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Impacts of Palm Oil-based Biofuel Utilization Promotion Policy in the Thai Transport Sector

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This paper aims to provide an analysis of the impacts of the promotion policy of palm oil-based biofuel utilization in the Thai transport sector for the period 2020–2037. For this purpose, three scenarios are developed to represent different proportions of palm oil-based biofuel blending implemented in Thailand and their impacts are analyzed through the application of the Low Emissions Analysis Platform (LEAP) model. The analysis reveals that an increase in the proportion of palm oil-based biofuel in a diesel mix would provide several noticeable benefits, for example, help reducing diesel consumption, decreasing crude oil requirement, and mitigating emissions of CO_2 and PM2.5 – a major source of current environmental health problems. In addition, increased proportion of palm oil-based biofuel in the diesel mix would contribute to a growing demand for oil palm production and a plantation area to meet an increase in palm oil-based biofuel production. A high demand for oil palm production and plantation land requirement could, however, be emerging challenges. In order to address these challenges, the effective strategies could include a plan for agricultural crop zoning, crop breeding, the efficiency enhancement of biofuel conversion technology, the reduction of chemical fertilizers and pesticides, and the support from the government for research and development of second-generation biofuels. The analysis will be useful for Thai planners and policy makers to design policies to overcome the issues of energy and food security as well as climate change problems.

Keywords: palm oil-based biofuel, transport sector, Thailand, energy, environment and agriculture.

Introduction

Over the last four decades, oil has been one of the major factors for driving the development of Thai economy. In Thailand, consumption of petroleum products accounted for more than 50% of final energy consumption for the period 1986–2020 (EPPO, 2021). Over the entire period, diesel consumption accounted for more than 47% of total petroleum products. In addition, Thailand has limited domestic fossil resources, and therefore, the country has mainly imported crude oil to supply the growing demand. During the period 1986–2020, more than 70% of crude oil supply has been imported from the Middle East, the ASEAN countries, Africa and Europe (EPPO, 2021). Such a high reliance on imported oil has, therefore, contributed to a lessening of energy security.

With a view to improve the security of energy supply and to mitigate the environmental impacts, the government has initiated several plans and strategies to promote the utilization of palm oil-based biofuel in the transport sector since 2000s. In 2004, the first Alternative Energy Development Plan (AEDP) has been developed for the period 2004–2011 with a view to promote biofuel utilization in the country (Precharjarn & Prasertsri, 2010). The primary focus of this plan was production mandates for biofuels, incentives and research supports. In 2005, the government started to promote biodiesel production and utilization. As a result of the government's promotion, B5 (a biofuel blend consisting of 5% palm oil-based biofuel and 95% petroleum diesel fuel) has been on the petroleum market since 2005 (Wattana, 2014). In 2008, the second AEDP covering the period 2008–2022 was developed with the aim of increasing the proportion of renewable energy in the gross final energy consumption to 20% by 2022 (DEDE, 2008). According to this plan, the pure palm oil-based biofuel (B100) production in 2022 would increase more than double comparing with the production in 2008 (DEDE, 2008). However, the second AEDP was revised in 2012 for the purpose of developing the country to become a 'low-carbon society'. With this aim, the government developed the third AEDP (2012–2021). Under this plan, biofuels were expected to help reduce oil consumption by about 44% in 2021. In order to meet the target, the palm oil-based biofuel production is expected to rise to 5.9 million liters per day in 2021 – a more than three-fold increase as compared with the production in 2012 (DEDE, 2012). In accordance with the plan, the government increased the proportion of palm oil-based biofuel in petroleum diesel fuel from 5% (B5) to 7% (B7) in 2014. In addition, with a view to increase the proportion of renewable energy, the Thai government has further developed the fourth AEDP (AEDP2015) covering the period 2015–2036 (DEDE, 2015). Under this plan, production of palm oil-based biofuel is estimated to grow significantly, from 3.3 million liters per day in 2015, to 14 million liters per day in 2036. In order to meet the target, the proportion of palm oil-based biofuel in petroleum diesel fuel would increase to 10% (B10) and 20% (B20) in 2019. This would help balance the domestic oil palm market, stabilize prices of palm oil, and help mitigate environmental pollutions (EPPO, 2019). For Thailand, palm oil has long been a major economic backbone of the Southern Thai economy. The promotion of palm oil utilization in the form of biofuel would be one suitable strategy for balancing between demand and supply for oil palm in the country. In addition to the palm oil biofuel product, the Thai government has also planned for alternative diesel fuel development, for example, a new energy crop development which includes non-food crops like jatropha and micro algae. The development of non-food crops for biofuel has received much attention from researchers around the World in the last decade. A number of studies have been conducted on the development of biofuel from jatropha and micro algae, for example, Surakasi et al. (2022), Bhuyar et al. (2021), Singh et al. (2021), Chamkalani et al. (2020).

In recognition of the importance of the promotion of palm oil-based biofuel consumption in Thailand, a number of research works have been conducted on the issues of palm oil–based biofuel promotion in Thailand. These studies have focused on various dimensions including economic, energy, environmental, social and technical. For example, a number of studies have assessed the economic impacts of palm oil-based biofuel in terms of subsidy, tax and prices of biodiesel, cost of economic production for biodiesel project, and life cycle cost of biodiesel, for example, Laung-Iem and Thanarak (2021), Chantawong et al. (2020), Romprasert and Jermsittiparsert (2019) and Siralertruksa et al. (2012a). Several studies have assessed the energy impacts of palm oil-based biofuel, for example, Nutongkaew et al. (2019), Prueksakorn et al. (2010), Pleanjai and Gheewala (2009) Prueksakorn and Gheewala (2008) and Keson et al. (2015) have focused specifically on resource potential assessment of palm oil-based biofuel production. Several research works have been carried out an analysis of palm oil-based biofuel production implications on the environment including Lecksiwilai and Gheewala (2020), Prapaspongsa et al. (2017), Permpool et al. (2016), Wibul et al. (2012), Silalertruksa and Gheewala (2012) and Raghareutai et al. (2010). A number of studies have focused on the technological advancement of biodiesel production processes including the works of Somnuk et al. (2019) and Roschat et al. (2017). Some studies have focused on the biodiesel impacts on social dimension in terms of employment opportunities and perceptions of stakeholders on biodiesel policy, for instance, Chantawong and Dhakal (2016) and Silalertruksa et al. (2012b). And, a recent study by Purathanung and Wattana (2021) has assessed the implications of biodiesel consumption promotion in the transportation sector. In this study, various percentages of biodiesel blending including B7, B10 and B20 were developed for different scenarios in order to examine the impacts of the different degrees of biodiesel promotion on the energy, environment and agriculture. However, the transport sector in recent years has been experiencing a profound disruptive transition involving a shift from internal combustion engine vehicles (ICEVs) toward all zero-emission vehicles (ZEVs). In April 2021, the Thai government has shown strong interests in EVs by announcing that Thailand aims to only sell ZEVs in the country from 2035 (The Bangkok Post, 2021). A policy shift toward EVs would directly affect the biofuel utilization promotion. Therefore, such changes in the government's policy would require new research studies to provide recommendations in accordance with such policy changes. Regarding the government's policy as discussed above, the biofuel utilization in the transportation sector would drop due to the replacement of ICEVs with EVs. This paper, therefore, aims to analyze the impacts of palm oil-based biofuel utilization promotion policy in the Thai transport sector according to the changes in the government's policy on the biofuel promotion. This analysis would be beneficial for policy planners and makers to design mechanisms to balance between promotion of biofuel utilizations and EVs adoption in the transport sector.

Methods

Analytical tool and scope of research

In order to assess the impacts of biodiesel on the energy and environment, the literature review provides several methodologies that are popular for analyzing the energy and environmental implications including MARKAL/TIMES, MESSAGE, EneryPLAN, LCA, CGE, Input-Output (I-O) analysis and LEAP. A study from Connolly et al. (2010) provides an insightful review of modelling tools for analyzing impacts on energy systems including MARKAL/TIMES, MESSAGE, EneryPLAN and LEAP. A number of studies (for example, Lecksiwilai & Gheewala, 2020; Prapaspongsa et al., 2017; Wibul et al., 2012; Silalertruksa & Gheewala, 2012; Pleanjai & Gheewala, 2009; Prueksakorn & Gheewala, 2008) have employed a Life Cycle Assessment (LCA) to evaluate environmental impacts of biodiesel across the whole life cycle. In addition, Chantawong et al. (2020) have employed Computable General Equilibrium (CGE) to analyze the impacts of biodiesel policies on the Thai economy. And Siralertruksa et al. (2012b) have assessed the impacts of biodiesel production on the employment in Thailand by applying I-O analysis.

In this study, the analytical tool employed to assess the scenario impacts is the Low Emissions Analysis Platform (LEAP) model. LEAP is a powerful and versatile software system for integrated energy planning and climate change mitigation assessment (Heaps, 2022). LEAP can be used to track energy consumption, production and resource extraction in all sectors of an economy. LEAP supports a wide range of different modeling methodologies. On the demand side, it supports bottom-up accounting techniques and top-down modelling. LEAP also includes a range of optional specialized methodologies including stock-turnover modeling for transport planning. On the supply side, LEAP provides a range of accounting, simulation and optimization methodologies (Heaps, 2022). In particular, LEAP has the advantages of ease-of-use, data flexibility, adaptability to different scales and policy-friendly reporting. A number of studies have employed LEAP to assess the implications of bioenergy on the energy and environment including Kemausuor et al. (2015), Sritong et al. (2014), Suganthi and Samuel (2012), Pagnarith and Limmeechokchai (2009) and Islas et al. (2007).

This paper focuses on assessing the impacts of increased proportion of palm oil-based biofuel in the diesel mix on the energy, environmental and agricultural dimensions. Regarding the energy impacts, three attributes (including projected diesel demand, projected demand for palm oil-based biofuel and crude oil demand) were assessed. For the impacts on the environment, two attributes (including emissions of CO_2 and PM2.5) were assessed. And the assessment of agricultural impacts focused on the projected demand for oil palm production and projected land extensions.

Scenario development

In this study, three scenarios (namely BAU, MOD and ADV) were developed to assess the impacts of different proportions of palm oil-base biofuel blending implemented in Thailand. The development of these three scenarios aims to examine the impacts of the different degrees of palm oil-based biofuel promotion on the energy, environment and agriculture. The BAU scenario represented the current situation that B7 continues to be the main diesel market share. Under this scenario, 85% of the diesel market share would be B7, and B10 would account for only 15% of the market share. In the MOD scenario, B10 would become the major share of the diesel market. In this scenario, 80% of the diesel market share would be B10, and B20 would account for 20% of the market share. In the ADV scenario, 100% of the diesel market share would be B20. In this study, the time frame for the analysis covers a projection period from 2020 to 2037. In this study, in order to assess the scenario impacts, the petroleum demand is expected to grow annually by 3.2% (MOE, 2016).

Data consideration

In order to assess the scenario impacts, this paper requires a broad range of information on various dimensions including energy, environmental and agricultural. The aforementioned information includes the existing and prospective biofuel policies, historical data of crude oil supply and petroleum product consumption. The information on the existing and prospective policies of biofuel and the petroleum demand growth is available from the Ministry of Energy (MOE) and the Department of Alternative Energy Development and Efficiency (DEDE) (DEDE, 2008; DEDE, 2015; DEDE, 2018). The historical data on crude oil supply, diesel consumption, biodiesel production and oil refinery capacity are collected from various Energy Balance reports and Alternative Energy Situation reports, published by the DEDE (DEDE, 2021a), (DEDE, 2021b). The growth for petroleum demand is obtained from Thailand Energy Outlook developed by the MOE (MOE, 2016). The data required calculating projected oil palm production and projected land extensions for growing crops, e.g., crop attainable yield is collected from various sources (OAE, 2020; NSO, 2020; DEDE, 2019).

Empirical Results and Discussions

This paper analyzes the impacts of an increased proportion of palm oil-based biofuel in the diesel mix on the energy, environmental and agricultural dimensions. In this study, seven attributes are employed in order to assess the scenario impacts. These attributes include projected diesel demand, projected demand for palm oil-based biofuel, crude oil demand, emissions of CO_2 and PM2.5, projected demand for oil palm production and projected land extensions.

Impacts on energy

For the impacts on energy, three attributes including projected diesel demand, projected demand for palm oil-based biofuel and crude oil demand are assessed.

Projected demand for diesel in the transport sector

The results from *Fig. 1* show that the demand for diesel in the transport sector in the case of the BAU scenario is expected grow to 27 959 million liters in 2037 – about a 74% increase as compared with diesel consumption in 2020. In 2037, the MOD scenario would result in a decrease of 11% (3188 million liters), in comparison with the demand for diesel in the BAU scenario. The diesel demand in the ADV scenario in 2037 is estimated to rise to 7072 million liters (25%) lower than the demand in the BAU scenario. Such a reduction is mainly due to an increased proportion of palm oil-based biofuel in the diesel mix under the MOD and ADV scenarios. A decrease in the diesel demand would provide numerous benefits; for example, regarding energy perspective, a reduction in diesel demand would help decrease primary energy requirements, especially crude oil, more than 70% of which has been imported for the last four decades (EPPO 2021). Therefore, the promotion of palm oil-based biofuel utilization would help decrease crude oil import and importantly help enhance the country's security of energy supply. In terms of the environmental perspective, a decreased demand for diesel would help mitigate the environmental pollutions which are mostly from incomplete fuel combustion in diesel engines, e.g., CO_2 emissions and PM2.5.

Projected demand for palm oil-based biofuel in the transport sector

In response to the promotion of palm oil-based biofuel utilization, the demand for palm oil-based biofuel would substantially increase. *Fig. 2* shows that the projected demand for palm oil-based biofuel in the BAU scenario is expected to increase slightly from 1358 million liters in 2020, to 2359 million liters in 2037. For the MOD scenario, the palm oil-based biofuel demand is expected to rise to 4116 million liters in 2037 – an increase of 11% as compared with the BAU scenario. The demand for palm oil-based biofuel in the ADV scenario would rise to 6333 million liters in 2037 – a nearly double increase in comparison with the BAU scenario. A high increase in palm oil-based biofuel consumption would certainly result in a rise in demand for oil palm production as well as future land extension for growing energy crops. In fact, a high demand for oil palm production would be beneficial for various sectors. For example, a growing oil palm demand would help farmers gain higher income. A rising growth in palm oil industry would also contribute by a high oil palm demand. However, a fast-growing demand would confront with the insufficient supply issues. In order to supply sufficient demand for palm oil-based biofuel, and especially to achieve efficient crop production practices, the government should carefully plan for oil palm plantation and suitable growing land for maximizing yield for oil palm.

Projected demand for crude oil in the transport sector

With a view to supply sufficient diesel demand, the projected demand for crude oil under the BAU scenario is estimated to grow to 25 709 KTOE in 2037 – an increase of more than 70% from the demand level in

Fig. 1. *Projected demand for diesel during the period 2020–2037*

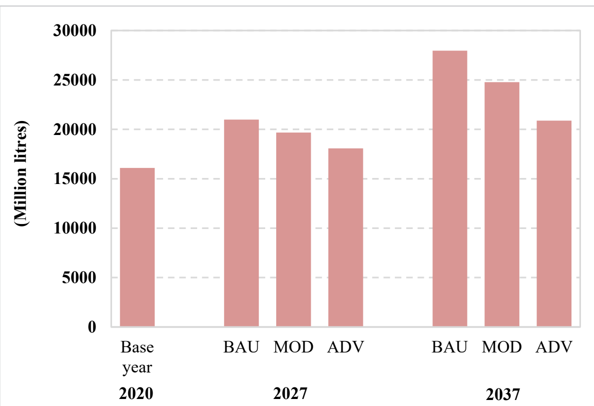
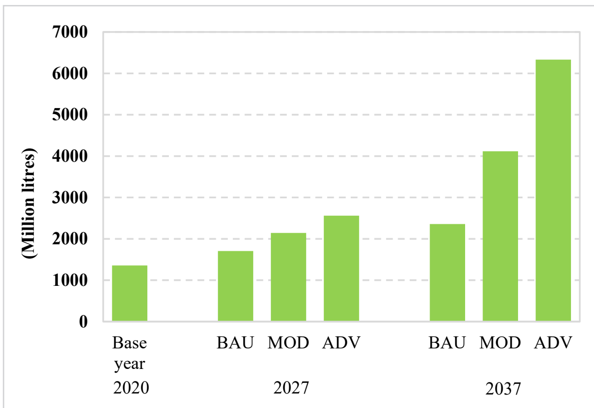


Fig. 2. *Projected demand for palm oil-based biofuel*



2020 (as shown in *Table 1*). In the case of MOD and ADV scenarios, crude oil demand over the entire studied period would decrease continuously as compared with the BAU scenario. In the case of the MOD scenario, for example, a decrease in the demand for crude oil would be 1207 KTOE in 2027 and would be higher – 2931 KTOE – in 2037 as compared with the BAU scenario. A reduction in the projected demand for crude oil, in the case of the ADV scenario, would reach 2677 KTOE in 2027and 6502 KTOE in 2037, when comparing with the demand for crude oil in the BAU scenario. These results, therefore, suggest that a higher proportion of palm oil-based biofuel in the diesel mix would certainly result in a reduction of the demand for crude oil. For Thailand, decreased demand for crude oil would provide benefits for the country in terms of less oil import dependency and enhanced energy security. For example, a decline in the demand for crude oil could help reduce crude oil imports. A decreased import for crude oil would help improve the security of energy supply if one considers the fact that more than 70% of crude oil supply has been imported over the last four decades.

Impacts on environment

This section assesses the environmental impacts of an increased proportion of palm oil-based biofuel in the diesel mix in terms of CO_2 emissions and emissions of Fine Particulate Matters (PM2.5).

Table 1. *Projected demand for crude oil in the transport sector*

Year	BAU Scenario (KTOE)	Change from BAU Scenario	
		MOD Scenario (KTOE)	AVD Scenario (KTOE)
2020	14 803	–	–
2027	19 294	(–1207)	(–2677)
2037	25 709	(–2931)	(–6502)

Notes: The number in brackets shows changes in the demand for crude oil comparing with the BAU scenario.

CO_2 emissions

It appears that the impacts on environment would correspond with the energy impacts. *Table 2* reveals that CO_2 emissions in the transport sector would decrease in response to a decline in demand for diesel. For example, CO_2 emissions, under the BAU scenario, would increase to 76.3 million tons in 2037 – a nearly double increase as compared with the 2020 level (as presented in *Table 2*). In the case of the MOD and ADV scenarios, CO_2 emissions in 2037 would be, respectively, by 9.8% and 21.8% lower than the emissions level in the BAU scenario. It is further observed that the ADV scenario would contribute to highest CO_2 savings, i.e., 16.6 million tons in 2037, as compared with the BAU scenario. It is, therefore, clear that a decrease in CO_2 emissions in the transport sector would be attributed to a reduction in diesel demand. Such a reduction would be due to a higher proportion of biodiesel in fossil diesel as discussed earlier.

Emissions of PM2.5

The results from *Table 3* show that emissions of PM2.5 under the BAU scenario are estimated to rise to 24.6 thousand tons in 2037 – an increase of 73% as compared with the emissions in 2020. In the MOD scenario, the emissions of PM2.5 in 2037 are estimated to drop by 11% as compared with the emissions under the BAU scenario. The emissions of PM2.5 in 2037, under the ADV scenario, would decrease by 6.2 thousand tons (25%) as compared with the emissions in the BAU scenario. The foregoing results clearly indicate that decreased emissions of PM2.5 would be attributed to a reduction in diesel demand as discussed earlier in section 5.1. It is widely known that diesel appears to be the main contributor of PM2.5 emissions. This is because PM2.5 mostly derives from inefficient combustion, such as the use of diesel fuels by motor vehicles, the widespread wood

Table 2. *CO_2 emissions in the transport sector*

Year	BAU Scenario (million tons)	Change from BAU Scenario	
		MOD Scenario (million tons)	AVD Scenario (million tons)
2020	43.9	–	–
2027	57.2	(–3.2)	(–7.3)
2037	76.3	(–7.5)	(–16.6)

Notes: The number in brackets shows changes in CO_2 emissions comparing with the BAU scenario.

burning and chemical processes involving mainly diesel fumes and ammonia released by farm fertilizers. The problem of PM2.5 currently appears to be one of the key topics for health discussion around the world including Thailand. In recognition of the importance of this problem, a number of studies (for example, Lin et al., 2020; Tsai et al., 2019; Hao et al., 2019) have been carried out an analysis of PM2.5 emissions from diesel engines with a view to provide strategies to help alleviate PM2.5 issues.

Agriculture

For the impacts on agriculture, two attributes (including projected demand for oil palm production and projected land extensions) are assessed.

Table 3. *Emissions of PM2.5 in the transport sector*

Year	BAU Scenario (thousand tons)	Change from BAU Scenario	
		MOD Scenario (thousand tons)	AVD Scenario (thousand tons)
2020	14.2	–	–
2027	18.5	(–1.2)	(–2.6)
2037	24.6	(–2.8)	(–6.2)

Notes: Number in brackets shows PM2.5 emissions changes comparing with the BAU scenario.

Oil palm production demand

An increased proportion of palm oil-based biofuel in the diesel mix in response to the government's policy would certainly affect the agricultural sector. This is because biodiesel is a product from energy crops, for example, oil palm, jatropha and soy bean. In the case of Thailand, oil palm appears to be a high commercially potential production among the existing Thailand's major oil crops. The demand for oil palm production for the period 2020–2037 is presented in *Fig. 3*. In this paper, it should be noted that in order to produce one liter of palm oil-based biofuel 4 kg of oil palm fresh fruit bunches are needed (Nupueng et al., 2018). *Fig. 3* shows that the oil palm production demand under the BAU scenario would increase to 9.4 million tons in 2037 – approximately a 70% increase comparing with the oil palm production in 2020. Under the MOD scenario, the oil palm demand in 2037 would be by 7 million tons higher than the production in the BAU scenario (as shown in *Fig. 4*). In the ADV scenario, the oil palm production demand in 2037 is expected to rise by about 16 million tons as compared with the demand under the BAU scenario (as shown in *Fig. 4*). A high increase in oil palm production would require more land and water for growing oil palm. Additionally, growing oil palm in Thailand also requires fertilizers in order to achieve the optimal yield. In Thailand, fertilizers, which are mostly chemical, are essential for growing crops. While most chemical fertilizers have been imported, organic fertilizers have been domestically produced (MOAC, 2017). An increased demand for oil palm production would, therefore, intensify fertilizer import.

Fig. 3. *Oil palm demand for palm oil-based biofuel production*

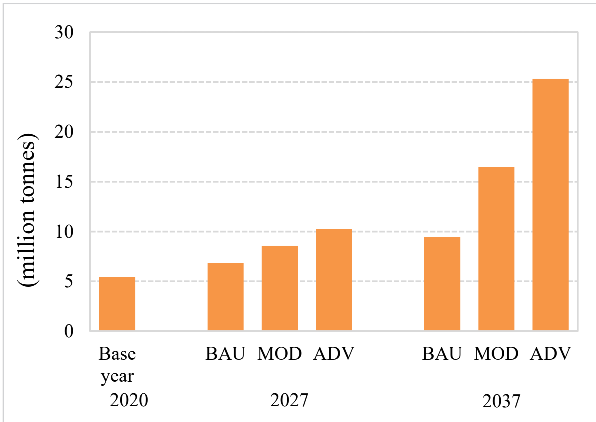
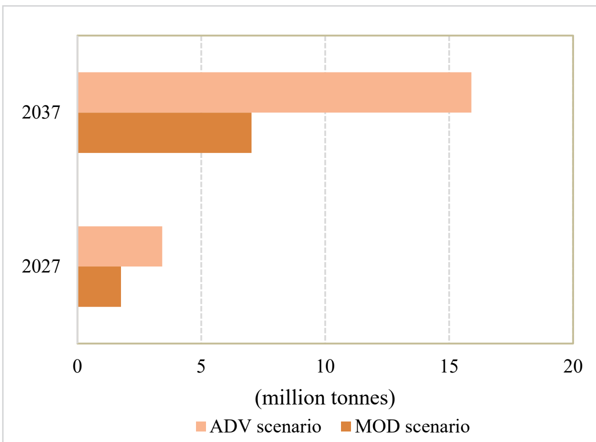


Fig. 4. *Changes in oil palm demand for the year 2027 and 2037*

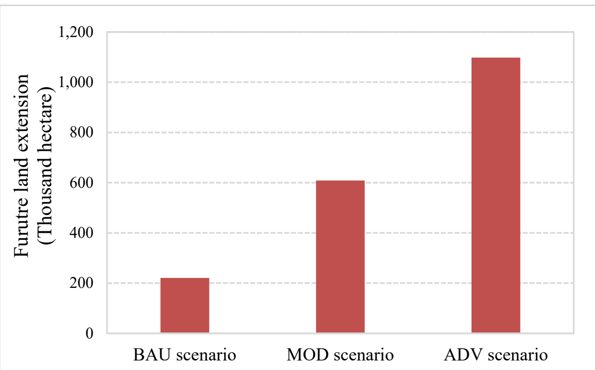


Note: This figure presents the changes in oil palm demand in the MOD and ADV scenarios compared with the BAU scenario.

Future land extensions

With the aim to supply the growing oil palm production demand, future land required for oil palm cultivation would increase accordingly. Over the period 2020–2037, future land extensions under the BAU scenario would increase by 221 thousand hectares as shown in *Fig. 5*. In the MOD and ADV scenarios, land required for oil palm cultivation would be higher by 3 times and 5 times, respectively, than under the BAU scenario (as presented in *Fig. 5*). An expansion of oil palm plantation areas could have a serious impact on food security and land use changes. For example, a high increase in land requirement for growing oil palm could result in a reduction of food crops plantation area. This would subsequently affect a decrease in food supply and hence supplement tremendous pressures on spike food prices (Brinkman et al., 2020). In terms of land use change, an expansion of plantation areas for oil palm in Thailand usually converts forest area to agricultural area. The deforestation for monoculture crop cultivation could substantially result in a loss of biodiversity and wildlife habitats as well as in a worsening of global climate change and a cause of soil degradation and flood risks (IIASA 2009).

Fig. 5. *Increased land requirement for growing oil palm*



Policy implications

With an aim to provide strategies for developing sustainable biofuel utilization in Thailand, this study assesses the implications of an increased proportion of palm oil-based biofuel in the diesel mix for the period of 2020–2037. In this study, seven attributes are employed in order to assess the scenario impacts. These attributes include projected diesel demand, projected demand for palm oil-based biofuel, crude oil demand, emissions of CO_2 and PM2.5, projected demand for oil palm production and projected land extensions.

The foregoing analysis suggests that the promotion of biofuel utilization appears to provide several benefits. For example, a high proportion of palm oil-based biofuel in the diesel mix would help reduce demand for diesel. The drop in the diesel demand would subsequently result in a decrease in the demand for crude oil. For instance, the demand for crude oil in 2037, under the ADV scenario, would be lower than the demand in the MOD and BAU scenarios by 16% and 25%, respectively. Regarding the impacts on environment, a higher proportion of palm oil-based biofuel in the diesel mix would help mitigate emission of CO_2 and PM2.5 – a major source of current environmental health problems. For instance, in the ADV scenario, CO_2 emissions in 2037 would be lower than the emissions under the MOD and BAU scenarios by 13% and 22%, respectively. And emissions of PM2.5 in 2037, under the ADV scenario, would be lower than the emissions in the MOD and BAU scenarios by 16% and 25%, respectively. Considering the above discussion, it appears that the ADV scenario would provide numerous benefits. However, it would require higher oil palm production as well as more land requirements than other scenarios. For instance, oil palm demand in 2037, under the ADV scenario, would be by 54% and 170%, respectively, higher than the demand in the case of the MOD and BAU scenarios. Furthermore, land extensions for oil palm cultivation under the BAU, MOD and ADV scenarios in 2037 would be about 2 times, 3 times and 5 times, respectively, higher than land requirements in 2020.

Based on the aforementioned inferences, it appears that a high crop production demand and future land extensions could be emerging challenges for promoting biofuel utilization. In order to address these challenges, this paper proposes several strategies including a plan for agricultural crop zoning, crop breeding, the efficiency enhancement of biofuel conversion technology, the reduction of chemical fertilizers and pesticides, and the support from the government for research and development of second-generation biofuels.

a *Plan for agricultural crop zoning*

One key strategy for maintaining a balance between food crops and energy crops production as well as enhancing productivity of crops is the agricultural crop zoning. In order to execute the strategy successfully, the Thai government has so far developed a twenty-year Agriculture and Cooperative Strategy (2017–2036) (MOAC 2017). This strategy aims at increasing agricultural productivity and maintaining a balance between food crops and energy crops production. Consequently, an increase in future land extension would not result in a lessening of food and energy security.

b *Crop breeding*

In addition to the agricultural crop zoning, crop breeding would not only help enhance the attainable yield of crops but also help reduce plantation area for crops. In fact, crop breeding appears to be an imperative strategy under the global climate changes situation. The continuous rise of air temperature and CO_2 levels caused by global climate change would alter the rainfall patterns and distribution, and hence result in drought stress in plants. The drought stress could severely affect crop's growth and productivity. Crop breeding would help increase plant adaptability to drought stress in plants, enhance plant tolerance and ameliorate the adverse effects of water stress (Seleiman et al., 2021).

c *Efficiency enhancement of biofuel conversion technology*

The enhancement of the efficiency of biofuel conversion (liters/ton) appears to be an essential strategy for energy crop demand reduction. The advancement of biofuel conversion technology would be an effective way of increasing the efficiency of biofuel conversion and accordingly contributing to a decrease in crop production demand as well as energy use in biofuel conversion process. The undertaking of research and development on advancing biofuel conversion technology is essentially needed in order to establish country's innovations on biofuels.

d *Reduction of chemical fertilizers and pesticides*

Due to a substantial demand for oil palm production, the use of chemical fertilizers and pesticides would increase significantly. This is because chemical fertilizers and pesticides have been mostly applied in the agricultural sector in Thailand in order to increase crop yield (MOAC 2017). The increasing application of chemical fertilizers and pesticides would, however, intensify adverse impacts on the environment. Moreover, an increased consumption of chemical fertilizers would further increase imported fertilizers. As discussed earlier, most chemical fertilizers used in Thailand have been imported from China, Saudi Arabia and Russia (MOAC, 2017). The promotion of the use of organic fertilizers and pesticides from agricultural residues would help utilizing agricultural wastes, lower cost of crop production and help alleviating adverse environmental impacts.

e *Research and development of second-generation biofuels*

As previously discussed, the production of biodiesel from oil palm might contribute to food supply reductions and hence to a lessening of food security. Furthermore, additional fertilizers, water and land are required to grow more energy crops like oil palm. Second-generation biofuels could be an alternative option for substituting first-generation biofuels which are mostly produced from food crops. Second-generation biofuels could be produced from non-food crops including the waste from food crops, agricultural residue, wood chips, and waste cooking oil (Groves et al., 2018). In order to practically drive the development of second-generation biofuels in Thailand, the Thai government should take a leading role in promoting and supporting the undertaking of research and development on the second-generation biofuel technology.

Conclusions

This paper analyses the impacts of the promotion policy of palm oil-based biofuel utilization in the Thai transport sector for the period 2020–2037. The analysis shows that the policy to promote a higher proportion of palm oil-based biofuel in the diesel mix appears to provide several benefits. For example, a high proportion of a biodiesel blend would help decreasing diesel demand, reducing crude oil requirements, mitigating emissions of CO_2 and PM2.5. However, a high proportion of palm oil-based biofuel in the diesel mix would require a considerable amount of oil palm and a large area for oil palm cultivation. Such a high crop production demand and large future land extensions could be emerging challenges for promoting biofuel utilization. Several strategies could be employed in order to address these challenges, and especially to develop sustainable biofuel utilizations. These strategies include a plan for agricultural crop zoning, crop breeding, the efficiency enhancement of biofuel conversion technology, the reduction of chemical fertilizers and pesticides, and the support from the government for research and development of second-generation biofuels. This paper further suggests that a comparative analysis between the implementation of EV and biofuel in the transport sector would provide a basis for identifying the trade-offs and co-benefits that may exist. This would be beneficial for policy planners and makers to design mechanisms to balance between promotion of biofuel utilizations and EVs adoption in the transport sector.

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