Energy Reports 2 (2016) 246–253

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Techno-economic and environmental assessment of bioethanol production from high starch and root yield Sri Kanji 1 cassava in Malaysia

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ARTICLE INFO

Article history:
Received 16 November 2015
Received in revised form
1 March 2016
Accepted 29 March 2016
Available online 31 October 2016

Keywords:
Bioethanol
Techno-economic analysis
Sri Kanji 1 cassava
Environmental assessment

ABSTRACT

Transportation played a significant role in energy consumption and pollution subsequently. Caused by the intense growth of greenhouse gas emission, efficient and sustainable improvement of the transportation sector has elevated the concern in many nations including Malaysia. Bioethanol is an alternative and renewable energy that has a great potential to substitute for fossil gasoline in internal combustion engine (ICE). Although bioethanol has been widely utilized in road transport worldwide, the production and application of bioethanol in Malaysia is yet to be considered. Presently there is comprehensive diversity of bioethanol research on distillation, performance and emission analysis available worldwide. Yet, the study on techno-economic and feasibility of bioethanol fuel in Malaysia condition is unavailable. Thus, this study is concentrated on bioethanol production and techno-economic analysis of cassava bioethanol as an alternative fuel in Malaysia. Furthermore, the current study attempts to determine the effect of bioethanol employment towards the energy scenario, environmental and economy. From the economic analysis, determined that the life cycle cost for 54 ktons cassava bioethanol production plant with a project life time of 20 years is $132 million USD, which is equivalent to $0.11 USD per litre of bioethanol. Furthermore, substituting 5 % of gasoline fuel with bioethanol fuel in road transport can reduce the CO_2 emissions up to 2,038 ktons in year 2036. In case to repay the carbon debt from converting natural forest to cassava cropland, cassava bioethanol required about 5.4 years. The cassava bioethanol is much cheaper than gasoline fuel even when 20 % taxation is subjected to bioethanol at current production cost. Thus, this study serves as a guideline for further investigation and research on bioethanol production, subsidy cost and other limitation factors before the extensive application of bioethanol can be implemented in Malaysia.

1. Introduction

In the past decades the Malaysia transportation energy consumption increased from 12.1 Mtoe in 2000 to 22.4 Mtoe in 2013 (ST, Comission; US Energy Information Administration, 2012). Concerns about fossil fuels dual issues of energy security and global warming have motivated interest in alternative and more sustainable energy resources (Lombardi, 2003; Ong et al., 2011). Transportation plays a major part in the greenhouse gas (GHG) production, in which motor vehicles responsible for 19% of global CO_2 production (Balat and Balat, 2009; Energy Information Administration, 2009). Therefore, decreasing emissions in this sector would extensively assist in realization of climate change targets (Jayed et al., 2011). Bio-ethanol, or ethanol produced from biomass, has been acknowledged as a potential alternative to gasoline in internal combustion engine (International Energy Agency, 2015; Siddegowda and Ventakesh, 2013; Shane et al., 2008; Cooney et al., 2009).

Currently the vast majority of bioethanol are produced from first generation feedstocks like corn, sugarcane, wheat and cassava (Renewable Fuels Association, 2010; Kovarik, 0000; Dai et al., 2006; Nguyen and Gheewala, 2008; Wongwatanapaiboon et al., 2012). In Malaysia, corn and sugarcane are cultivated for food and animal feed purposes, while cassava is cultivated for starch

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http://dx.doi.org/10.1016/j.egyr.2016.03.004

production. At this time, cassava has been recognized as a potential bioethanol feedstock in Asia as it can be cultivated on marginal land and content high ethanol yield of 3600 L/ha (The State of Food and Agriculture, 2008). Furthermore, Malaysia Agricultural Research and Development Institute (MARDI) has bring in a new cassava variety known as Sri Kanji 1 which has higher crop yield of 92.9 ton/ha and starch content of 30.5% (NurulNahar and Tan, 2012). Hence the theoretical ethanol yield of Sri Kanji 1 would be 19,000 L/ha. Therefore Sri Kanji 1 cassava is selected as raw material for bioethanol production due to high productivity and high bioethanol conversion. The comparison of ethanol yield for various feedstocks is simplified in Fig. 1.

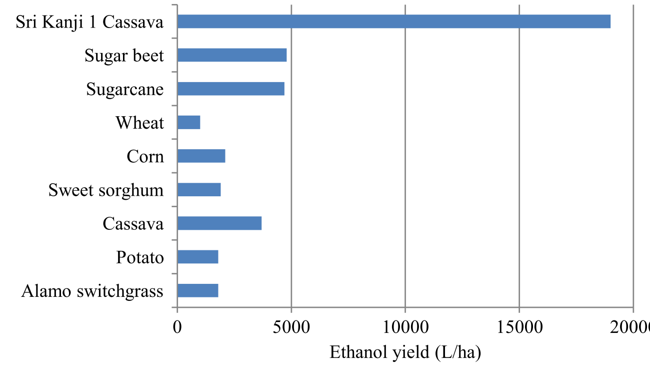

Fig. 1. Production ethanol yield for various source of bioethanol feedstock (The State of Food and Agriculture, 2008).

Nomenclatures

Symbol	Descriptions	Unit
BC	Bioethanol needed	tons
BCC	Carbon stock for bioethanol cropland	ton/ha
BFP	Bioethanol fuel price	$/litre
BP	By product credit	$
CC	Capital cost	$
CDG	Carbon dioxide generated	tons
CDP	Carbon dioxide price	$/ton
CLR	Cropland required	hectare
CPP	Carbon payback period	year
CPW	Compound present worth factor	$
EC	Energy content of gasoline fuel	GJ/ton
EY	Ethanol yield	kg/ha
FBC	Final bioethanol unit cost	$/litre
FC	Feedstock cost	$
FP	Feedstock price	$
FU	Feedstock consumption	tons
GC	Gasoline consumption	tons
GR	Gasoline replacement	tons
HVB	Heating value of bioethanol fuel	MJ/kg
HVG	Heating value of gasoline fuel	MJ/kg
i	Project year	year
LCC	Life cycle cost	$
LSC	Carbon stock for natural forest	ton/ha
MC	Maintenance cost	$
MR	Maintenance rate	%
NAE	Net avoided emission	tons_{CO_2}/tons
n	Project life time	year
η	Fossil gasoline replacement rate	%
OC	Operating cost	$
OR	Operating rate	$/ton
PC	Annual bioethanol production capacity	tons/year
PP	Payback period	year
PV	Present value	–
PWF	Present worth factor	–
ρ	Density	kg/m^3
r	Discount rate	%
RC	Replacement cost	$
RM	Ringgit Malaysia (currency)	RM
SR	Substitution ratio of bioethanol to gasoline fuel	–
SV	Salvage value	$
TAX	Annual total tax	$/year
TBS	Annual total bioethanol sales	$/year
TCS	Total carbon saving	tons
TGS	Total gasoline saving	tons
TPC	Annual total production cost	$/year
TR	Tax ratio	%

The major advantages of cassava over other crops are growth tolerance to poor environmental condition, all year long planting and harvesting, high root productivity, continuous development of high yield-improved varieties, less input in planting and harvesting, high quantity and quality carbohydrate source, starchy crop with highest energy content per acre and higher ethanol yield per acre (Kuakoon, 2011).

The main challenge to utilize Sri Kanji 1 cassava as raw material for bioethanol production is the raw material supply capabilities. With current cultivation area for cassava is only 3000 hectare and most of it is used for starch industry, it would be insufficient for bioethanol production (FAO, 0000). This can be solved by increasing the cassava cultivation area as cassava can be cultivated in a marginal land. A new policy on cassava plantation for bioethanol production needs to be considered to support the development of cassava bioethanol industry.

The aim of this study is to conduct techno-economic and environmental analysis of ethanol production from Sri Kanji 1 cassava as gasoline replacement in road transport. The analysis consists of the estimation of ethanol production cost in Malaysia, taxation and subsidiary scenario, energy and environmental impact and ecosystem carbon payback period.

2. Methodology

2.1. Prediction of energy consumption

The polynomial curve fitting equation is used to evaluate and project long-term time series and to determine a smooth curve that best fits the data but does not necessarily pass through all the data points. Mathematically, a polynomial of order k in x is an expression in the following form:

$$y = c_0 + c_1x + c_2x^2 + \cdots + c_kc^k. \tag{1}$$

In this research, the forthcoming energy consumption is assumed comparable to the pattern of past years by utilizing polynomial curve fitting to evaluate long term time series for energy consumption pattern. Thus, Eq. (1) is used to estimate and forecast future energy consumption pattern.

2.2. Life cycle cost and payback period analysis

2.2.1. Life cycle cost

In this section, life cycle cost model for bioethanol production plant is established and clustered into six groupings as follows:

$$LCC = CC + OC + MC + FC - SV - BP. \tag{2}$$

By applying the given approach, the present value model for the life cycle cost is presented as follow:

$$LCC = CC + \sum_{i=1}^{n} \frac{OC_i + MC_i + FC_i}{(1+r)^i} - \frac{SV}{(1+r)^n} - \sum_{i=1}^{n} \frac{BP_i}{(1+r)^i}. \tag{3}$$

Present worth factor
Present worth factor (PWF) is used to define the practicability of investment in bioethanol production plant for a particular discount percentage. For year "i", the present worth factor is given as,

$$PWF = \frac{1}{(1+r)^i}. \tag{4}$$

Summing this over a project period of n years yields the compound present worth factor (CPW),

$$CPW = \sum_{i=1}^{n} \frac{1}{(1+r)^i} \tag{5}$$

$$CPW = \frac{(1+r)^n - 1}{r\,(1+r)^n}. \tag{6}$$

Capital cost
Based on the research by Howell (Howell, 2005) the maximum, typical and minimum initial capital costs of biofuel plant based on production capability can be stated in the given equation:

$$CC_{high} = -517.76 \times PC^2 + 252\,928 \times PC + 3\,446\,300 \tag{7}$$

$$CC_{avg} = -430.13 \times PC^2 + 205\,235 \times PC + 2\,696\,000 \tag{8}$$

$$CC_{low} = -342.49 \times PC^2 + 157\,542 \times PC + 1\,945\,700. \tag{9}$$

Operating cost
Given their reliance on production capacity, operating costs are estimated by fixing the cost per ton of bioethanol produced. The operating costs over the project period are estimated as,

$$OC = \sum_{i=1}^{n} \frac{OR \times PC}{(1+r)^i}. \tag{10}$$

Maintenance cost
The yearly scheduled maintenance and service cost is considered to be a percentage of maintenance ratios to the initial capital cost and assumed unchanged for the whole project life span. The sum of maintenance costs for the project period is,

$$MC = \sum_{i=1}^{n} \frac{MR \times CC}{(1+r)^i}. \tag{11}$$

Feedstock cost
The sum of feedstock cost is the product of the total yearly feedstock consumption and cost of feedstock. Based on this price, sum of feedstock cost over the plant life span is calculated as,

$$FC = \sum_{i=1}^{n} \frac{FP \times FU}{(1+r)^i}. \tag{12}$$

Salvage value
Depreciation rate is assumed to happen yearly in this study. The salvage value model is centered on the substitution cost rather than the early capital cost. The salvage value can be estimated as,

$$SV = RC \times (1-d)^{n-1}. \tag{13}$$

Therefore, salvage cost in the present value can be expressed by the following equation:

$$SV_{PV} = \sum_{i=1}^{n} \frac{RC \times (1-d)^{n-1}}{(1+r)^n}. \tag{14}$$

By product credit
Carbon dioxide is the by-product of bioethanol production process and usually compressed and sells to carbonated drink manufacturer. Estimation is based on the price of carbon dioxide and its production volume, which the by-product credit value over the plant life span is calculated as,

$$BP = \sum_{i=1}^{n} \frac{CDP \times CDG}{(1+r)^i}. \tag{15}$$

Payback period
The payback period utilizes the ratio of capital cost over yearly income as a method to observe the project. Taxes are comprised as a fraction of total bioethanol sales. The payback period is expressed as,

$$PP = \frac{CC}{TBS - TPC - TAX}. \tag{16}$$

Whereby,

$$TBS = \frac{BFP \times PC}{\rho} \tag{17}$$

$$\mathrm{TPC} = 1.1 \times \frac{\mathrm{LCC}}{n} \tag{18}$$

$$TAX = (TBS - TPC) \times TR. \tag{19}$$

Total bioethanol cost
Final bioethanol costs consist of the total life cycle cost, distribution cost and profit margin, which the sum of distribution cost and profit margin are usually 10% of bioethanol production cost. The total bioethanol cost can be calculated by the following equation:

$$\mathrm{TPC} = 1.1 \times \frac{\mathrm{LCC}}{n}. \tag{20}$$

Final bioethanol unit cost
Final bioethanol unit cost is defined as the total bioethanol production cost derived as the cost per litre of bioethanol produced. The conversion unit is defined as the function of total bioethanol production cost and density of bioethanol over the yearly production capability. The final bioethanol unit cost can be estimated using the equation below:

$$FBC = \frac{TPC \times \rho}{PC}. \tag{21}$$

Sensitivity analysis
Sensitivity analysis is an assessment to disclose the difference of the predicted performance with alteration in main factors in which the predictions are based. Essential factors are feedstock price, discount rate, initial capital cost and operating cost. Feedstock price which is cassava is probably the most important factor. Cassava price in this study is referred to the cassava production cost including the distribution and profit margin.

2.3. *Potential fuel saving and environmental impact*

Potential fuel saving
Bioethanol and gasoline fuels have dissimilar heating value or energy content. Therefore, the bioethanol to gasoline fuel substitution ratio is expressed as the following equation:

$$SR_w = \frac{HVG}{HVB}. \tag{22}$$

The sum of gasoline fuel substitution is a function of yearly gasoline fuel consumption with a substitution ratio which is presented by applying the equation below:

$$GR_i = \eta \times GC_i. \tag{23}$$

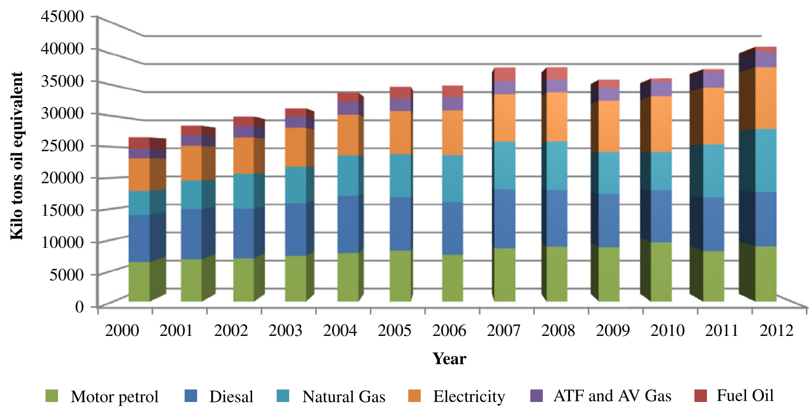

Fig. 2. Energy consumption pattern of transportation sector by fuel types.

The total bioethanol required for replacing the gasoline fuel is estimated by gasoline fuel substitution multiply with bioethanol to gasoline fuel substitution ratio which is shown in equation below:

$$BC_i = GR_i \times SR_w. \quad (24)$$

The gasoline energy savings can be calculated by using the following equation:

$$TGS = \sum_{i}^{n} GR_i \times EC. \quad (25)$$

Potential environmental impact
The environmental impacts presented in this study are potential emission reductions, crop land use for bioethanol feedstock and environment carbon payback period.

Total carbon saving
The potential carbon saving is calculated by multiplying the net avoided emission with the amount of bioethanol needed.

$$TCS_i = NAE \times BC_i. \quad (26)$$

Cropland needed
The needed cropland is calculated by dividing required feedstock with the ethanol yield, which is expressed as,

$$CLR = \frac{BC \times 1000}{EY}. \quad (27)$$

Ecosystem carbon payback period
Ecosystem carbon payback period is estimated by dividing the difference between the carbons stock from converting the natural land into bioethanol feedstock cropland with the yearly carbon savings by utilizing bioethanol fuel. The ecosystem carbon payback period is calculated by using the following equation:

$$CPP = \frac{LSC - BCC}{TCS/CLR}. \quad (28)$$

3. Results and discussion

3.1. Energy Consumption by Transportation Sector

The necessary analysis information of the road transportation and fuel use were taken from the department of road transport (Department of Road Transport, 2008), Malaysia Energy Agency (Malaysia Energy Centre, 2009) and the department of statistic (Department of Statistic, 2008).
The distribution of energy use in Malaysia transportation by fuel types is shown in Figure 2 (Malaysia Energy Centre, 2009). Transport final energy consumption increased from 12.1 Mtoe in 2000 to 22.4 Mtoe in 2012. The core petroleum products are fossil fuels in which the main application goes to motor petrol and diesel.

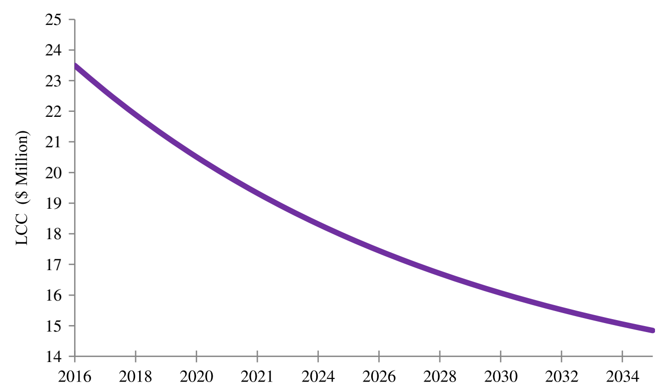

Fig. 3. Life cycle cost of bioethanol production over 20 year's lifetime.

Prediction of gasoline fuel consumption
The upcoming transport gasoline consumption is forecast by using the polynomial curve fitting approach as stated in Eq. (1) with evaluation of the previous statistics from 2000 to 2012. Based on the Fig. 2, gasoline consumption is predicted by the given polynomial equation.

$$y = 3.0519x^2 + 170.6x + 566.59, \qquad R^2 = 0.9606.$$

The outcomes of the transport gasoline consumption forecast from year 2017 to 2036 in Malaysia are presented in Table 1. The total gasoline used will rise to 21,256 ktoe or 27,420 million litres in 2036.

3.2. Life cycle cost

The potential bioethanol feedstock investigated is Sri Kanji 1 cassava variety, introduced by MARDI which produced higher root yield and starch content. The average production cost for Sri Kanji 1 with mini-cutting technique is presented in Table 2.
The project period has been fixed to be 20 years and presumed that the plant functions in 100% capacity throughout the project's lifespan. The initial capital cost is assumed to be funded by private investment and no loans have been taken into account. Another assumption is that the bioethanol and carbon dioxide gas selling price does not differ over time. The economic indicator for life cycle model is summarized into Table 3.

Life cycle cost is evaluated for a distinctive 54 ktons bioethanol plant sited in Malaysia. The life cycle cost of bioethanol production from Sri Kanji 1 is presented in Fig. 3 and the cost distribution is presented in Fig. 4.

Table 1
Gasoline consumption forecast for transportation sector from 2017 to 2036.

Year	Gasoline consumption (ktoe)	Gasoline consumption (million litres)
2017	12,274	15,833
2018	12,691	16,372
2019	13,115	16,919
2020	13,545	17,473
2021	13,981	18,036
2022	14,424	18,607
2023	14,872	19,185
2024	15,326	19,771
2025	15,787	20,365
2026	16,254	20,967
2027	16,726	21,577
2028	17,205	22,195
2029	17,690	22,820
2030	18,181	23,454
2031	18,678	24,095
2032	19,182	24,744
2033	19,691	25,401
2034	20,206	26,066
2035	20,728	26,739
2036	21,256	27,420

Table 2
Average cost of Sri Kanji 1 cassava production per hectare (NurulNahar and Tan, 2012).

Item		Cost (RM)
1.	Labor cost (RM/ha)	4240
	Land preparation	1000
	Planting	300
	Fertilizer application	180
	Weeding	360
	Harvesting	1300
	Pre-sprout in polybag	300
	Pre-sprout (weeding, watering)	300
	Pre-sprout (transportation to the field and preparations of planting holes)	500
2.	Agricultural input costs (RM/ha)	3200
	Planting material	400
	Fertilizers, herbicides	2000
	Polybags	800
3.	Non-variable costs (RM/ha)	500
	Land rental, machinery	500
4.	Total production costs (RM/ha)	7940
	Production cost per tonne	**85.45**

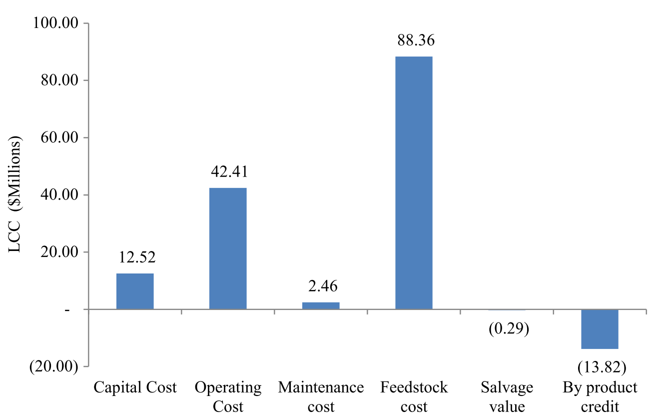

Fig. 4. Distribution of bioethanol production life cycle cost.

Table 3
Summary of economic data and indicators.

Item	Data
Project lifetime	20 years
Plant capacity	54 ktons
Depreciation model	10% annually
Feedstock price	$24/ton
Operating rate	$80/ton
Maintenance cost	2% of capital cost annually
Replacement cost	$10 million
Tax ratio	15% of bioethanol profit
CO_2 price	$40/ton
Discount rate	8%

The life cycle cost is presented in present value assuming 8% discount rate. Bioethanol production life cycle cost and payback period were summarized in Table 4. The total life cycle cost of bioethanol production from cassava in Malaysia is $145 million USD without taken into account the byproduct credit. Feedstock cost is the largest cost-effective aspect which accounted for 67.1% of the total production cost. The other essential costs are operating a cost which contributes 32.2% of the total production cost. Byproducts sales are a basis of earnings which covers 10.5% of total life cycle cost. Then, the total bioethanol production cost reduced to $132 million USD by taking into consideration the CO_2 credit. Furthermore, the cost to produce 1 L bioethanol from Sri Kanji 1 cassava is calculated to be $0.11 USD. The 54 ktons bioethanol production plant payback period was evaluated to be 0.66, which is smaller than one tenth of the 20 year life cycle, point out that the project is economically feasible.

Sensitivity analysis

The outcomes of sensitivity analysis for cassava bioethanol production for four input variables are given in Fig. 5. As anticipated, deviation in the raw cassava price denotes the main influence on total production cost. For example, raw cassava price of $10 USD/ton decreases the production cost to $79 million USD and increases to

Table 4
Summary of life cycle cost and payback period for bioethanol production.

Item	Value ($ USD)	Distribution (%)
Capital cost	12,524,430	9.5%
Operating cost	42,414,396	32.2%
Maintenance cost	2459,334	1.9%
Feedstock cost	88,363,326	67.1%
Salvage value	289,822	0.2%
By product credit	13,816,097	10.5%
LCC w/o byproduct	145,471,664	
Total life cycle cost	131,655,567	
Production unit cost ($/L)	0.11	
Payback period	0.66	

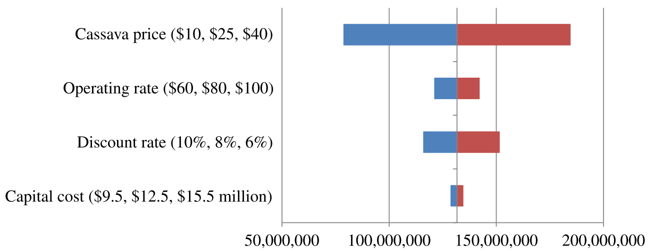

Fig. 5. Sensitivity analysis of life cycle cost for cassava bioethanol production.

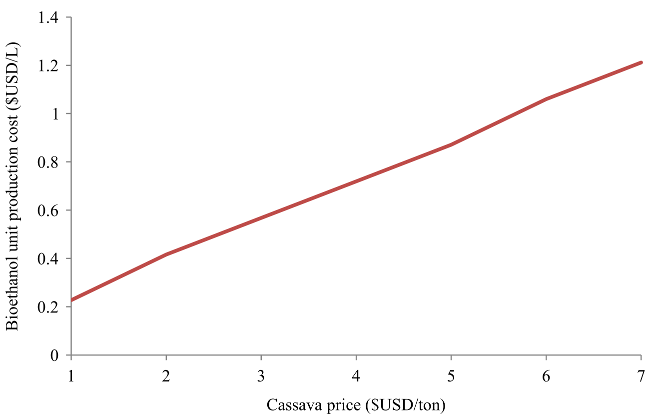

Fig. 6. The impact of raw cassava price on the bioethanol production cost.

$185 million USD when cassava price is $100 USD/ton. Moreover, the present value discount rate also causes a great effect on the cassava bioethanol production life cycle cost. Deviation in operating cost has the lesser influence on the total production cost, but enhancement in operating efficiency could results in cost savings as it contains about 32% of total life cycle cost.

The raw cassava price is the main factor of cassava bioethanol production. Thus, the influence of variations in raw cassava price on bioethanol unit production cost was further examined and the outcomes are presented in Fig. 6. It is revealed that raw cassava price has a direct relationship with bioethanol unit production cost; a growth of cassava price by $1 USD/ton results in $0.003 USD/litre growth in bioethanol unit production cost. The bioethanol unit production cost will rise to $0.32 USD/litre when the cassava price rises to $100 USD/ton.

Taxation and subsidiary scenario on bioethanol fuel

Final bioethanol unit production cost consists of the total production life cycle cost, distribution cost and profit margin. The distribution cost and profit margin is usually accounting for 10% of total bioethanol production cost. The examined scenarios are total tax exemption, 20% taxation, subsidy of 39% and 66%. The percentage of subsidy given is selected based on market price subsidy for low and high estimate (Koplow and Track, 2007). The measured

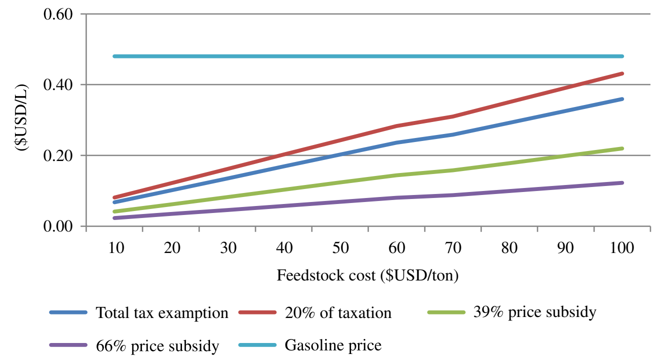

Fig. 7. Taxation and subsidy scenarios of bioethanol on cassava price.

gasoline price is based on $0.48 USD/litre current (Feb 2015) market price of gasoline price in Malaysia. The total bioethanol production cost equivalent to gasoline substitute is calculated based on 0.89 substitution ratio of fuel consumption between bioethanol and gasoline (Nguyen et al., 2007). Table 5 shows an assessment of final cassava bioethanol cost with conventional gasoline at various tax policies and support at current production cost. The outcomes point out that final cassava bioethanol price is much lower than gasoline fuel at all examined scenarios, even when 20% taxation is subjected to the final bioethanol price.

Also examined is the final bioethanol cost as a function of feedstock price for the same four scenarios; total tax exemption, 20% taxation, 39% and 66% price subsidy. Fig. 7 illustrates the taxation and subsidiary scenarios of cassava bioethanol as a function of raw cassava price. The bioethanol fuel is economically competitive with gasoline fuel for all range of cassava price and scenarios, even when 20% tax are subjected to final bioethanol price as shown in Fig. 7.

Energy and environmental impact

The total gasoline consumption is predicted by using polynomial curve fitting approach as mentioned in previous section. The evaluation outcomes for gasoline fuel savings are based on 5% replacement of gasoline fuel with cassava bioethanol, and presented in Table 6. When 5% of total gasoline consumption substituted by bioethanol in Malaysia, the total gasoline fuel saving is 584 ktons in year 2017 and predicted to increase to 1012 ktons in year 2036. By The required cassava bioethanol and cassava cropland in 2017 are estimated at 657 ktons and 47 thousand hectare. It is projected that required cassava bioethanol will surge to 1137 ktons and the cropland required will increase to 82 thousand hectare in 2036 for 5% of gasoline fuel substitution.

It was estimated that the production and application of cassava bioethanol substituting for conventional gasoline would avoid about 1176 ktons of CO_2 equivalent in 2017, and projected to increase up to 2038 ktons in 2036. The effects of cassava bioethanol production to the energy and environmental is projected in Fig. 8.

Ecosystem carbon payback period

In general, bioethanol displays lower life cycle emission and provide enhancement of ecological performance when compared to conventional gasoline fuel. However, land usage change from natural forest converted to bioethanol cropland leads to additional greenhouse gas emission, which is measured as 'carbon debt'. It is due to the natural forest carbon stock (145 ton/ha) (FAAO, FAO) which was estimated to be 15 times higher than cassava bioethanol cropland plantation (9.55 ton/ha) (Gnanavelrajah, 2008). Life cycle emission saving of bioethanol substituting for conventional gasoline can repay the carbon debt from land usage change over time. The results from this study found that, it would took about 5.43 years to repay the carbon debt due to land usage change from natural forest to cassava bioethanol cropland in Malaysia, which considered very environmentally feasible. Above that, cassava

Table 5
Bioethanol taxation and subsidy scenarios at current production cost.

	Cassava bioethanol				Fossil gasoline
	Total tax exemption	20% of taxation	Subsidy 39%	Subsidy 66%	
Bioethanol cost ($/litre)	0.11	0.11	0.11	0.11	–
Taxes/subsidy ($/litre)	–	0.02	0.04	0.07	–
Total ($/litre)	0.11	0.13	0.07	0.04	0.48
Total ($/litre gasoline)	0.12	0.15	0.08	0.05	0.48

Table 6
Cassava bioethanol and cropland needed, and total carbon saving.

Year	Gasoline consumption (ton)	Gasoline saving (ton)	Bioethanol needed (ton)	Cropland needed (ha)	Carbon saving (ton)
2017	11,689,524	584,476	656,715	47,157	1,176,926
2018	12,086,667	604,333	679,026	48,760	1,216,911
2019	12,490,476	624,524	701,712	50,389	1,257,568
2020	12,900,000	645,000	724,719	52,041	1,298,800
2021	13,315,238	665,762	748,047	53,716	1,340,607
2022	13,737,143	686,857	771,750	55,418	1,383,085
2023	14,163,810	708,190	795,720	57,139	1,426,043
2024	14,596,190	729,810	820,011	58,883	1,469,576
2025	15,035,238	751,762	844,676	60,655	1,513,780
2026	15,480,000	774,000	869,663	62,449	1,558,559
2027	15,929,524	796,476	894,917	64,262	1,603,818
2028	16,385,714	819,286	920,546	66,103	1,649,749
2029	16,847,619	842,381	946,495	67,966	1,696,254
2030	17,315,238	865,762	972,766	69,853	1,743,335
2031	17,788,571	889,429	999,358	71,762	1,790,991
2032	18,268,571	913,429	1,026,324	73,698	1,839,319
2033	18,753,333	937,667	1,053,558	75,654	1,888,126
2034	19,243,810	962,190	1,081,113	77,633	1,937,508
2035	19,740,952	987,048	1,109,042	79,638	1,987,561
2036	20,243,810	1,012,190	1,137,293	81,667	2,038,190

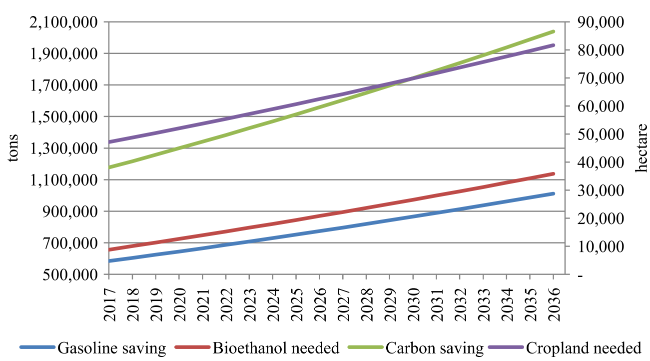

Fig. 8. Impact of gasoline saving, bioethanol needed, carbon saving and cropland needed for 5% bioethanol substitution for gasoline consumption.

bioethanol cropland area will be a net carbon reduction source after the ecological carbon payback period. Contrary to that, cassava farm can cultivate on tarnished and abandoned plantations which would results in less or no carbon debt and sustained greenhouse gas benefits.

Bioethanol potential energy and emission saving
The gasoline fuel consumption in transport sector in Malaysia is estimated to rise to 9911 ktons in year 2015. The impact of various potential replacement rates of fossil gasoline fuel by cassava bioethanol is presented in Table 7. The prospective gasoline and life cycle CO_2 emission saving are described to be around 31 million GJ and 2.3 million ton respectively for 10% of fossil gasoline fuel replacement by cassava bioethanol. The total cropland needed for cassava cultivated area is up to 94 thousand hectares when 10% of fossil gasoline is substituted with cassava bioethanol.

4. Conclusion

Bioethanol are becoming more and more important substitute fuel for the motor vehicles as to address the fossil fuel energy and emission issues. The energy consumption by transportation sector in Malaysia is estimated at 12.3 Mtoe in 2017, and increased to 21.3 Mtoe or 28.1 billion litre in 2036. Life cycle cost model and payback period of Sri Kanji 1 cassava were established and assessed for a period of 20 years. It has been estimated that the cassava bioethanol total life cycle cost is $132 million USD by considering the CO_2 credit over the project life cycle, with the production cost per unit of $0.11USD/litre. Payback period for 54 ktons of cassava bioethanol production plant was calculated to be 0.66 years. Ever since the estimated payback period is smaller than one third of the project lifetime of 20 years, the outcomes showed that bioethanol production plants are economically feasible. Bioethanol fuel is cheaper than fossil gasoline for the current production costs even when 20% of tax is subjected to bioethanol final price. Carbon payback period from land conversion for cassava bioethanol production would take about 5.43 years. Bioethanol is a feasible solution for fuel shortage and environmental pollution. As a final note, bioethanol policies and subsidies should be appraised instantly in order to pursuit the aim of energy saving, emissions reduction and economic impact. Thus, more research and studies on bioethanol production, subsidizing cost and other limitation factors are vital before the broader application of bioethanol in Malaysia.

Acknowledgments

The authors would like to acknowledge the Ministry of Higher Education of Malaysia and The University of Malaya, Kuala Lumpur, Malaysia, for the financial support under UM.C/HIR/MOHE/ENG/06 (D000006-16001) and Exploratory Research Grant Scheme (ERGS) with reference number ERGS/1/2013/TK07/UNITEN/01/01.

Table 7
Impact of cropland, energy and CO_2 saving for cassava bioethanol at various replacement rate.

Fossil gasoline replacement rate (%)	Fossil gasoline replaced (ton)	Bioethanol needed (ton)	Cropland needed (ha)	Gasoline energy saving (GJ)	CO_2 saving (ton)
10	1,168,952	1,313,430	94,315	31,327,924	2,353,852
20	2,337,905	2,626,859	188,630	62,655,848	4,707,705
30	3,506,857	3,940,289	282,945	93,983,771	7,061,557
40	4,675,810	5,253,719	377,260	125,311,695	9,415,409
50	5,844,762	6,567,148	471,575	156,639,619	11,769,262
60	7,013,714	7,880,578	565,890	187,967,543	14,123,114
70	8,182,667	9,194,007	660,204	219,295,467	16,476,967
80	9,351,619	10,507,437	754,519	250,623,390	18,830,819
90	10,520,571	11,820,867	848,834	281,951,314	21,184,671
100	11,689,524	13,134,296	943,149	313,279,238	23,538,524

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