at the current production costs. Apart from that, the key factor for biodiesel fuel to be able to compete with diesel fuel is due to the high crude petroleum price coupled with low feedstock oil price. Therefore, this study serves as a guideline for further investigation and research on biodiesel production, subsidy cost and other limiting factors before the wider utilization of biodiesel in Malaysia.

ABSTRAK

Sektor pengangkutan telah mendominasi penggunaan bahan api global dan pelepasan gas rumah hijau telah meningkat pada kadar yang membimbangkan. Ini telah menyebabkan kebimbangan kebanyakan negara termasuk Malaysia untuk memajukan tenaga mampan bagi sektor ini. Biodiesel adalah tenaga boleh diperbaharui yang mempunyai potensi besar sebagai bahan api alternatif kepada diesel dalam enjin pencucuhan mampatan. Malaysia merupakan salah satu pengeluar terbesar bahan api biodiesel, tetapi pengkomersilan biodiesel tidak sepenuhnya dilaksanakan secara besar-besaran. Selain halangan teknikal, terdapat beberapa faktor bukan teknikal yang mengehadkan pembangunan biodiesel. Pelbagai penyelidikan biodiesel prestasi transesterification dan kajian pelepasan di seluruh dunia telah dijalankan. Walau bagaimanapun, kajian mengenai analisis tekno-ekonomi dan kemungkinan bahan api biodiesel bagi keadaan Malaysia masih amat terhad dan tidak diiktiraf secara meluas. Oleh itu, kajian ini memberi tumpuan kepada menghasilkan biodiesel dan analisis tekno-ekonomi perbandingan kelapa sawit, *jatropha curcas* and *calophyllum inophyllum* biodiesel sebagai bahan api pengangkutan di Malaysia. Selain itu, kajian ini juga penting untuk mencari kesan pelaksanaan biodiesel dari segi senario tenaga, kesan alam sekitar dan ekonomi. Jumlah pelepasan CO_2 bagi pengangkutan jalan adalah sebanyak 59,383 juta kg. Oleh itu, proses transesterification digunakan untuk menghasilkan biodiesel daripada kelapa sawit, *jatropha curcas* and *calophyllum inophyllum* sebagai biobahan api bagi pengangkutan jalan. Adalah didapati bahawa kos kitaran hayat selama 50 ktoe sawit, *jatropha curcas* and *calophyllum inophyllum* bioidesel dengan tempoh beroperasi 20 tahun ialah $764, $583 dan $604 juta masing-masing. Faktor terbesar bagi pengeluaran biodiesel adalah kos bahan mentah. Selain itu, 5% daripada diesel yang digantikan dengan bahan api biodiesel dalam pengangkutan jalan boleh mengurangkan sebanyak 1200 juta kg CO_2 pada tahun 2031.

Untuk bayaran balik hutang karbon daripada penukaran tanah kepada tanah pertanian buah mentah, *Calophyllum inophyllum* biodiesel memerlukan tanah pertanian dan tempoh bayar balik karbon ekosistem yang paling rendah berbanding dengan sawit dan *jatropha* biodiesel kerana hasil minyaknya yang tinggi iaitu 4680 kg/ha. Apabila dasar subsidi dan pengecualian cukai ini dilaksanakan, bahan api biodiesel adalah lebih berdaya saing berbanding dengan diesel berasaskan kos pengeluaran semasa. Selain itu, faktor utama untuk bahan api biodiesel dapat bersaing dengan minyak diesel adalah disebabkan fakta harga petroleum mentah yang lebih tinggi ditambah pula dengan harga bahan mentah biodiesel yang rendah. Oleh itu, kajian ini berfungsi sebagai garis panduan untuk kajian dan penyelidikan lanjut mengenai pengeluaran biodiesel, kos subsidi dan faktor-faktor terhad yang lain sebelum penggunaan biodiesel boleh dilaksanakan secara meluas di Malaysia.

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NOMENCLATURE

Symbol	Description	Unit
β	Fraction of mileage driven with cold engines or catalyst operated below the light-off temperature.	-
BC	Biodiesel needed	(toe)
BCC	Carbon stock for biodiesel cropland	(toe/ha)
BFP	Biodiesel price	($/litre)
BL	Unit conversion : barrel to litre (1 barrel = 159 litre)	(litre/barrel)
BP	By product credit	($)
C_{NaOH}	Molarity or molar concentration	(mol/L)
CC	Capital cost	($)
CE	Yield of biodiesel (FAME) conversion	(%)
CLR	Cropland required	(hectare)
CPW	Compound present worth factor	-
COP	Crude oil price	($/barrel)
CPP	Carbon payback period	(year)
d	Deprecation ratio	(%)
DC	Diesel consumption	(toe)
DR	Diesel replacement	(toe)
E	Emissions pollutant	(g)
e	Emission factor	(g/km)
EC	Energy content of diesel fuel	(GJ/toe)
EFB	Life cycle emission factor by biodiesel fuel	(kg/GJ)
EFD	Life cycle emission factor by diesel fuel	(kg/GJ)
FBC	Final biodiesel unit cost	($/litre)
FC	Feedstock cost	($)
FDC	Fossil diesel cost	($/litre)
FP	Feedstock price	($)
FU	Feedstock consumption	(kg)
GCF	Glycerol conversion factor	-
GP	Glycerol price	($/kg)
HVB	Heating value of biodiesel fuel	(MJ/kg)
HVD	Heating value of diesel fuel	(MJ/kg)
i	Year	(year)
k	Constant value	-
LCC	Life cycle cost	($)
LSC	Carbon stock for natural forest	(kg/ha)
M	Mileage per vehicle	(km/veh)
m_{NaOH}	Mass of NaOH	(g)
m_{OC}	Mass of oleic acid in oil	(g)
M_{NaOH}	Molar mass of NaOH (Molecular weight of NaOH = 40 g/mol)	(g/mol)

M_{OA}	Molar mass of oleic acid (Molecular weight of oleic acid is 282.5 g/mol)	(g/mol)
MO_{NaOH}	Mole of NaOH solution used in titration	(mol)
MC	Maintenance cost	($)
MR	Maintenance rate	(%)
η	Fossil diesel replacement rate	(%)
N	Number of vehicles	(Veh)
n	Project life time	(year)
OC	Operating cost	($)
OR	Operating rate	($/toe)
OY	Oil yield of biodiesel feedstock	(kg/ha)
ρ	Density	(kg/m^3)
PC	Annual biodiesel production capacity	(toe/year)
PP	Payback period	(year)
PWF	Present worth factor	-
r	Discount rate	(%)
RC	Replacement cost	($)
RP	Feedstock reference price	($/kg)
s	Growth rate of feedstock price	(%)
SR	Substitution ratio of biodiesel fuel to diesel fuel	-
SV	Salvage value	($)
TAX	Annual total tax	($/year)
TBS	Annual total biodiesel sales	($/year)
TCB	Total carbon emitter by biodiesel fuel	(kg)
TCD	Total carbon emitter by diesel fuel	(kg)
TCS	Total carbon saving	(kg)
TDS	Total diesel energy saving	(GJ)
TPC	Annual total production costs	($/year)
TR	Tax ratio	(%)
v_{NaOH}	Volume of NaOH solution used in titration	(ml)
x	Starting year of prediction	(year)
y	Prediction value	-

Subscript

avg	Average capital cost
cold	Emissions during transient thermal engine operation (cold start)
d	Diesel fuel
high	Highest capital cost
hot	Emissions during stabilised (hot) engine operation
j	Vehicles category j
k	Road type k
low	Lowest capital cost

n	Biodiesel fuel (palm, , *jatropha curcas* and *calophyllum inophyllum*)
p	Emission pollutant p
vol	Volume
w	Weight

Superscript

e	Biodiesel for feedstock e (palm, *jatropha curcas* and *calophyllum inophyllum*)

Abbreviation

ATF & AVgas	Airline turbine fuel and aviation gasoline
CBO	Crude *calophyllum inophyllum* oil
CH_4	Methane
CIME	*Calophyllum inophyllum* methyl ester
CJO	Crude *jatropha curcas* oil
CO	Carbon monoxide
CO_2	Carbon dioxide
CPO	Crude palm oil
GHG	Greenhouse gas
GWP	Global warming potential
HDV	Heavy duty vehicle
JCME	*Jatropha curcas* methyl ester
LDV	Light duty vehicle
NO_X	Nitrogen oxides (NO and NO_2)
N_2O	Nitrous oxide
NMVOC	Non Methane VOC
PM	Particulate matter
POME	Palm oil methyl ester
VOC	Volatile organic compound