An Assessment of the Impacts of Biodiesel Production on Agriculture, Water, Energy and Environment in Thailand

Buncha Wattana and Supannika Wattana*

Abstract— *In recognition of concerns about energy security and climate change, the Thai government has developed the Alternative Energy Development Plan (AEDP) for the period 2015–2036. Under this plan, the production of biodiesel would increase to 14 million litres per day in 2036 – more than four-fold increase as compared to 2015. Such a substantial rise in biodiesel production would result in a considerable growing demand for energy crops and subsequently land use and water for growing energy crops. This paper, therefore, aims to assess the impacts of biodiesel production on agriculture, water, energy, and environment. For this purpose, four scenarios (AEDP, OJ50, O100, and J100) are developed and their implications analyzed, through the application of GAEZ, CROPWAT, and LEAP, for the period 2015–2036. The analyses suggest that producing biodiesel from oil palm would require less crop cultivation area, fertilizer, and water than jatropha. Moreover, biodiesel production from oil palm would contribute to higher net energy gain and higher crude oil savings than from jatropha. It is, further, showed that biodiesel production from oil palm would generate less CO_2 emissions than jatropha. A high crop production demand could, however, become a challenge. This paper, therefore, recommends that the advancement of biodiesel conversion technology could be an effective strategy in order to overcome this challenge.*

Keywords— **Agriculture, biodiesel production, environment and water.**

1. INTRODUCTION

Due to limited indigenous resources of fossil fuels, Thailand is heavily dependent on imported oil to meet the growing demand of the nation – accounting for more than 7.5% of crude oil consumption [1]. Being heavily reliance on imported oil and agricultural-based economy, the Thai government has, therefore, implemented policies to promote and support biofuels. In 2015, the Thai government has developed Alternative Energy Development Plan (AEDP2015) for the period 2015–2036 [2]. Under this plan, biodiesel production is expected to grow considerably, from 3.3 million litres per day in 2015, to 14 million litres per day in 2036.Such an increase in the biodiesel production would require a substantial demand for energy crops. Under the AEDP plan, biodiesel production would be from oil palm and jatropha. A rising demand for energy crops would, subsequently, require more land and water resources for growing crops. This is likely to contribute to worsening the security of water and food supply because energy, water and land are intimately interconnected. In fact, a number of studies have been conducted on the implications of biofuel policy in context of Thailand. A review of these studies, however, revealed that the studies mainly focused on analyzing each system separately. For example, several studies have investigated the environmental impacts of biofuels production [3]–[8]. While an assessment of the implications on water was carried out by some research studies [9]–[11], other studies focused on the impacts on land use [12]–[15]. However, it appears that there is a recent study from Buncha et al. [16] that has analyzed the implications of bioethanol production on land, water and energy resources. This paper aims to provide an extended study by assessing the impacts of biodiesel production on agriculture, water, energy and environment. This impact assessment would provide an understanding about the relationships between biodiesel, water, land and environment. This will be useful for planners and policy makers to get better understanding about the interrelationship and to be able to develop practical policy responses to the energy, water and food security issues.

2. RESEARCH METHODOLOGY

The multidisciplinary nature of this study requires the application of several methodologies. The Global Agro-Ecological Zones (GAEZ) is selected for assessing the impacts on agriculture. GAEZ is an integrative land-use model developed by International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO) [17]. This tool is a global land resource database combining soil, terrain, and climate data, typically at a 5 arc-minute and 30 arc-second resolutions [18]. In order to analyze the impacts on energy and environment, the Long-range Energy Alternative Planning (LEAP) system is employed. LEAP is the energy model which is maintained and supported by the Stockholm Environment Institute (SEI) [19]. LEAP is a widely used tool for energy policy analysis

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and climate change mitigation assessment. For the impacts on water, this paper adopts CROPWAT 8.0 for calculating crop water requirements and irrigation requirements. CROPWAT is a decision support tool developed by the FAO [20]. Buncha et al. [16] provides a summary of several studies that employ GAEZ, LEAP and CROPWAT to analyze various impacts.

In this paper, the impacts of biodiesel production are assessed in terms of a range of attributes. For example, the impacts on agriculture are assessed in terms of projected future land requirements, projected production demand for oil palm and jatropha, and fertilizer requirement. The impacts on energy are assessed in terms of crude oil imports, net energy balance of biodiesel production. The impacts on water are assessed in terms of crop water requirements and irrigation requirements. And, the impacts on environment are assessed in terms of CO_2 emissions.

3. SCENARIO DEVELOPMENT

In order to analyze the impacts of biodiesel production on agriculture, water, energy and environment, scenarios are developed quantitatively to assess their impacts for the period 2015–2050. In fact, time period of the AEDP is from 2015 to 2036. This study extends time period of AEDP to the year 2050 because crop potential assessment by GAEZ is available in the 30-year future time periods of 2020s, 2050s and 2080s. And, the development of scenario is mainly based on the Alternative Energy Development Plan (AEDP). Four scenarios (namely AEDP, OJ50, O100 and J100) represent a mix of energy crops including oil palm and jatropha. The AEDP scenario reflects the alternative energy planning. In this scenario, the percentage share of oil palm and jatropha in biodiesel production is based on the AEDP. The biodiesel production in the OJ50 scenario is 50% from oil palm and 50% from jatropha. In the O100 and J100 scenarios, the biodiesel production employs 100% oil palm and 100% jatropha respectively. For more details of each scenario, an overview of the key scenario features and assumptions is provided in Table 1.

4. DATA CONSIDERATION

This study requires extensive data including energy, water, land-use and climate. The aforementioned data is available in the form of time-series data of energy data, climate data, crop pattern information, land-use data and macroeconomic data. The information on energy (for example, consumption of crude oil, diesel and biodiesel) is available from various Thailand Energy Balance reports and Thailand Alternative Energy Situation reports, annually published by the Department of Alternative Energy Development and Efficiency (DEDE) [21]–[22]. The growth for final energy demand can be obtained from the Ministry of Energy (MOE) and the DEDE [2], [23]. The data required for calculating net energy balance can be taken from various sources [24]–[26]. For monthly climate data, a climatic database, namely CLIMWAT developed by the FAO, provides monthly climate data that can be exported in an appropriate format required by CROPWAT [27]. This data includes yearly minimum and maximum temperatures, humidity, wind speed and sunshine hours. The data of monthly rainfall can be collected from the Thai Meteorological Department (TMD) [28]. The crop pattern information required for calculating crop water requirement includes planting date, crop coefficient (Kc), stages length, rooting depth, critical depletion fraction, maximum crop height and yield response factor. This information can be collected from the FAO and the Royal Irrigation Department (RID) [29]–[31]. Land-use information can be taken from the Office of Agricultural Economics (OAE) and supplemented by the National Statistical Office (NSO) [32]–[33].

Table 1. Key scenario features and assumptions

Scenario theme	Scenario key features and assumptions
Biodiesel-AEDP (AEDP scenario)	• Reflect the Alternative Energy Development Plan (AEDP) developed by DEDE • Achieve the AEDP's goal by producing biodiesel 14 million litres per day in 2036 and 20 million litres per day in 2050 from both oil palm and jatropha.[1] • Assign the percentage share of oil palm and jatropha in biodiesel production to be 60% and 40% respectively for the entire studied period (2015–2050).
Biodiesel-OJ50 (OJ50 scenario)	• Achieve the AEDP's goal • Assume percentage share in biodiesel production to be 50% from oil palm and 50% from jatropha for the entire studied period (2015–2050).
Biodiesel-O100 (O100 scenario)	• Achieve the AEDP's goal by producing biodiesel from oil palm 100%
Biodiesel-J100 (J100 scenario)	• Achieve the AEDP's goal by producing biodiesel from jatropha 100%

Note: [1] According to the AEDP, biodiesel is expected to substitute about 25% of diesel consumption in 2036. And, diesel demand would increase to 66.8 million litres per day in 2036 – an average annual growth of 1.3 per- cent. Based on the same demand growth, diesel demand in 2050 is expected to grow to 80 million litres per day. Accordingly, biodiesel production is estimated to 20 million litres per day in 2050 [2].

5. EMPIRICAL RESULTS AND DISCUSSIONS

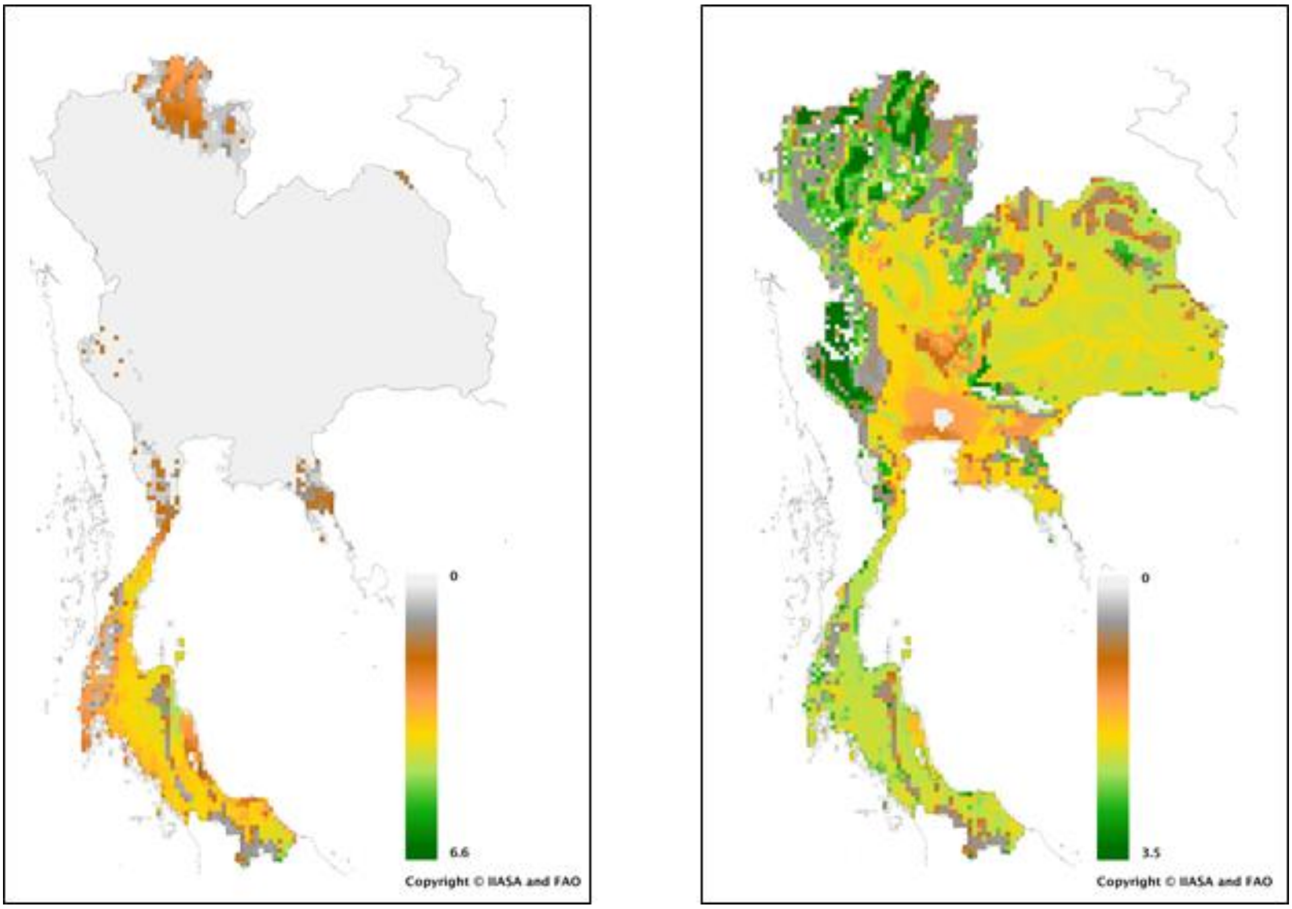
This paper provides the assessment of the scenario impacts on agriculture, energy, environment and water. The assessment is accordingly divided into four sub-sections, namely, agriculture, water, energy and environment.

5.1 Agriculture

In this paper, the scenario impacts on agriculture are assessed in terms of projected future land requirements, projected production demand for oil palm and jatropha, and fertilizer requirement. In order to assess future land requirements, this study estimates the attainable yields by employing GAEZ. This method provides the attainable yields of oil palm and jatropha in the 2050s under the IPCC SRES B2 climate scenario from the Australian Commonwealth Scientific and Research Organization (CSIRO), rain-fed condition and intermediate input level [34]. It should be noted that this study employs the aforementioned assumptions because of the fact that the Thai government has put an emphasis on local solutions to economic, social and environmental sustainability. And, energy crops including oil palm and jatropha are mostly grown under rain-fed condition.

Attainable yields of energy crops

The attainable yields of oil palm and jatropha (as presented in Figure 1) showed that the maximum production yields of oil palm and jatropha in the 2050s would be about 6.6 and 3.5 tonnes dry matter per hectare respectively. It should be noted that the unit of attainable yield is in the form of dry matter weight. It can be seen from Figure 1 that the growing areas for oil palm in the south of the country are more suitable than any other area. It is further revealed that oil palm cultivation in the central, north and northeastern parts of the country is impossible due to the fact that the annual rainfall is insufficient to support cultivation without any kind of irrigation. For jatropha, it appears that most of the land area in the country is suitable for growing jatropha. This is because jatropha has the ability to grow on poor soil, in areas with low rainfall, and is more tolerant to drought and flood.



a) Oil palm

b) Jatropha

Fig. 1. Attainable yield of energy crops in the 2050s (tonnes dry matter/ha).

Projected production demand for energy crops

In order to produce biodiesel for 20 million litres per day in 2050, the demand for both oil palm and jatropha production in the AEDP scenario is expected to grow substantially. Figure 2 shows the projected oil palm and jatropha production demand. The results from Figure 2 showed that the demand for oil palm production would increase by about 13.32 million tonnes, from 3.86 million tonnes in 2015 to 17.18 million tonnes in 2050. For jatropha, the demand for jatropha production is expected to grow to 17.52 million tonnes in 2050. As a result, total crop production demand in the AEDP scenario would rise to 34.7 million tonnes in 2050. The demand for crop production in the OJ50 is expected to grow to 36.07 million tonnes in 2050 – an increase of 4 per cent in crop production demand in comparison with the AEDP scenario. Additionally, the demand for crop production in the case of O100 scenarios would be 24 per cent higher than crop production demand under the AEDP scenario. In contrast, the J100 scenario would contribute to a decrease of 15 per cent in comparison with the AEDP scenario. It is noticed that the J100 scenario would require less crop production demand as compared with other scenarios. This is because jatropha would require less tonnes of crops than oil palm in order for producing the same amount of biodiesel. For example, crop production for oil palm and jatropha would be 5.9 kg and 4 kg respectively for 1 litre of biodiesel [35].

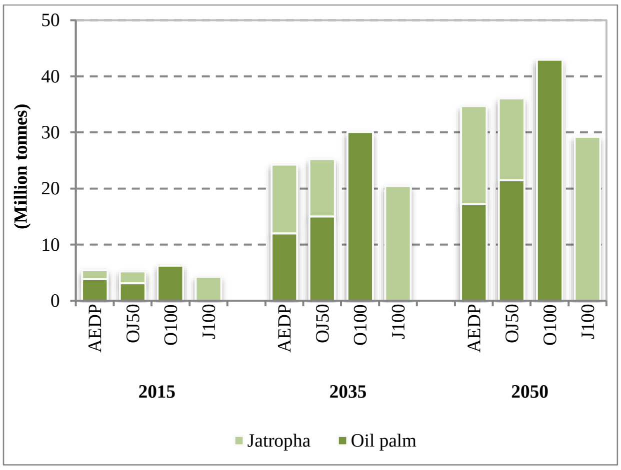


Fig. 2. Projected production demand.

Projected future land requirement

To supply the increasing demand for oil palm and jatropha production, the projected future land requirement for both energy crops is expected to rise continuously. The results from Figure 3 revealed that the projected future land extension for growing oil palm and jatropha in the AEDP scenario is expected to rise by about 5.78 million hectares. The requirement for land extension in the J100 scenario would be about 7.47 million hectare – an increase of nearly 30 per cent in comparison to the land extension in the case of AEDP scenario. On the contrary, the demand for future land extension in the case of OJ50 and O100 scenarios would be 10 and 63 per cent, respectively, lower than in the AEDP scenario. It is important to note that in order to meet the biodiesel target, the O100 scenario would contribute to a lowest future land extension in comparison with other scenarios. This could be due mainly to higher attainable yield of oil palm as compared to jatropha. As noted above, the attainable yield of jatropha is less than half of oil palm yield.

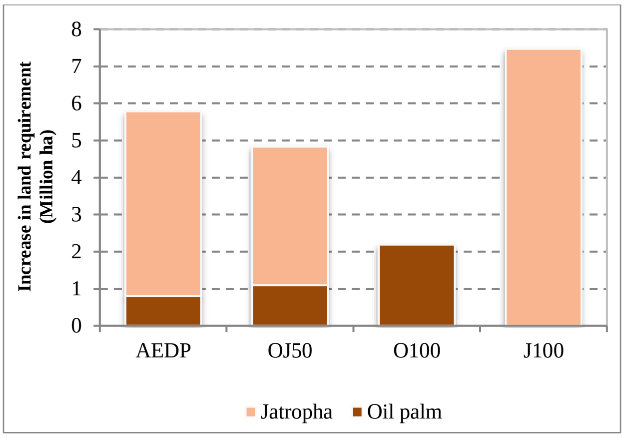


Fig. 3. Projected future land extension.

Fertilizer requirement

Projected fertilizer requirement in the case of the AEDP scenario is expected to increase from 432 thousand tonnes in 2015 to 2,642 thousand tonnes in 2050 – more than six-fold increase over the period 2015–2050 (as shown in Figure 4). Fertilizer required for energy crops, in 2050, under the OJ50 scenario would reach 2,543 thousand tones, under the J100 scenario would be even higher – 3,041 thousand tones. Such a substantial increase would result in a rise of imported fertilizer because fertilizer used in Thailand is mainly dependent on imported fertilizer – accounting more than 90 per cent of total fertilizer requirement. In contrast, the O100 scenario would contribute to the lowest growth rate of an increase in fertilizer requirement for growing energy crops. The requirement for fertilizer, in 2050, under the O100 scenario would be about 2,044 thousand tones. It is interesting to note that fertilizer demand for oil palm farming is, in fact, much more than for jatropha when considering equal cultivated area. Fertilizer requirement for oil palm and jatropha cultivation are 418 kg/ha and 141 kg/ha respectively [25]–[26]. Total fertilizer requirement under the O100 scenario would be, however, less than under the J100 scenario. This is due to the fact that the J100 scenario would contribute to a substantial increase in land requirement for crop cultivation. As discussed earlier, future land extension in the case of J100 scenario would be more than three times higher than that in the O100 scenario. Such a significant increase in land requirement in the BJ scenario would, therefore, result in the highest fertilizer requirement.

5.2 Water

This paper assesses the impacts on water in terms of crop water requirements and irrigation requirements. Table 2 presents average crop water requirements and irrigation requirements for oil palm and jatropha cultivation in Thailand. The projected irrigation demand for growing oil palm and jatropha for the AEDP, OJ50, O100 and J100 scenarios is shown in Figure 5.

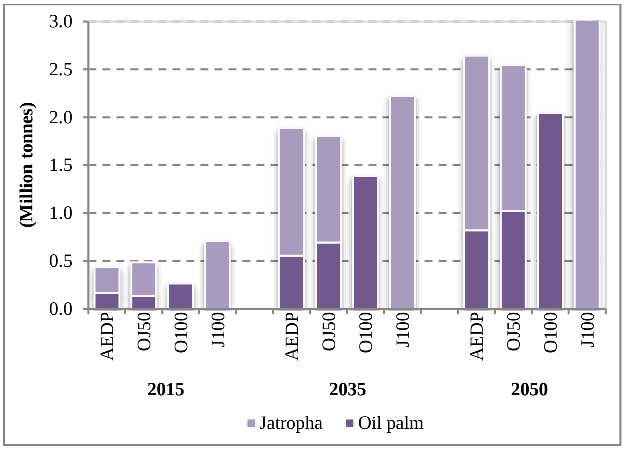


Fig. 4. Projected fertilizer requirement.

Table 2. Average crop water requirement and irrigation requirement for oil palm and jatropha

	Crop water requirement (m^3/ha/year)	Irrigation requirement (m^3/ha/year)
Oil palm		
- North	13,287	6,056
- Northeast	14,500	6,606
- Central	15,031	6,837
- South	14,118	4,325
Jatropha		
- North	9,743	3,581
- Northeast	10,518	3,743
- Central	10,793	3,887
- South	9,837	1,937

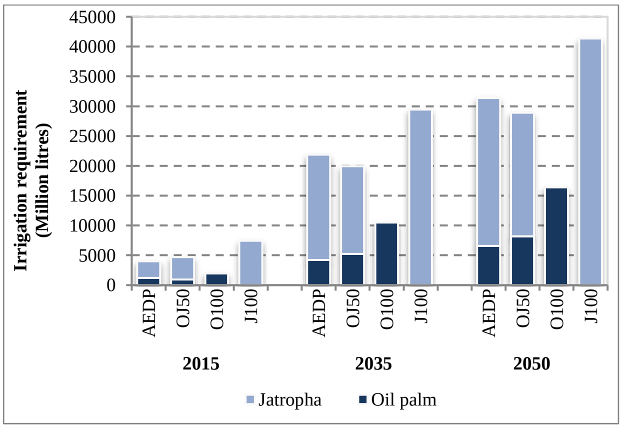


Fig. 5. Projected irrigation requirement.

With the objective of supplying sufficient demand for crops cultivation, water demand for growing oil palm is nearly 40 per cent greater than jatropha (as presented in Table 2). Additionally, irrigation requirement for oil palm is more than 70 per cent higher than for jatropha. It is, further, observed that irrigation requirement varies across the country. The results from Table 2 revealed that water demand in the southern region is lowest as compared with water demand in other regions for both oil palm and jatropha. This is because the precipitation in the southern region is higher than that in other regions.

Figure 5 shows that irrigation requirement in the case of AEDP scenario would increase to 31,384million litres in 2050. In the OJ50 scenario, irrigation requirement is expected to rise to 28,888 million litres in 2050 – a reduction of 8 per cent in comparison with the AEDP scenario. In the case of O100 scenario, additional water needed for growing oil palm would increase to 16,409 million litres in 2050 – a decrease of nearly 50 per cent in comparison with the AEDP scenario. In contrast, the J100 scenario would contribute to an increase of more than 30 per cent as compared with the AEDP scenario. It is further observed that the O100 scenario would require less irrigation requirement, as compared with other scenarios. This is because of the fact that in order to achieve biodiesel target, jatropha cultivation would require more land area than oil palm cultivation as previously discussed in Section 5.1. Such an increase would, therefore, result in higher water demand in the J100 scenario.

5.3 Energy

In this section, the impacts of the biodiesel production on the energy are analyzed. This analysis incorporates two main attributes, namely, crude oil imports and energy balance of biodiesel production.

Crude oil imports

It can be seen from Table 3 that over the period 2015–2050, crude oil imports in the case of AEDP scenario increased substantially, from 31,659 million litres in 2015, to 89,324 million litres in 2050. In 2050, an import of crude oil requirement in the OJ50 and J100 scenarios would be 0.60 and 2.11 per cent, respectively, higher than in the case of the AEDP scenario. It is interesting to note that the O100 scenario would, however, help slowdown an increase in crude oil requirement for imports. In the O100 scenario, an increase in crude oil imports in 2050 is expected to be 88,517 million litres – a reduction of 0.9 per cent in crude oil requirement for import in comparison with the AEDP scenario. Figure 6 further reveals that crude oil imports in the O100 scenario is expected to reduce continuously as compared with the AEDP scenario. For example, in the O100 scenario, a reduction in crude oil imports in 2015 would reach 134 million litres, in 2035 would be higher – 519 million litres, in 2050 would be at its highest – 807 million litres, as compared with the AEDP scenario. This signifies that biodiesel production from oil palm would contribute to a higher crude oil savings than from jatropha.

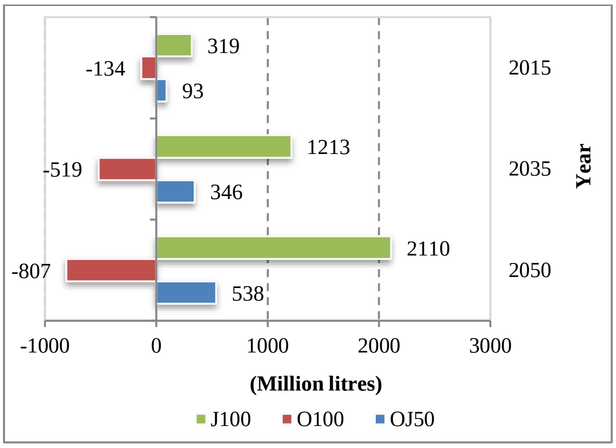
Energy balance of biodiesel production

This paper employs net energy balance as an indicator for assessing the energy efficiency of biodiesel production. Net energy balance, in this paper, refers to the difference between total energy outputs and total energy inputs. Total energy outputs is the energy content of biodiesel and total energy inputs is the energy consumption in transportation, cultivation, fertilizers and biodiesel conversion.

Table 3. Crude oil imports in the case of various scenarios over the period 2015–2050

Year	AEDP	OJ50	O100	J100
	Crude oil imports	Changes from AEDP	Changes from AEDP	Changes from AEDP
	(Million litres)	(%)	(%)	(%)
2015	31,659	0.29	-0.43	1.01
2035	64,611	0.54	-0.81	1.88
2050	89,324	0.60	-0.90	2.11

Note: Diesel demand for the period 2015–2050 is expected to increase by 1.3 per cent annually [23].



Note: This figure presents the changes in crude oil imports in the OJ50, O100 and J100 scenarios as compared with the AEDP scenario.

Fig. 6 Changes in crude oil imports for biodiesel scenarios over the period 2015–2050.

The energy balance for the AEDP, OJ50, O100 and J100 scenarios is presented in Figure 7. The results from Figure 7 revealed that in order to produce the same amount of biodiesel, energy inputs under the AEDP scenario would be about 175,691 TJ, under the OJ50 scenario would be lower – 162,939 TJ and under the O100 scenario would be at its lowest – 99,298 TJ. The energy inputs in the J100 scenario would in order of nearly 226,619 TJ – highest as compared with other scenarios. And, achieving biodiesel target would enable a total energy content of approximately 238,273 TJ. It is, therefore, observed that all four scenarios would have positive net energy balance and the O100 scenario would contribute to a highest net energy gain. This is because in order to achieve the same amount of biodiesel, oil palm cultivation would require much less land area than jatropha cultivation. In fact, with the same amount of land area, energy required for biodiesel conversion, cultivation, fertilizer and transportation in the case of oil palm would be more than in the case of jatropha [25]–[26]. For example, energy required for cultivation for oil palm would be more than four–fold as compared with jatropha. In addition, energy required for biodiesel conversion in the case of oil palm would be more than double as compared with in the case of jatropha. Large land extension for jatropha would, however, enable such a high energy requirement for all biodiesel production processes. It is further observed that, for all four scenarios, energy use for biodiesel conversion and fertilizer have higher share in comparison with cultivation and transportation. Energy required for biodiesel conversion and fertilizer for all scenario's accounts for more than 90 per cent of total energy inputs. Therefore, in order to improve net energy gain, a lessening of energy use in the process of biodiesel conversion and fertilizer is essential.

5.4 Environment

The impacts on the environment are assessed in terms of CO_2 emissions from fuel consumption. Table 4 presents CO_2 emissions in the case of AEDP, OJ50, O100 and J100 scenarios over the period 2015–2050. Figure 9 shows changes in CO_2 emissions for AEDP, OJ50, O100 and J100 scenarios for the period 2015–2050.

CO_2 emissions

The results from Table 4 reveal that, the CO_2 emissions under the AEDP scenario is estimated to reach from 84 million tonnes in 2015, to 237 million tonnes in 2050, an increase of 153 million tonnes over the 2015 emission level – an average annual growth rate of 5.2 per cent. The CO_2 emissions in the case of OJ50 and J100 scenarios in 2050 would be, respectively, 0.60 and 2.11 per cent higher than the emissions in the AEDP scenario. On the other hand, in the case of O100 scenario, the CO_2 emissions in 2050 would be 235 million tonnes (0.91 per cent) lower as compared to the CO_2 emissions in the AEDP scenario. Figure 8 further shows that the O100 scenario would contribute to higher CO_2 savings in comparison with the AEDP, OJ50 and J100 scenarios. For example, CO_2 emissions in the O100 scenario is expected to reduce continuously as compared with the AEDP. In the O100 scenario, a reduction of CO_2 emissions in 2015 would reach 363 thousand tonnes, in 2035 would be higher – 1,384 thousand tonnes, in 2050 would be at its highest – 2,151 thousand tonnes, as compared with the AEDP scenario (as shown in Figure 8). This could be due to the fact that biodiesel conversion process for oil palm requires less energy than the process for jatropha (as discussed above) and hence CO_2 emissions in the case of oil palm would be accordingly lower than that in case of jatropha.

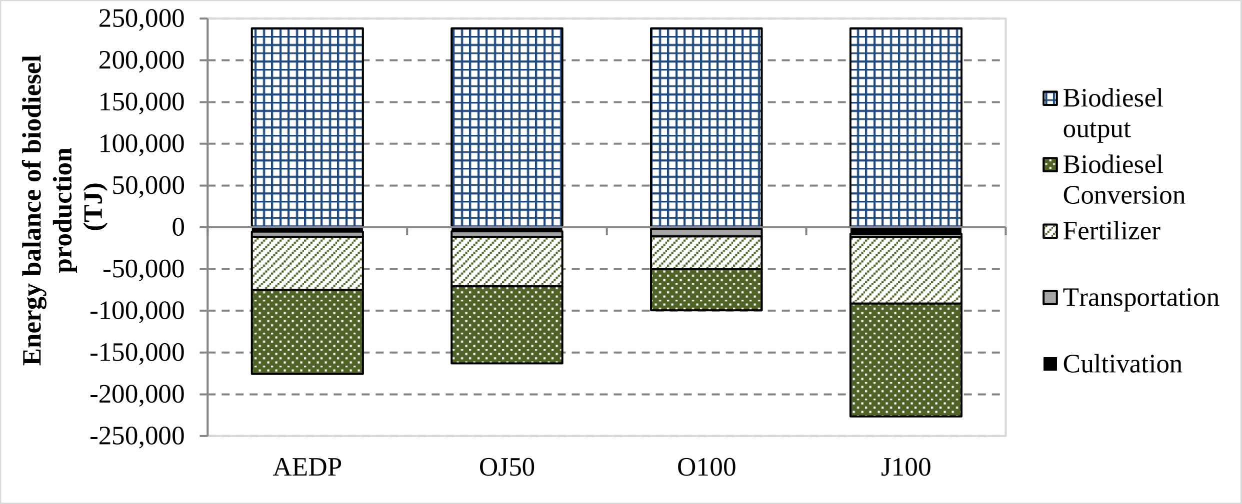
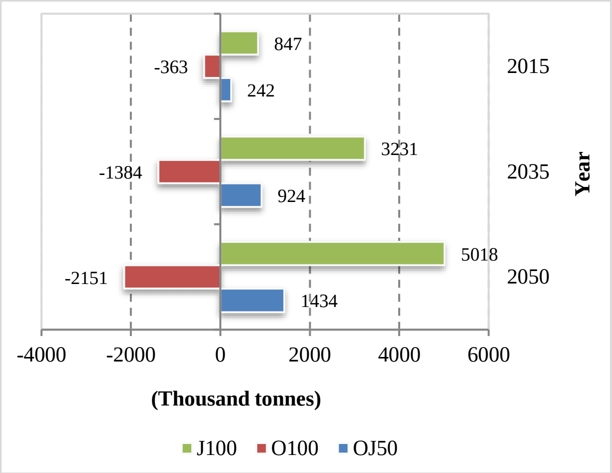


Fig. 7. Energy balance of biodiesel production for various scenarios in 2050.

Table 4 CO_2 emissions in the case of various scenarios over the period 2015–2050

Year	**AEDP**	**OJ50**	**O100**	**J100**
	CO_2 emissions	Changes from AEDP	Changes from AEDP	Changes from AEDP
	(Million tonnes)	(%)	(%)	(%)
2015	84.3	0.29	-0.43	1.01
2035	172.0	0.54	-0.81	1.88
2050	237.8	0.60	-0.90	2.11



Note: This figure presents the changes in crude oil imports in the OJ50, O100 and J100 scenarios as compared with the AEDP scenario.

Fig. 8. Changes in CO_2 emissions for biodiesel scenarios over the period 2015–2050.

6. POLICY IMPLICATIONS

In this paper, biodiesel scenario impacts are assessed in terms of agriculture, water, energy and environment. The assessment is accordingly divided into four sub-sections, namely, agriculture, water, energy and environment. A summary of key finding is provided in Table 5.

6.1 Agriculture

- In objective to meet biodiesel target, the O100 scenario would require more energy crops than other scenarios. The demand for energy crops in the O100 scenario is expected to grow to 42.94 million tonnes in 2050, which is 16 per cent, 19 per cent and 32 per cent, respectively, more than that in the case of OJ50, AEDP and J100 scenarios. It is noticed that the J100 scenario would require less crop production demand as compared with other scenarios. This is because jatropha would require less tonnes of crops than oil palm in order for producing the same amount of biodiesel.
- In order to supply the increasing demand for energy crops, the O100 scenario would contribute to a double decrease in future land requirement as compared to the AEDP and OJ50 scenarios. Especially, future land extension in the case of J100 scenario is expected to grow significantly – about 4 times in comparison with the O100 scenario. Such a substantial increase could be due mainly to lower attainable yield of jatropha as compared with oil palm. The attainable yield of jatropha is less than half of oil palm yield.

For fertilizer demand for achieving optimal crop production, the O100 scenario would result in a lowest growth in fertilizer requirement in comparison with the OJ50, AEDP and J100 scenarios. Fertilizer demand for crop cultivation in the case of OJ50, AEDP and J100 scenarios would be 24 per cent, 29 per cent and 49 per cent, respectively, higher than in the O100 scenario.

Table 5. A Summary of the biodiesel scenarios impacts on various aspects for the year 2050

	AEDP scenario	OJ50 scenario		O100 scenario		J100 scenario	
Agriculture							
Crop production demand (million tonnes)	34.7	36.1	*(4)*	42.94	*(24)*	29.2	*(-15)*
Future land extension (million ha)[a]	5.78	4.83	*(-16)*	2.19	*(-62)*	7.47	*(29)*
Fertilizer requirement (million tonnes)	2,643	2,543	*(-4)*	2,045	*(-22.6)*	3,042	*(15)*
Water							
Irrigation requirement (million litres)	31,384	28,887	*(-8)*	16,409	*(-47)*	41,367	*(32)*
Energy							
Crude oil import (million litres)	89,324	89,862	*(0.6)*	88,516	*(-0.9)*	91,209	*(2.0)*
Crude oil saving (million litres)[b]		-538		808		-1,884	
Net energy balance (TJ)	18,444	17,031		19,277		14,785	
Environment							
CO_2 emissions (thousand tonnes)	237,807	239,241	*(0.6)*	235,656	*(-0.9)*	242,825	*(2.1)*
CO_2 savings[c] (thousand tonnes)		-1,434		2,151		-5,018	

Notes: 1. Number in brackets show percentage change from the AEDP scenario.

2. [a] Future land extension represents an extension of land requirement comparing with the year 2015.

[b] Crude oil saving represents a reduction in crude oil imports in comparison with the AEDP scenario.

[c] CO_2 savings represents a reduction in CO_2 emissions in comparison with the AEDP scenario.

- It is interesting to note that the fertilizer demand in the case of J100 scenario would be highest as compared to other scenarios. In fact, fertilizer demand for oil palm farming is much more than for jatropha when considering equal cultivated area. Total fertilizer requirement under the AEDP, OJ50 and O100 scenarios would be, however, less than under the J100 scenario. This is due to the fact that the J100 scenario would contribute to a substantial increase in land requirement for crop cultivation. As discussed earlier, future land extensions in the case of J100 scenario would be 129 per cent, 154 per cent and 341 per cent, respectively, higher than those in the AEDP, OJ50 and O100 scenarios. Such a significant increase in land requirement in the J100 scenario would, therefore, result in a highest fertilizer requirement.

- To sum up, in comparison with other scenarios, the O100 scenario, which producing biodiesel from oil palm, would play a more active role in substantially reducing future land extension for crop cultivation as well as decreasing fertilizer requirements. However, a high crop production demand could become a challenge.

6.2 Water

- In order to supply sufficient demand for crops production, the O100 scenario would require less irrigation requirement, as compared with the AEDP, OJ50 and J100 scenarios. Irrigation requirement in the case of O100 scenario would be 76 per cent, 91 per cent and 152 per cent, respectively, lower than that in the OJ50, AEDP and J100 scenarios. Despite that fact that water demand for growing oil palm is greater than for growing jatropha (as discussed in section 5.2), oil palm cultivation would require much less land requirement than jatropha cultivation. Such a substantial demand for land cultivation would, therefore, result in a higher water demand in the OJ50 scenario, AEDP scenario and especially in the J100 scenario.

- More interestingly, in order to achieve the same amount of biodiesel, oil palm cultivation would also require less water demand than jatropha cultivation. Even though growing oil palm would need more water than jatropha, land area for oil palm cultivation would be less than for jatropha cultivation and importantly the production yield of oil palm is much higher than of jatropha.

6.3 Energy

- In comparison with other scenarios, the O100 scenario would help slowdown an increase in crude oil requirement for imports. An increase in crude oil imports in the O100 scenario would be lower by 0.91 per cent, 1.50 per cent and 3.04 per cent, respectively, as compared to the AEDP, OJ50 and J100 scenarios. As a result, the O100 scenario would contribute to a highest crude oil savings – 808 million litres, as compared with the AEDP scenario.

- In order for achieving biodiesel target, all scenarios would result in a gain in net energy balance and the O100 scenario would contribute to a highest net energy gain. This is because in order to achieve the same amount of biodiesel, oil palm cultivation would require much less land area than jatropha cultivation. In fact, with the same amount of land area, energy required for cultivation, fertilizer, irrigation, transportation, and biodiesel conversion in the case of oil palm would be more than in the case of jatropha [25]–[26]. Large land extension for jatropha would, however, enable such a high energy requirement for all biodiesel production processes.

- It is interesting to note that, for all four scenarios, energy use for biodiesel conversion and fertilizer have higher share in comparison with cultivation and transportation. Energy required for biodiesel conversion and fertilizer for all scenarios accounts for more than 90 per cent of total energy inputs. Therefore, in order to improve net energy gain, a lessening of energy use in the process of biodiesel conversion and fertilizer is essential.
- In summary, the O100 scenario would contribute to a significant crude oil savings and also would have a higher net energy gain. This suggests that the O100 scenario gains more credence if one considers the fact that adopting this scenario would not only contribute to a positive impact on energy but also lead to a significant reduction in future land extension, fertilizer requirement, and irrigation requirement.

6.4 Environment

- In recognition of emerging environmental concerns, the O100 scenario would be a relatively attractive approach in terms of generating less CO_2 emissions, as compared to other scenarios. In 2050, CO_2 emissions in the case of the O100 scenario would be lower by 2,151 thousand tonnes, 3,585 thousand tonnes and 7,169 thousand tonnes, respectively, in comparison with the emissions in the AEDP, OJ50 and J100 scenarios.

The forgoing summary suggests that the O100 scenario which produces biodiesel from oil palm only, would be an attractive option for Thailand. This is because the adoption of this scenario would significantly reduce future land area for crops cultivation and also decrease fertilizer requirement. In the case of O100 scenario, future land extension for crop cultivation in 2050 would be lower by 143 per cent, 172 per cent and 287 per cent, respectively, as compared with the OJ50, AEDP and J100 scenarios. For fertilizer requirement, fertilizer demand for crop cultivation in the case of the O100 scenario would be 24 per cent, 29 per cent and 49 per cent, respectively, lower than in the OJ50, AEDP and J100 scenarios. Furthermore, in order to achieve an optimal harvest, irrigation requirement in the case of O100 scenario would be 76 per cent, 91 per cent and 152 per cent, respectively, lower than that in the OJ50, AEDP and J100 scenarios. The O100 scenario would not only result in higher crude oil savings but also generate less CO_2 emissions and hence help mitigating CO_2 emissions. Especially, it would contribute to a highest gain in net energy balance. Despite the fact that the O100 scenario would contribute to a positive impact on several perspectives, it would require more energy crops for biodiesel production in comparison with other scenarios. Such an increase of crops could become a challenge. This paper, therefore, recommends that the advancement of biodiesel conversion technology could be an effective strategy in order to overcome this challenge. The enhancement of biodiesel conversion technology would help increase efficiency of biodiesel conversion and, accordingly, contribute to a decrease in crop production demand as well as energy use in biodiesel conversion process. This paper further suggests that the Thai government should take a leading role in promoting and supporting the undertaking of research and development on the conversion technologies. This would help enhance the efficient conversion technology and, importantly, establish the country-specific energy innovation.

7. CONCLUSION

This paper provides an assessment of the implications of biodiesel production on land-use, water, energy and environment in Thailand. The results revealed that the selection of suitable crops for biodiesel production would have significant impacts on energy, water, and food security issues. For example, producing biodiesel from oil palm would significantly reduce crop cultivation area, decrease fertilizer requirements, require less additional water demand for obtaining optimal harvests, contribute to higher crude oil savings, help to mitigate CO_2 emissions and would have higher net energy gain. It would, however, require high crop production demand. In order to reduce the demand for crop production, the enhancement of the efficiency of biodiesel conversion is crucial. This paper, therefore, suggests that the advancement of biodiesel conversion technology would be an effective way of increasing the efficiency of biodiesel conversion. This would result in a decrease in crop production demand as well as energy use in the biodiesel conversion process.

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