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Implications of Ethanol Production on Agriculture, Water, Energy and Environment in Thailand

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Abstract

Given growing demand for clean energy to mitigate greenhouse gases emissions, the Thai government has developed Alternative Energy Development Plan (AEDP) for the period 2015–2036. Under this plan, the production of ethanol is expected to grow considerably, from 3.5 million litres per day in 2015, to 11.3 million litres per day in 2036. Such an increase in the ethanol production would, inevitably, have a direct impact on water consumption and land use for growing energy crops. This paper, therefore, aims to assess the implications of ethanol production on agriculture, water, energy and environment. For this purpose, four scenarios (AEDP, SC50, S100 and C100), developed in this paper, represent a range of energy crops for ethanol production. An assessment developed in this study – employing a combination of GAEZ, CROPWAT and LEAP – has suggested that the selection of suitable crops for the purpose of ethanol production would have significant impacts on agriculture, energy, water and environment. The results show that ethanol production from sugar cane would require less crop cultivation area and less irrigation requirement than the production from cassava. In addition, it would not only contribute to higher crude oil savings but also generate less CO_2 emissions and hence help mitigating CO_2 emissions. Importantly, it would result in a higher net energy gain. A high crop production demand and fertilizer requirement could, however, become a challenge. This paper, therefore, recommends that the implementation of agricultural zoning, the advancement of crop species and ethanol conversion technology, and the promotion of organic fertilizer from agricultural residues and organic pesticides could be the effective strategies in order to overcome this challenge.

Keywords: ethanol production, GAEZ, agriculture, energy, and environment

1. Introduction

With increasing energy demand but limited resources of fossil fuels, bioenergy has been promoted as a way to slow down consumption of conventional energy and to mitigate greenhouse gases emissions. While promotion of biofuels receives increased attentions, concerns have risen about the potential implications of biofuel produced from energy crops on the security of water and food supply. Since energy, water and land are intimately interlinked, an increasing demand for energy crops would essentially require more water and more land use.

In Thailand, crude oil supply depends largely on imports, accounting for more than 85 % of crude oil consumption [1]. In recognition of the concerns about heavy reliance on imported oil, the Thai government has implemented policies to promote and support biofuels. In 2015, the Thai government has developed Alternative Energy Development Plan (AEDP2015) for the period 2015–2036. The main objective of this plan is to increase the proportion of alternative energy, from 9,025 KTOE in 2014 to 39,402 KTOE in 2036 or 30.1 per cent of total energy consumption [2]. According to the AEDP, ethanol production is expected to rise to 11.3 million litres per day in 2036 – more than three-fold increase as compare to 2015. A rising demand for ethanol would require a substantial amount of energy crops. Under the AEDP plan, ethanol production would be from sugar cane and cassava. An increase in energy crop production would, inevitably, have a direct impact on water consumption and land use for growing crops. This is likely to contribute to worsening the security of water and food supply. Therefore, a satisfactory solution must be found to deal with these issues in order to maintain the security of energy, water, and food. It is clear that such a solution cannot be found by looking at each system separately, because of the linkages that exist between these systems. Therefore, an assessment of the implications of ethanol production on land, water and energy resources is essential in order to provide a basis for identifying the trade-offs and co-benefits that may exist. With this background, this paper aims to assess the potential impacts of ethanol production on agriculture, water, energy and environment. This assessment will be useful for the Thai planners and policy makers to design policies to overcome the energy, water and food security issues.

2. Methodology

In accordance with the multidisciplinary nature of this study, a combination of methodologies is employed to assess the impacts of ethanol production on agriculture, water, energy and environment. The first task is to develop baseline and alternative scenarios by taking into account the bioenergy policies in Thailand. In the second task, the implications of various scenarios are assessed in terms of, for example, crop production demand, future land extensions, fertilizer requirement, crude oil imports, net energy balance, crop water requirement, irrigation requirements, and CO_2 emissions. The results of scenario impacts provide various insights into the nature of energy-water-land-climate interactions. In order to put forward recommendations, it is important to assess these insights in terms of their policy implications and policy trade-offs and co-benefits that may exist.

2.1. Analytical tools and scope of research

In this paper, the analytical tools employed to assess the scenario impacts are land production planning model, energy model and water model. For the land production planning model, the Global Agro-Ecological Zones (GAEZ) is selected for this assessment. 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) [3]. 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 [4]. A number of studies have employed GAEZ as a tool for assessing the potential production of agricultural crops including biofuel crops [5-10]. For the energy model, the Long-range Energy Alternative Planning (LEAP) system is employed in order to assess the energy and environmental impacts. LEAP is the energy model which is maintained and supported by the Stockholm Environment Institute (SEI) [11]. LEAP is a widely used tool for energy policy analysis and climate change mitigation assessment. LEAP has been employed by several studies to assess the energy and environmental impacts of bioenergy including biofuels [12-16]. For water model, CROPWAT 8.0 is employed in this study for calculating crop water requirements and irrigation requirements. CROPWAT is a decision support tool developed by the FAO [17]. Several studies have applied CROPWAT in order to evaluate crop water requirement of energy crops [18-22].

This paper considers the implications of ethanol targets of AEDP on agriculture, energy, water and environment. Time frame for the analysis covers a projection period from 2015 to 2050.

2.2. Data considerations

This study requires a broad range of data including energy, water, land-use, climate, economy and environment. The aforementioned data are available in the form of the existing bioenergy policies, energy development plans, time-series data of energy industry, climate data, crop pattern information, land-use data and macroeconomic data. The existing bioenergy policies, the alternative energy development plan and the growth for final energy demand can be obtained from the Ministry of Energy (MOE) and the Department of Alternative Energy Development and Efficiency (DEDE) [2, 23]. The information on energy (for example, consumption of crude oil and gasoline) is available from various Thailand Energy Balance reports and Thailand Alternative Energy Situation reports, annually published by the DEDE [1, 24-25]. For the 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 [26]. 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) [27]. 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 achieved from the FAO and the RID [28-30]. Land-use information can be collected from the Office of Agricultural Economics (OAE) and supplemented by the National Statistical Office (NSO) [31-32]. The data required for calculating net energy balance can be obtained from various sources [33-38].

2.3. Scenario development

In this paper, the scenario development process generally involves developing a set of alternative options by employing a set of various assumptions. These assumptions are developed by taking into account various drivers that envision how the future might unfold. The scenarios are then modelled quantitatively to assess their impacts on agriculture, water, energy and environment. In this study, the development of scenario is mainly based on the Alternative Energy Development Plan (AEDP) and is focused on ethanol production. The scenario analysis covers for the time period of 2015–2050. In fact, time period of the AEDP is from 2015 to 2036. Due to the fact that crop potential assessment by GAEZ is available in the 30-year future time periods of 2020s, 2050s and 2080s, this study extends time period of AEDP to the year 2050.

According to the AEDP, sugar cane and cassava are major crops in order to produce ethanol. For this purpose, four scenarios (namely AEDP, SC50, S100 and C100), developed in this research, represent a range of energy crops for ethanol production. The AEDP scenario reflects the alternative energy planning. In this scenario, the percentage share of sugar cane and cassava in ethanol production is based on the AEDP. The ethanol production in SC50 scenario is 50% from sugar cane and 50% from cassava. In the S100 and C100 scenarios, the ethanol production, however, employs sugar cane-based production and cassava-based production respectively. For more details of each scenario, an overview of the scenario key features and assumptions is provided in Table 1.

Table 1 Scenario key features and assumptions

Scenario theme	Scenario key features and assumptions
Ethanol-AEDP (AEDP scenario)	• Reflect the Alternative Energy Development Plan (AEDP) developed by DEDE • Achieve the AEDP's goal by producing ethanol 11.3 million litres per day in 2036 and 14.9 million litres per day in 2050 from both sugar cane and cassava.[1] • Assign the percentage share of sugar cane and cassava in ethanol production to be 66% and 34% respectively for the period 2015–2025. • Change the percentage share in ethanol production to be 42% from sugar cane and 58% from cassava for the period 2026–2050.
Ethanol-SC50 (SC50 scenario)	• Achieve the AEDP's goal by producing ethanol 11.3 million litres per day in 2036 and 14.9 million litres per day in 2050 from both sugar cane and cassava.[1] • Assume percentage share in ethanol production to be 50% from sugar cane and 50% from cassava for the entire studied period (2015–2050).
Ethanol-S100 (S100 scenario)	• Achieve the AEDP's goal by producing ethanol 11.3 million litres per day in 2036 and 14.9 million litres per day in 2050 from sugar cane only.[1]
Ethanol-C100 (C100 scenario)	• Achieve the AEDP's goal by producing ethanol 11.3 million litres per day in 2036 and 14.9 million litres per day in 2050 from cassava only.[1]

Note: [1]According to the AEDP, ethanol is expected to substitute about 32% of gasoline consumption in 2036. And, gasoline demand would increase to 35 million litres per day in 2036 – an average annual growth of 1.8 per- cent. Based on the same demand growth, gasoline demand in 2050 is expected to grow to 46.6 million litres per day. Accordingly, ethanol production is estimated to 14.9 million litres per day in 2050. [2]

[2]Maintain current per capita consumption of other products from sugar cane and cassava and assume constant net export for sugar cane and cassava products

2.4. Key attributes for assessing scenario impacts

The scenario impacts in this study are assessed in terms of a wide range of attributes. For example, the scenario impacts on agriculture are assessed in terms of projected future land requirements, projected production demand for sugar cane and cassava, and fertilizer requirement. The impacts on energy are assessed in terms of crude oil imports, net energy balance of ethanol 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. Implications of ethanol production on agriculture, water, energy and environment

This section assesses the impacts of the AEDP, SC50, S100 and C100 scenarios on agriculture, water, energy and environment. The assessment is accordingly divided into four sub-sections, namely, agriculture, water, energy and environment.

3.1. Agriculture

As previously discussed in Section 2.4, the scenario impacts on agriculture are assessed in terms of projected future land requirements, projected production demand for sugar cane and cassava, and fertilizer requirement. In order to evaluate future land requirements and projected production demand, this research estimates the attainable yields and potential production capacity by employing the Global Agro-Ecological Zone (GAEZ). This tool provides the attainable yields of energy crops and potential production capacity in the 2050s under the B2 climate scenario from the Hadley Centre, UK Meteorological Office climate model 3 (HadCM3), rain-fed condition and intermediate input level [39]. These assumptions are based on the fact that the Thai government has put an emphasis on local solutions to economic, social and environmental sustainability. And, all energy crops selected in this study are mostly grown under rain-fed condition. It should be noted that this paper employs the average of potential yields in three suitability classes
(very suitable, suitable and moderately suitable) in order to estimate future land requirement and projected production demand

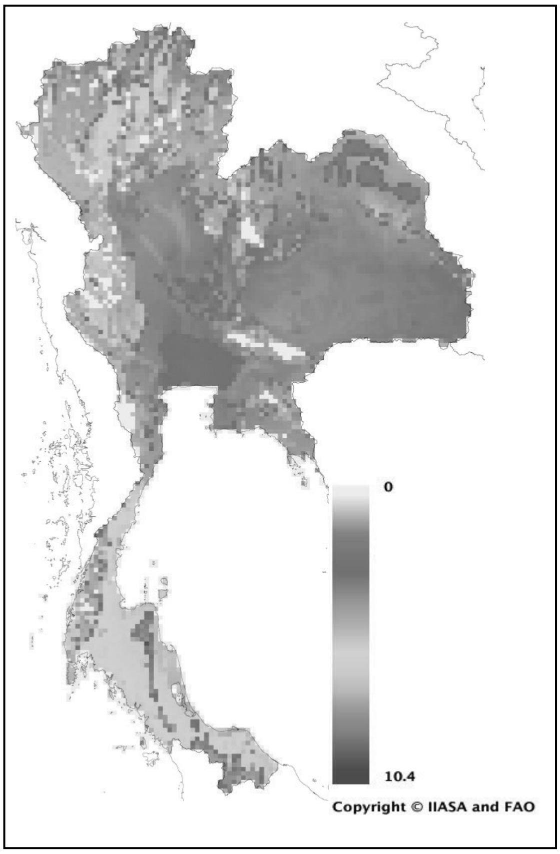
3.1.1 Attainable yields of energy crops

The attainable yields of sugar cane and cassava are presented in Figure 1. It should be noted that the unit of attainable yield is in the form of dry matter weight.
The results from Figure 1 show that the maximum production yields of sugar cane and cassava in the 2050s would be about 10.4 and 10.0 tonnes dry matter per hectare respectively. From Figure 1, it can be seen that the area in the north and south of the country are more suitable for growing sugar cane than any other area. The

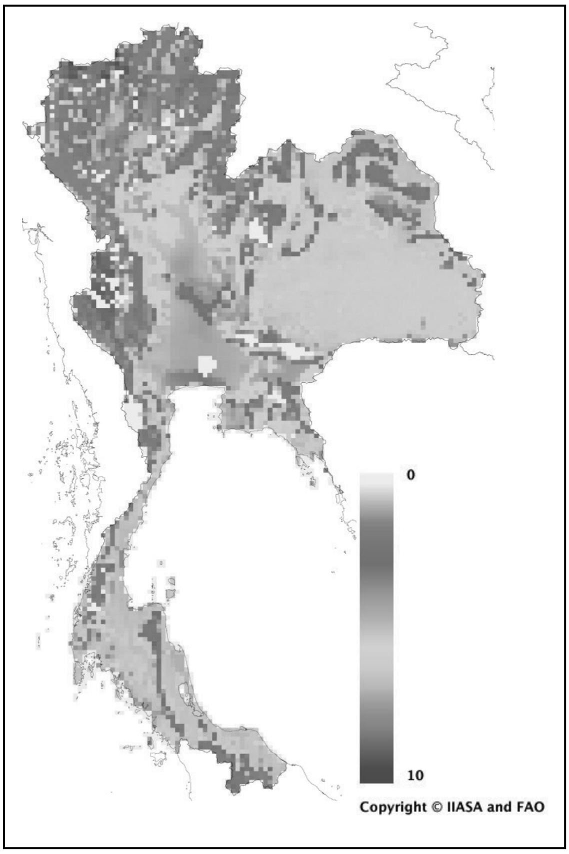
southern region, however, is mostly for growing oil palm and rubber tree due to its high precipitation. In the northern area, sugar cane cultivation is not popular due to its characteristic of steep terrain. For cassava, growing cassava in the northern, northeastern and southern parts of the country is more suitable than in the central region as shown in Figure 1. This is because cassava does not grow well in the area with poorly drained soils like in the central region.

In terms of the suitability of agricultural area, it is shown from Table 2 that the suitable area for crop cultivation in the 2050s would decrease. For example, the land area with very suitable level for both sugar cane and cassava in the 2050s would be marginally available – less than 1,000 hectare. In addition, the availability of the cultivation land with suitable and moderately suitable level for sugar cane would decline. And, the cultivation area with suitable level for cassava would decrease substantially. It is further observed that most of land area in the case of sugar cane would be in the marginally suitable level. The cultivation area for cassava would, however, be categorized in the moderately suitable which is higher level than in the case of sugar cane. In view of the potential yields, harvest yields of sugar cane in the 2050s would slightly decrease comparing with that in the 2020s. For example, the harvest yields of sugar cane in the very suitable level would be 118.2 tonnes per hectare in the 2020s and decrease to 115 tonnes per hectare in the 2050s. Similarly, harvest yields of cassava in most suitability levels in the 2050s would slightly decrease in comparison with that in the 2020s. For example, the harvest yields of sugar cane in the very suitable level would be 118.2 tonnes per hectare in the 2020s and decrease to 115 tonnes per hectare in the 2050s.
Similarly, harvest yields of cassava in most suitability levels in the 2050s would slightly decrease in comparison with that in the 2020s.

From Table 2, the harvest yields of cassava in the moderately level would be 18.4 tonnes per hectare in the 2020s and decrease to17.8 tonnes per hectare in the 2050s. It appears that there would be a reduction in suitable cultivated area and potential yields of energy crops. This could be due to a consequence of climate change resulting in an increase in global temperature and a lessening of precipitation. Such an increase in temperature and low rainfall would directly affect crop yields.



a) Sugar cane



b) Cassava

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

Table 2 Agro-ecological suitability and productivity: Potential production capacity

Land Suitability Class	Sugar cane				Cassava			
	2020s		2050s		2020s		2050s	
	Area	Potential yield[1]	Area	Potential yield[1]	Area	Potential yield[1]	Area	Potential yield[1]
	(1,000 ha)	(tonnes/ha)	(1,000 ha)	(tonnes/ha)	(1,000 ha)	(tonnes/ha)	(1,000 ha)	(tonnes/ha)
Very suitable	1	118.2	(-)	115.0	(-)	28.7	(-)	29.3
Suitable	467	86.7	250	86.5	7,196	22.6	2,156	23.5
Moderately suitable	5,229	63.8	3,844	64.2	16,616	18.4	19,000	17.8
Marginally suitable	21,543	42.1	22,698	37.9	5,659	11.9	8,068	11.4
Very marginally suitable	9,438	10.2	9,895	9.7	8,312	3.3	8,455	3.1
Not suitable	15,003	(-)	14,994	(-)	13,899	(-)	14,003	(-)

Notes: 1. The potential yield is in the form of harvest weight.
2. The conversion factor for sugar cane and cassava are 0.1 and 0.35 respectively. [15]
3. The conversion factor refers factor for converting crops from fresh to dry matter.
4. (-) shows that the available area is less than 1,000 ha.

3.1.2 Projected production demand for sugar cane and cassava

In this paper, the target for ethanol is expected to be 14.9 million litres per day in 2050. In order to achieve ethanol target, the demand for both sugar cane and cassava production in the AEDP scenario would continuously increase (as shown in Figure 2). The demand for sugar cane production is expected to rise by about 19.8 million tonnes, from 11.3 million tonnes in 2015, to 31.1 million tonnes in 2050. For cassava, the demand for cassava production would increase by about 19.8 million tonnes, from 3.5 million tonnes in 2015, to 23.3 million tonnes in 2050. Therefore, total crop production demand in the AEDP scenario is expected to grow to 54.4 million tonnes in 2050. The demand for crop production in the case of SC50 and S100 scenarios would be 7 and 43 per cent, respectively, higher than in the AEDP scenario. The C100 scenario would, however, result in a decrease of 29 per cent as compared to the AEDP scenario. It is observed that the C100 scenario would require less crop production demand as compared with other scenarios. This is mainly because by producing the same amount of ethanol, cassava would require less tonnes of crops than sugar cane.

3.1.3 Projected future land requirement

With the objective of meeting the increasing demand for sugar cane and cassava production, projected future land requirement for both energy crops would increase accordingly. Figure 3 shows the projected future land extension for growing sugar cane and cassava for the AEDP, SC50, S100 and C100 scenarios. In the case of AEDP scenario, future land extension is expected to rise by about 1.63 million hectare. An increase in land requirement in the SC50 scenario would be 1.50 million hectare – a decrease of 8 per cent as compared with the AEDP scenario. In addition, the S100 scenario would contribute to a reduction of 34 per cent in future land extension in comparison with the AEDP. In contrast, the requirement for land extension in the C100 scenario would be about 1.93 million hectare – an increase of nearly 20 per cent in comparison with the AEDP scenario. It is noticed that future land extension in the S100 scenario would be lower by 39, 51 and 79 per cent, respectively, as compared with the SC50, AEDP and C100 scenarios. Such a reduction in land extension could be due to higher production yield of sugar cane as compared to cassava. As discussed in Section 3.3.1, the production yield of sugar cane is more than 3 times higher than that of cassava.

In view of food security, concerns have risen about a reduction in the land area for growing food crops due to a surging demand for energy crops. This paper examines the implications of future land expansion for growing energy crops. Figure 4 shows how projected future land area for energy crops in the case of the AEDP scenario would encroach on other agricultural areas. As shown in Figure 4, projected future land requirement for sugar cane and cassava is expected to rise by 1.63 million hectare, from 2.67 million hectare in 2015, to 4.30 million hectare in 2050. Such an increase would inevitably encroach on other agricultural area, accounting about 18 per cent of cultivated land. This is likely to have an impact on food crops. In order to alleviate the impact, the implementation of agricultural zoning could be an effective strategy for balancing between food crops and energy crops.

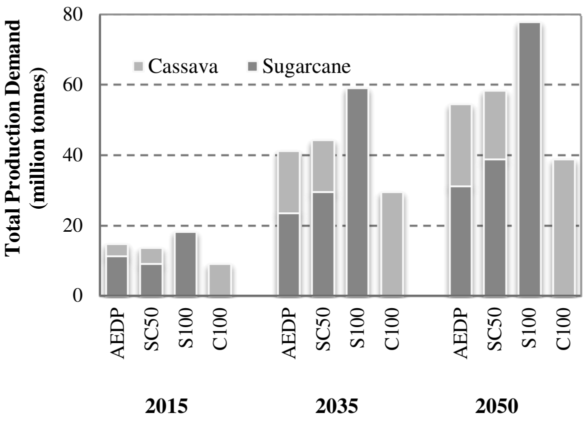


Figure 2 Projected production demand

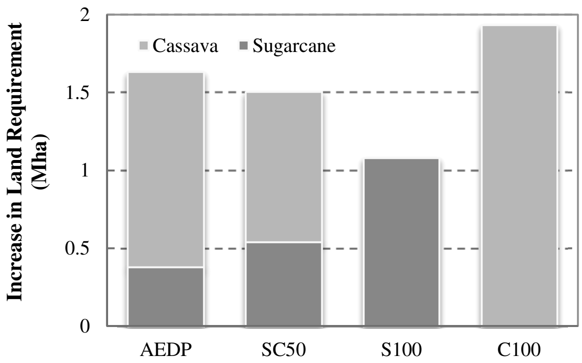


Figure 3 Projected future land extension

3.1.4 Fertilizer requirement

In terms of fertilizer demand for crop cultivation, projected fertilizer requirement, in 2050, under the AEDP scenario would increase to 692,000 tonnes, under the SC50 scenario would be higher – 700,000 tonnes, under the S100 scenario would be at its highest – 741,000 tonnes (as presented in Figure 5).

However, fertilizer demand for crop cultivation in the case of C100 scenario is expected to rise to 660,000 tonnes – lowest as compared with other scenarios. This is because fertilizer required for sugar cane cultivation is higher than fertilizer demand for cassava farming. Fertilizer requirement for sugar cane and cassava cultivation are 193 kg/ha and 96 kg/ha respectively [33-34].

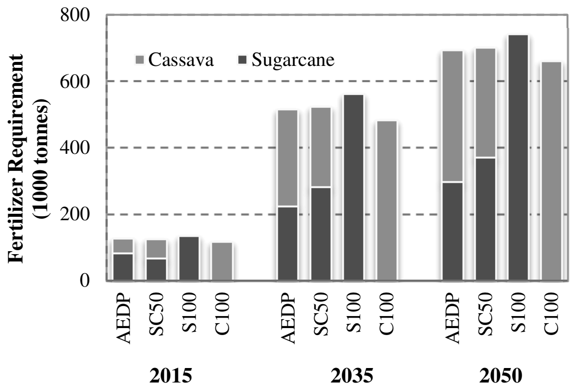
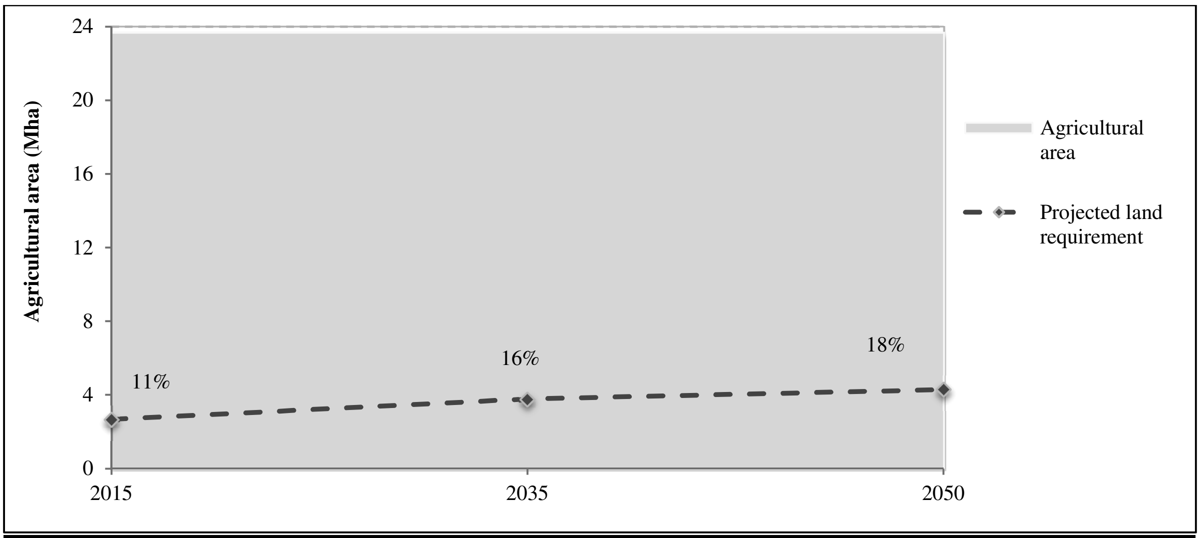


Figure 5 Projected fertilizer requirement



Note: Percentage shown in figure represents a share of land area for energy crops in total agricultural area in the country.

Figure 4 Projected future land requirements for sugar cane and cassava in the case of AEDP scenario

3.2 Water

In order to assess the water demand for growing crops, the CROPWAT model enables the calculation of crop water requirements and irrigation requirements. The calculation requires monthly climate data, rainfall data and crop pattern information. For the 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 [26]. The climate data includes minimum and maximum temperatures, humidity, wind speed and sunshine hours. The crop pattern information required for calculating crop water requirements includes planting date, crop coefficient (Kc), stages length, rooting depth, critical depletion fraction, maximum crop height and yield response factor. It should be noted that the assessment applies climate data covering the period of 1971–2000. Table 3 presents average crop water requirements and irrigation requirements for sugar cane and cassava.

The results from Table 3 show that sugar cane cultivation would require more water than cassava cultivation. In addition, in order to achieve optimal harvest, irrigation requirement varies across the country. It appears that only modest amount of additional water is needed in the northern and southern regions in order to gain optimal water balance for both sugar cane and cassava. On the other hand, achieving suitable crop yield in the northeastern and central regions would require more additional water than in the northern and southern regions. This could be due to the uneven geographical distribution of rainfall.

Table 3 Average crop water requirement and irrigation requirement for sugar cane and cassava

	Crop water requirement (m^3/ha/year)	Irrigation requirement (m^3/ha/year)
Sugar cane		
- North	11,435	4,893
- Northeast	12,854	6,143
- Central	13,100	5,804
- South	12,522	3,429
Cassava		
- North	8,491	4,208
- Northeast	9,527	5,157
- Central	9,757	4,650
- South	9,260	2,252

In order to gain optimal water balance for growing sugar cane and cassava, irrigation requirement in the case of AEDP scenario would increase to 10,000 million m^3 in 2050 (as shown in Figure 6). In the SC50 scenario, additional water demand in order for obtaining an optimal harvest is expected to grow to 9,622 million m^3 in 2050 – a decrease of approximately 4 per cent in comparison with the AEDP scenario. In the case of S100 scenario, irrigation requirement for growing cassava would increase to 7,703 million m^3 in 2050 – a reduction of 23 per cent as compared with the AEDP scenario.

It is further observed that the C100 scenario would contribute to a highest growth rate of additional water requirement for growing cassava. In the C100 scenario, irrigation requirement would be 11,540 million m^3 in 2050 – an increase of 15 per cent as compared to the AEDP scenario. Despite the fact that cassava cultivation would require less water than sugar cane farming, irrigation requirement in the case of C100 scenario would be highest in comparison with the AEDP, SC50 and S100 scenarios. This is mainly because the C100 scenario would require much more land for crop cultivation than other scenarios.

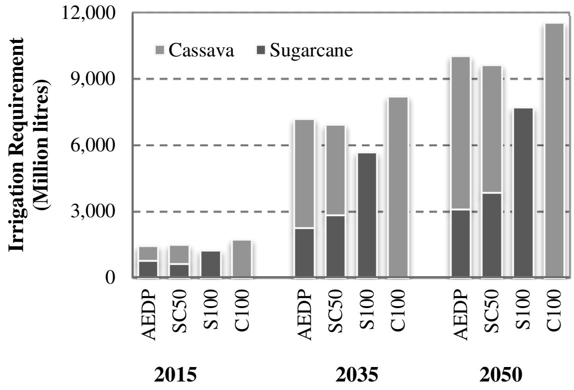


Figure 6 Irrigation requirement for sugar cane and cassava cultivation

3.3 Energy

The scenario impacts on energy are assessed in terms of the energy balance of ethanol production and crude oil imports. In order to evaluate changes in crude oil imports, this study employs the Long-range Energy Alternative Planning (LEAP) system. This tool provides crude oil requirement in 2050 under the assumption that maintain current crude oil domestic production. In order to estimate crude oil requirement, this study requires a broad range of energy data. The information on energy (for example, consumption of crude oil and gasoline) is available from various Thailand Energy Situation reports, and Thailand Alternative Energy Situation reports [1, 24-25]. The demand growth for final energy demand is obtained from Thailand Energy Outlook, Ministry of Energy [23].

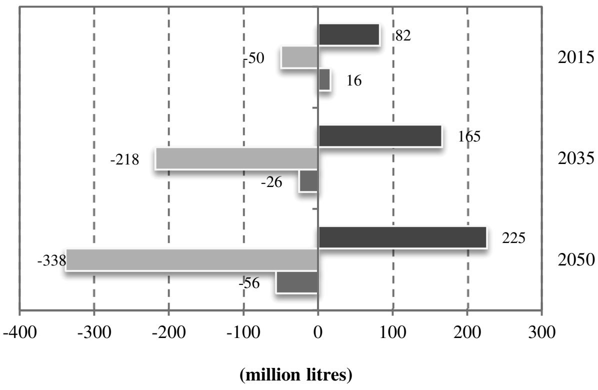
3.3.1 Crude oil imports

In order to meet the gasoline demand in 2050, crude oil imports in the case of AEDP scenario would increase considerably – more than three-fold increase as compared to the year 2015 (as shown in Table 4). According to Table 4, crude oil imports under the AEDP scenario are expected to rise from 20,707 million litres in 2015 to 74,874 million litres in 2050. In the case of the SC50 and S100 scenarios crude oil imports in 2050 would be 0.07 and 0.45 per cent, respectively, lower than in the case of the AEDP scenario. Crude oil imports in the C100 scenario are estimated to grow to 75,099 million litres in 2050 – an increase of 0.3 per cent in comparison with the AEDP scenario. The results from Figure 7 further suggest that crude oil imports in the S100 scenario is likely to change more noticeable than in the SC50 scenario. For example, crude oil imports in the S100 scenario is expected to reduce continuously as compared with the AEDP scenario. In the S100 scenario, a reduction in crude oil imports in 2015 would reach 50 million litres, in 2035 would be higher – 218 million litres, in 2050 would be at its highest – 338 million litres, as compared with the AEDP scenario (as shown in Figure 7).

Table 4 Crude oil imports in the case of various scenarios over the period 2015–2050

Year	AEDP	SC50		S100		C100	
	Crude oil imports	Changes from AEDP		Changes from AEDP		Changes from AEDP	
	(10^6 litres)	(10^6 litres)	(%)	(10^6 litres)	(%)	(10^6 litres)	(%)
2015	20707	16	0.08	-50	-0.24	82	0.40
2035	51885	-26	-0.05	-218	-0.42	165	0.32
2050	74874	-56	-0.07	-338	-0.45	225	0.30

Note: Gasoline demand for the period 2015–2050 is expected to increase by 1.8 per cent annually [34].



Note: This figure presents the changes in crude oil imports in the SC50, S100 and C100 scenarios as compared with the AEDP scenario.

Figure 7 Changes in crude oil imports

3.3.2 Energy balance of ethanol production

With a purpose to investigate whether ethanol produced from energy crops yields positive net energy gain, this paper employs net energy balance as an indicator for analysing the energy efficiency of ethanol. Net energy balance refers to the difference between total energy outputs and total energy inputs. In this paper, total energy outputs is the energy content of ethanol and total energy inputs is energy use in transportation, cultivation, fertilizers and ethanol conversion. It should be noted that this paper take into consideration other by-products of sugar cane and cassava in order to calculate net energy inputs. For example, electricity produced from bagasse is employed for the process of ethanol conversion. And, biogas from cassava wastes is used for steam production in order for ethanol conversion. To calculate net energy balance, the data required for the calculation can be obtained from various sources [33-38].

In objective to achieve ethanol target, the energy balance for the AEDP, SC50, S100 and C100 scenarios is provided in Figure 8. The results from Figure 8 show that in order to produce the same amount of ethanol, energy inputs under the SC50 scenario would reach 98,600 TJ, under the SC50 would be higher – 100,512 TJ, and under the C100 would be at its highest – 108,136 TJ. In contrast, energy inputs in the case of the S100 scenario would be in order of 89,000 TJ – lowest as compared with other scenarios. And, achieving ethanol target would enable a total energy content of approximately 115,000 TJ. It is, therefore, appeared that all four scenarios have positive net energy balance. It is further observed that the S100 scenario would contribute to a highest net energy gain. This could be due to the fact that ethanol conversion process for sugar cane requires less energy than the process for cassava. Energy requirement for ethanol process in the case of sugar cane would be nearly 50 per cent lower than in the case of cassava [36-37]. It is interesting to note that, for all four scenarios, energy use for ethanol conversion has highest share in comparison with cultivation, fertilizers and transportation. Energy required for ethanol conversion for all scenarios scenario accounts for more than 60 per cent of total energy inputs. This signifies that reducing energy use in the ethanol conversion process would significantly help improve net energy gain.

3.4 Environment

3.4.1 CO_2 emissions

In this section, the environmental impacts are assessed in terms of CO_2 emissions from fuel consumption. In accordance with the energy impacts, LEAP model also enables the calculation of CO_2 emissions for ethanol scenarios. It is shown from Table 5 that CO_2 emissions in 2050, in the case of the AEDP scenario, would increase by about 3 times (147 million tonnes) as compared to 2015 level. In 2050, CO_2 emissions in the SC50 and S100 would be, respectively, 0.07 and 0.45 per cent lower than the emissions level in the AEDP scenario. On the other hand, in the case of the C100 scenario, CO_2 emissions in 2050 are expected to increase by about 0.25 per cent in comparison with the emissions level in the case of the AEDP scenario (as shown in Table 5).

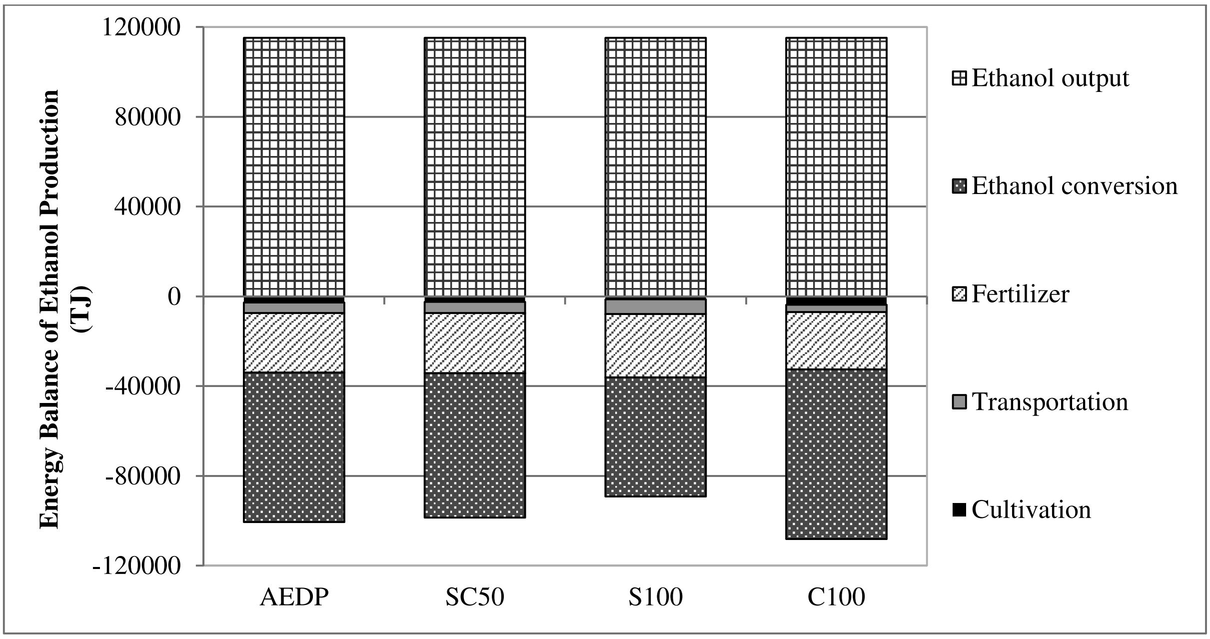
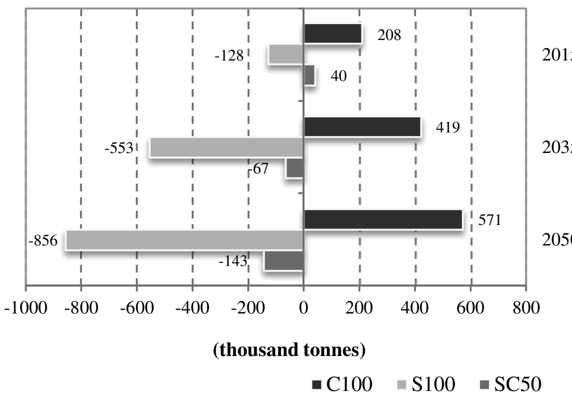


Figure 8 Energy balance of ethanol production in 2050

Table 5 CO_2 emissions in the case of various scenarios over the period 2015–2050

Year	AEDP	SC50		S100		C100	
	CO_2 emissions	Changes from AEDP		Changes from AEDP		Changes from AEDP	
	(10^3 tonnes)	(10^3 tonnes)	(%)	(10^3 tonnes)	(%)	(10^3 tonnes)	(%)
2015	75,682	40	0.05	-127	-0.17	207	0.27
2035	161,254	-66	-0.04	-552	-0.34	419	0.26
2050	222,376	-142	-0.06	-856	-.038	570	0.25



Note: This figure presents the changes in CO_2 emissions in the SC50, S100 and C100 scenarios as compared with the AEDP scenario.

Figure 9 Changes in CO_2 emissions

It is further observed in Figure 9 that the S100 would contribute to a slowdown in a rise of CO_2 emissions as compared with the AEDP scenario. In the S100 scenario, a reduction of CO_2 emissions in 2015 would reach 128 thousand tonnes, in 2035 would be higher – 553 thousand tonnes, in 2050 would be at its highest – 856 thousand tonnes, as compared with the AEDP scenario (as shown in Figure 9). In contrast, CO_2 emissions in 2050, under the C100 scenario, would be higher by about 571 thousand tonnes in comparison with the emissions in the case of the AEDP scenario.

4. Policy implications for scenario analyses

In this paper, the assessment of scenario impacts are analysed in terms of agriculture, water, energy and environment. These impacts are summarised in Table 6. A summary of key findings is as follows.

4.1 Agriculture

- In order to achieve ethanol target, the demand for both sugar cane and cassava production in the AEDP scenario is expected to grow to 54 million tonnes in 2050. The demand for crop production in the case of the SC50 and S100 scenarios would be 7 and 43 per cent, respectively, higher than in the AEDP scenario. The C100 scenario would, however, result in a decrease of 29 per cent as compared to the AEDP scenario.
- It is observed that the C100 scenario would require less crop production demand as compared with other scenarios. This is mainly because by producing the same amount of ethanol, cassava would require less tonnes of crops than sugar cane.

Table 6 Summary of the ethanol scenarios impacts on various aspects for the year 2050

	AEDP scenario	SC50 scenario		S100 scenario		C100 scenario	
Agriculture							
Crop production demand (million tonnes)	54.4	58.3	*(7)*	77.7	*(43)*	38.8	*(-29)*
Increase in land requirement (million ha)[a]	1.63	1.50	*(-8)*	1.08	*(-34)*	1.93	*(18)*
Fertilizer requirement (1000tonnes)	692	700	*(1)*	741	*(7)*	660	*(-5)*
Water							
Irrigation requirement (million litres)	10,005	9,622	*(-4)*	7,703	*(-23)*	11,540	*(15)*
Energy							
Crude oil import (million litres)	74,874	74,818	*(-0.075)*	74,536	*(-0.45)*	75,099	*(0.3)*
Crude oil saving (million litres)[b]		56		338		-225	
Net energy balance (TJ)	14,675	16,581		26,111		7051	
Environment							
CO_2 emissions (thousand tonnes)	222,376	222,234	*(-0.06)*	221,520	*(-0.38)*	222,946	*(0.25)*
CO_2 savings[c] (thousand tonnes)		143		856		-571	

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

2. [a] Increase in land requirement 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.

- With the objective of meeting the increasing demand for sugar cane and cassava production, future land extension in the S100 scenario would be lower by 39, 51 and 79 per cent, respectively, as compared with the SC50, AEDP and C100 scenarios. Such a reduction in land extension could be due to higher production yield of sugar cane as compared to cassava. As discussed in Section 3.3.1, the production yield of sugar cane is more than 3 times higher than that of cassava.
- In view of food security, an increase in future land requirement would inevitably encroach on other agricultural area, accounting about 7 per cent of cultivated land. This is likely to have an impact on food crops. In order to alleviate the impact, the implementation of agricultural zoning could be an effective strategy for balancing between food crops and energy crops.
- In terms of fertilizer demand for crop cultivation, the C100 scenario would result in a lowest growth in fertilizer requirement in comparison with other scenarios. Fertilizer demand for crop cultivation in the case of AEDP, SC50 and S100 scenarios would be 5 per cent, 6 per cent and 12 per cent, respectively, higher than in the C100 scenario.

4.2 Water

- In order to gain optimal water balance for growing sugar cane and cassava, irrigation requirement in the case of the S100 scenario would increase to 7,703 million m^3 – lowest as compared with the AEDP, SC50 and C100 scenarios.
- It is interesting to note that irrigation requirement in the case of C100 scenario would be highest in comparison with the AEDP, SC50 and S100 scenarios even though cassava cultivation would require less water than sugar cane farming. This is mainly because the C100 scenario would require much more land for crop cultivation than other scenarios.

4.3 Energy

- In order to meet the gasoline demand in 2050, crude oil imports in the S100 scenario would be lower as compared with other scenarios. Crude oil imports in the case of the S100 scenario would be lower than the imports in the AEDP, SC50 and C100 scenarios by 0.45 per cent, 0.38 per cent and 0.75 per cent respectively. Accordingly, the S100 would result in highest crude oil savings – 338 million litres, as compared with the AEDP scenarios.

- In objective to achieve ethanol target, all four scenarios have positive net energy balance. It is further observed that the S100 scenario would contribute to a highest net energy gain. This could be due to the fact that ethanol conversion process for sugar cane requires less energy than the process for cassava. Energy requirement for ethanol process in the case of sugar cane would be nearly 50 per cent lower than in the case of cassava [36-37].
- It is observed that, for all four scenarios, energy use for ethanol conversion has highest share in comparison with cultivation, fertilizers and transportation. Energy required for ethanol conversion for all scenarios scenario accounts for more than 60 per cent of total energy inputs. This signifies that reducing energy use in the ethanol conversion process would significantly help improve net energy gain.

4.4 Environment

- In view of environmental impacts, the S100 scenario would contribute to a slowdown in a rise of CO_2 emissions as compared with other scenarios. In 2050, CO_2 emissions in the case of the SC50, AEDP and C100 scenarios would be higher by 714 thousand tonnes, 856 thousand tonnes and 1,426 thousand tonnes, respectively, in comparison with the emissions in the S100 scenario.

The inference drawn from the above analyses is that the S100 scenario which produces ethanol from sugar cane only, would be a comparatively attractive approach due mainly to its ability to provide appreciable benefits. The adoption of this scenario would help reduce future land area for crop cultivation. In the case of S100 scenario, the future land extension for crop cultivation in 2050 would be lower by 39 per cent, 51 per cent and 79 per cent, respectively, as compared with the SC50, AEDP and C100 scenarios. And, it would result in a reduction in additional water demand in order to achieve an optimal harvest. Irrigation requirement in the case of the S100 scenario would be less than in the case of other scenarios. Furthermore, it would contribute to a highest crude oil saving (among other scenarios) and, in particular, help mitigating CO_2 emissions – an issue of contemporary significance. Importantly, it would result in a highest gain in net energy balance. In fact, the S100 scenario would require more crop production and fertilizer demand in comparison with other scenarios. In order to reduce the demand for crop production and fertilizer, the enhancement of the efficiency of ethanol conversion (litres/tonne) is essential. This paper, therefore, suggests that the advancement of ethanol conversion technology would be an effective way of increasing the efficiency of ethanol conversion. This would help not only decreasing the demand for crop production and fertilizer but also reducing the energy use in the ethanol conversion process.

To sum up, the analysis of the scenario impacts reveals that the selection of suitable crops for the purpose of ethanol production would have significant impacts on agriculture, energy, water and environment. For example, ethanol production from sugar cane would require less future land extension for crop cultivation and irrigation requirement than the production from cassava. It would help reducing crude oil imports, help mitigating CO_2 emissions and contribute to higher net energy gain. However, it would require higher crop production demand and fertilizer requirement. It appears that high crop production demand and fertilizer requirement could become a challenge. In order to overcome this challenge and especially to achieve sustainable development goals, this paper proposes the following:

i. Implementation of agricultural zoning

The implementation of agricultural zoning is one of the key strategies to help balancing between food crops and energy crops production and increasing productivity of crops. Clearly, it is the government that has authority to establish stringent measures for agricultural zoning in order to achieve sustainable agricultural development. So far, the Thai government has developed a five-year Agricultural Development Plan (2012–2016) in consistent with the 11th National Economic and Social Development Plan [40]. This plan aims at increasing agricultural productivity and balancing production between food crops and energy crops. Consequently, an increase in future land extension would not result in a lessening of food and energy security.

ii. Advancement of crop species and ethanol conversion technology

In addition to the agricultural zoning, the advancement of crop species would help improve crop yield and hence help reduce crop cultivation area. And, the enhancement of the efficiency of ethanol conversion is essential to reduce the demand for crop production. The advancement of ethanol conversion technology would be an effective way of increasing the efficiency of ethanol conversion process. Therefore, the Thai government should take a leading role in promoting and supporting the undertaking of research and development on the crop species and conversion technologies. This would help improve crop yield, enhance the efficient conversion technology and, importantly, establish the country-specific energy innovation.

iii. Reduction in the use of chemical fertilizers and pesticides

In Thailand, chemical fertilizers and pesticides have been largely applied in order to increase crop yield. The application of chemical fertilizers and pesticides is likely to increase due mainly to a surging demand for feedstock of energy crops. The increasing use of chemical-based fertilizers and pesticides would, however, intensify environmental impacts in terms of air, water and soil pollutions. With a view to achieve sustainable development goals, this paper suggests that the promotion of organic fertilizer from agricultural residues and organic pesticides such as wood vinegar would help utilizing agricultural wastes, lower cost of crop production and help reducing pollutions. This suggestion follows the philosophy of sufficiency economy developed by King Bhumibol Adulyadej of Thailand.

5. Conclusion

This paper assesses the implications of ethanol production on agriculture, water, energy and environment in Thailand. The assessment reveals that the selection of suitable crops for the purpose of ethanol production would have significant impacts on agriculture, energy, water and environment. The results show that the S100 scenario which produces ethanol from sugar cane only would be an attractive option for Thailand. This is because the adoption of this scenario would help slowdown an increase in crop cultivation area, irrigation requirement and crude oil imports. It would also help mitigating CO_2 emissions and provide high net energy gain. It would, however, require high crop production demand and fertilizer requirement. Therefore, the recommendation to adopt the S100 scenario should be viewed in terms of the trade-offs that will ensue while simultaneously pursuing multiple objectives. For example, in order to reduce 0.55 million ha of future land extension, 2,302 million litres of irrigation requirements and 338 million litres of crude oil imports, to decrease 856 thousand tonnes of CO_2 emissions and especially to achieve 26,111 TJ of net energy gain, the S100 scenario would contribute to a 23.3 million tonnes increase of crop production demand and would result in a 49 thousand tonnes increase of fertilizer requirement. It appears that high crop production demand and fertilizer requirement could become a challenge. In order to overcome this challenge and especially to achieve sustainable development goals, this research suggests the implementation of agricultural zoning, the advancement of crop species and ethanol conversion technology, and the promotion of organic fertilizer from agricultural residues and organic pesticides such as wood vinegar.

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