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Article

An Assessment of Thailand's Biofuel Development

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Abstract: The paper provides an assessment of first generation biofuel (ethanol and biodiesel) development in Thailand in terms of feedstock used, production trends, planned targets and policies and discusses the biofuel sustainability issues—environmental, socio-economic and food security aspects. The policies, measures and incentives for the development of biofuel include targets, blending mandates and favorable tax schemes to encourage production and consumption of biofuels. Biofuel development improves energy security, rural income and reduces greenhouse gas (GHG) emissions, but issues related to land and water use and food security are important considerations to be addressed for its large scale application. Second generation biofuels derived from agricultural residues perform favorably on environmental and social sustainability issues in comparison to first generation biofuel sources. The authors estimate that sustainably-derived agricultural crop residues alone could amount to 10.4×10^6 bone dry tonnes per year. This has the technical potential of producing 1.14–3.12 billion liters per year of ethanol to possibly displace between 25%–69% of Thailand's 2011 gasoline consumption as transportation fuel. Alternatively, the same amount of residue could provide 0.8–2.1 billion liters per year of diesel (biomass to Fischer-Tropsch diesel) to potentially offset 6%–15% of national diesel consumption in the transportation sector.

Keywords: biofuel; ethanol; biodiesel; Thailand; policy; sustainability; GHG emissions; second generation

1. Introduction

Asia is emerging as an important biofuel producer, with an annual average growth rate of 33% during 2005 to 2010 [1], based largely on first generation biofuels. Thailand is one of the major producers of biofuels in Asia, along with India, China, Indonesia and Malaysia. These countries have accelerated their biofuel production, thereby establishing themselves as global players in the biofuels market. Thailand, one of the rapidly growing Asian economies, has seen its primary energy consumption increase from 69.1 million tonnes in 2001 to 106 million tonnes in 2011 [2] and also increases in its oil imports. Between 2002 and 2007, the expenditure on imported energy (electricity, coal, natural gas, petrol and crude oil) increased from 360 billion Baht (8.37 billion US Dollars) to 912 billion Baht (24 billion US Dollars) [3].

The total energy consumption of Thailand's transportation sector is dominated by petroleum products, as shown in Table 1 [4]. Realizing the country's over-reliance on fossil fuel and imported energy, the Thai government initiated policies to diversify its energy resources and to develop, promote and utilize renewable energy sources [5]. Biofuels is one of the priority areas of national renewable energy policy of Thailand, particularly for the transport sector.

Table 1. Energy consumption in transportation sector by type (kt and %) in Thailand [4]. LPG, liquefied petroleum gas; NGV, natural gas vehicle.

Year	LPG	Unleaded Gasoline	Gasohol E10[a]	Gasohol E20[b]	Gasohol E85[c]	Jet Fuel[d]	Diesel	Biodiesel[e]	Fuel Oil	NGV	Electricity	Total
2007	667	4,080	1,314	-	-	4,031	11,228	543	1,539	208	5	23,615
	(2.8%)	(17.3%)	(5.6%)			(17.1%)	(47.5%)	(2.3%)	(6.5%)	(0.9%)	(0%)	(100%)
2008	904	2,706	2,505	22	-	3,789	7,586	3,260	1,593	659	5	23,024
	(3.9%)	(11.8%)	(10.9%)	(0.1%)		(16.5%)	(32.9%)	(14.2%)	(6.9%)	(2.8%)	(0%)	(100%)
2009	778	2,228	3,254	61	-	3,623	6,722	4,735	1,466	1,260	5	24,132
	(3.2%)	(9.2%)	(13.5%)	(0.3%)		(15%)	(27.9%)	(19.6%)	(6.1%)	(5.2%)	(0%)	(100%)
2010	794	2,204	3,157	101	1	3,852	7,054	4,462	1,366	1,597	6	24,594
	(3.2%)	(8.9%)	(12.8%)	(0.4%)	(0%)	(15.7%)	(28.7%)	(18.1%)	(5.6%)	(6.5%)	(0%)	(100%)
2011	1,073	2,265	2,962	165	7	4,150	11,179	595	1,028	2,036	9	25,469
	(4.2%)	(8.9%)	(11.7%)	(0.7%)	(0%)	(16.3%)	(43.9%))	(2.3%)	(4%)	(8%)	(0%)	(100%)

[a,b,c]Gasoline with Ethanol 10%, 20% and 85% by volume, respectively; [d]including aviation gasoline; [e]including diesel with palm oil 10% by volume and 5% bio-oil by volume, respectively.

The rapid growth of biofuel production in recent years in Thailand has been largely policy driven [6,7]. The Thai government has continuously formulated and modified its policies and plans to increase the production and consumption of biofuels. The current 10-year Alternative Energy Development Plan (AEDP) (2012–2021) targets the renewable energy share to increase from 7,413 kt in 2012 to

25,000 kt in 2021, *i.e.*, using renewable energy at 25% of total energy consumption by 2021, while biofuel is to replace 44% of oil consumption in the transport sector by 2021 [8].

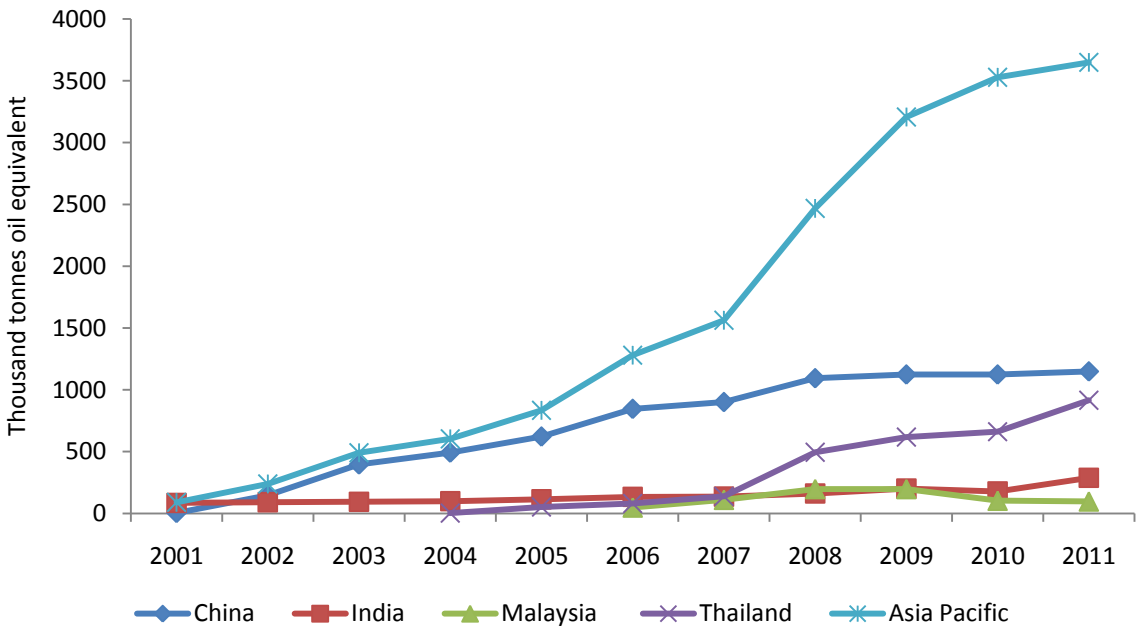
This article presents an overview of biofuel development in Thailand, an assessment of its biofuel potential, including estimation from agricultural residues, the role of policies in biofuel development and sustainability issues of biofuel production. The study is based on the review of available literatures, information and analysis of secondary data obtained from online sources, published reports and statistics. The paper is organized as follows. Section 2 discusses the biofuel production and potential of Thailand, particularly the production of first generation biofuels and the estimated potential of second generation biofuels from agricultural residues. Section 3 elaborates on the biofuel policies of Thailand. Section 4 discusses the sustainability aspects of first generation biofuels in Thailand, and Section 5 provides concluding comments.

2. Liquid Biofuel Production and Potential

2.1. Current Practices and Production of First Generation Biofuel

The production of biofuels in Thailand increased more than ten-fold within five years from 2005 to 2010, and the share of its production in the Asia Pacific region increased considerably from around 6% in 2005 to 19% in 2010 [9] (Figure 1). Ethanol is produced in Thailand mainly by the fermentation of molasses, a by-product of sugar manufacturing and cassava (also known as tapioca); while biodiesel is manufactured by transesterification of vegetable oil, mainly palm oil [10]. Ethanol blended with gasoline (petrol), is called gasohol.

Figure 1. Biofuel production in Thailand in the Asia Pacific [9].

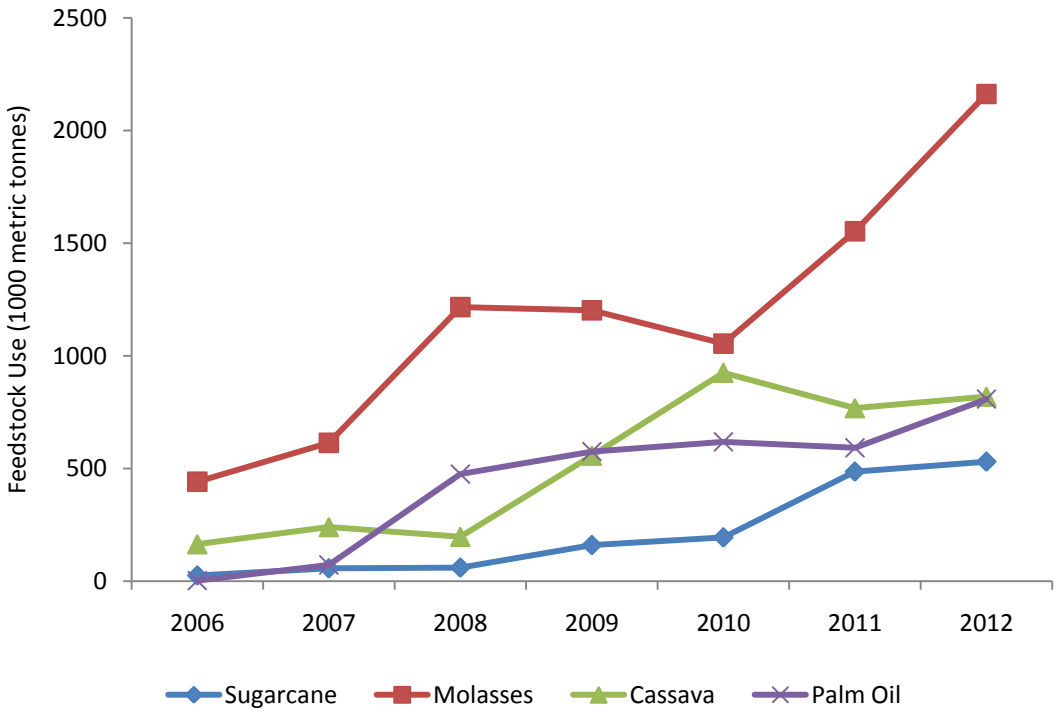


Sugarcane and cassava are the base crops for ethanol production, while palm oil and jatropha are used for biodiesel production. Sugarcane can be directly used to produce ethanol, whereas molasses, a by-product during sugar production, is fermented by yeast to produce ethanol [11]. Molasses-based

ethanol dominates ethanol production in Thailand, amounting to 1.17 million liters/day in 2011, up 54.5% from the 2010 average production of 0.76 million liters/day. This accounts for 80% of the country's total ethanol production [12]. Cassava-based ethanol production was 0.28 million liters/day in 2011, down 12.8% from the average 0.33 million liters/day in 2010, due to record high cassava prices [13].

The biodiesel production was favored by increases in the harvested palm crop area by 33,600 hectares in 2008, 48,700 ha in 2009 and an estimated 45,000 ha in 2010, compared to the annual target of 80,000 ha [12]. In spite of fluctuating Crude Palm Oil (CPO) yield, it is estimated that the CPO production should be enough to meet demand for use in biodiesel production [14]. The government is also promoting jatropha production by encouraging small farmers to grow it on small tracts of land without affecting their primary cash crops [3]. Figure 2 shows the quantities of various feedstocks for biofuel production in Thailand during 2006–2011.

Figure 2. Feedstock use for ethanol and biodiesel production in Thailand [14].



Note: The data for 2012 is an estimate [14].

The prioritization of sugarcane, cassava, oil palm and jatropha as feedstock is primarily based on their production potential, which is dependent on soil characteristics, climate, water availability, the farming system and farm management. Apart from the biophysical conditions, other socio-economic and environmental parameters, such as competing uses of biofuel crops, the threat to food security, economic risks to producers and small farmers, and the impact on land use and climate change are also considered (Table 2). Among the four basic feedstocks of biofuels, oil palm appears to have negative impacts on food security, farm practice issues, land use and marginalization of small farmers.

2.1.1. Ethanol Production

Although ethanol and biodiesel were promoted at the same time in Thailand, ethanol had penetrated the market successfully before biodiesel, because of its feedstock supply readiness [15]. The Thai government set the National Ethanol Program and Gasohol Strategic plan on December 6, 2003 with an ethanol production target of 1.0 million liter/day by the end of 2006 and of 3.0 million liters/day by the end of 2011. At the same time, the government also made provisions for excise tax incentives, investment promotion incentives to manufactures of ethanol and promotion for ethanol [16].

Table 2. Qualitative basis for prioritizing biofuel crops in Thailand [3]

	Social Risks		**Economic Viability**		**Environmental Impact**		
Feedstock	**Uses as Food, Feed and Fuel**	**Threat to Food Security**	**Risks to Primary Producers**	**Marginalization of Small Farmers**	**Changes to Existing Farming Practices**	**Land use Change and Potential for Conflicts**	**Favorable Impact on Climate Change**
Sugarcane	Competing	Little	Yes	No	No	No	No
Cassava	Competing	Little	No	No	No	No	No
Oil Palm	Competing	Considerable	Yes	Possible	Yes	Yes	Yes
Jatropha	Competing	Little	Yes	No	No	Yes	Yes

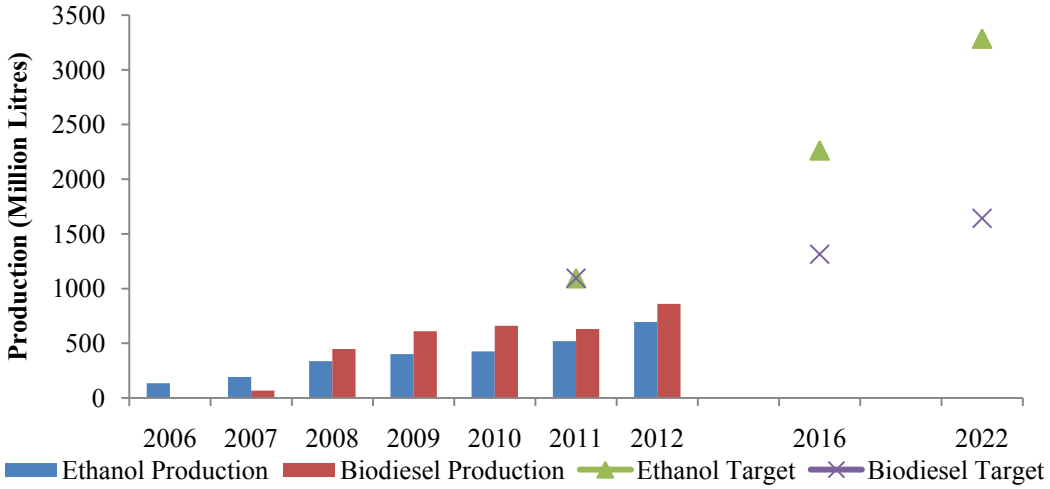
Ethanol production further increased in line with an upward trend in domestic gasohol consumption following its relatively cheaper price compared to regular gasoline. Unlike biodiesel, the government did not regulate compulsory use or sale of gasohol to substitute regular gasoline. Instead, gasohol prices remained 10%–15% below regular gasoline prices due to the excise tax, plus a price subsidy for E20 and E85 (a mixture of 85% ethanol and 15% premium gasoline) gasohol derived from the State Oil Fund and increasing the number of gasoline stations that could accommodate E20 gasohol [17].

Although ethanol production steadily increased over the years, it fell short of achieving the target production of 3.0 million liters/day in 2011. The actual production was only around 1.42 million liters/day (Figure 3). The consumers have substituted both gasoline and gasohol for the highly-subsidized liquefied petroleum gas (LPG) and natural gas vehicles (NGVs) [13]. However, ethanol consumption is likely to continue its growth, due to an increase in the number of E20 vehicles and E20 gasohol stations and the government's tax incentives for eco-car manufacturers, and as the price subsidy for E20 and the phase out of gasoline 91 from the market bear fruition.

2.1.2. Biodiesel Production

Thailand began a campaign to promote biodiesel production and consumption in 2005, but the initial production of biodiesel was insignificant until February 1, 2008, when the government adopted a policy requiring replacing all regular diesel with B2 biodiesel (a mixture of diesel with 2% biodiesel) [12]. Due to compulsory use of B100 (pure biodiesel) for B2 biodiesel production and increased B5 biodiesel demand, B100 production increased in 2009 and 2010.

Figure 3. Ethanol and biodiesel production in Thailand and 15 year Alternative Energy Development Plan (AEDP) target [8,14].



Note: The data for 2012 is an estimate [14].

Although, it is mandatory to regular diesel with biodiesel, the production has fallen short of the targeted production of 3 million liters/day in 2011 (Figure 3), as the actual production in 2011 was only around 1.72 million liters/day, mainly due to under-targeted planting of palm oil trees and unpredictable weather patterns [14]. However, biodiesel production is expected to grow significantly, due to the mandatory B5 rule (a mixture of diesel with 5% biodiesel) that came into force in January 2012 and growing diesel consumption.

The production trend for ethanol and biodiesel in Thailand has been increasing over the years. The number of registered biofuel plants (Table 3) has increased and so has their production efficiency. However, it is not clear whether the current trend is likely to meet the government's long-term target. Both ethanol and biodiesel production fell short of achieving their targeted production in 2011, and future compliance to the target not only depends on climatic conditions for crop yield, but also to a greater extent on the government's incentives, which affect the price difference, blending rates and consumption preference. According to Preechajarn and Prasertsri [14]:

- Although the production of ethanol is likely to increase with the operation of new ethanol plants, the consumption level of ethanol depends on whether the government is able to completely suspend all Octane 91 regular sales as planned.
- Five out of the total six refineries are not ready to shift from Octane 91 regular gasoline production to gasohol production by October 2012 and have been negotiating with the government to delay the plan until 2014 or else the government will have to subsidize the additional costs of imported petroleum products for gasohol production during their production restructuring process.
- In the case of biodiesel, although the number of biodiesel plants has remained constant since 2010, increased production of biodiesel is likely due to the compulsory mandate of B5 that came into force in January 2012.
- However, the productivity of fresh fruit bunches of crude palm oil is estimated to drop in 2012 as a result of dry conditions and a natural reduction in productivity a year after palm plantations reaped record yields in 2011.

2.2. Estimated Potential and Production of Second Generation Biofuel from Agricultural Residues

Thailand with its agriculture-based economy employs agricultural wastes and by-products for the generation of biofuels using commercially viable technologies. According to the Department of Alternate Energy Development and Efficiency (DEDE), the potential of electricity generation through biomass resources in Thailand is 4,400 MW and that for ethanol and biodiesel are estimated at 6–10 million liters/day and 4–5 million liters/day, respectively [18]. Although the study by DEDE does not specify which particular agricultural residues and by-products are utilized to estimate the potential, other studies indicate that bagasse (a by-product of sugar production) and rice husk (the remains from rice milling), with a total energy content between 560–620 PJ, are the major biomass used for energy production in Thailand [19,20]. We have estimated that by using 20% of available agricultural residues alone, there exists the potential to produce between 3.1–8.6 million liters/day of ethanol and 2.1–5.7 million liters/day of biomass to Fischer-Tropsch (F-T) diesel (Table 4). These values were derived by assuming a 365 day/year operation for biofuel (bioethanol and biomass to F-T diesel) production amounts in Table 4

Table 3. Number of registered biofuel plants in Thailand since 2006 [14].

Year	No. of approved/registered ethanol plants			No. of approved/registered biodiesel plants		
	No. of bio-refineries	Combined production capacity (million liters/day)	Capacity in use (%)	No. of bio-refineries	Combined production capacity (million liters/day)	Capacity in use (%)
2006	5	0.78	48	3	0.6	1
2007	7	0.96	54	5	1.3	14
2008	11	1.6	58	9	2.3	53
2009	11	1.7	65	14	5.4	31
2010	19	2.9	40	13	5.4	34
2011	19	2.9	50	13	5.4	32
2012	21	3.7	51	13	5.4	44

Note: The data for 2012 is an estimate [14].

Bioenergy from agricultural residues is acknowledged as possessing favorable sustainability benefits, notably greenhouse gas emissions (direct and indirect), net energy balances, water consumption and usage, food security and biodiversity [21–24]. Sustainable extraction rates of agricultural residues are influenced by edaphic factors (*i.e.*, soil type, soil fertility), land slope, tillage, cutting height, crop yield, weather and wind patterns [25–27]. For example, findings from a Canadian study show that the sustainable extraction rate of agricultural residues could range from 44% to 64% [28]. The actual amount of residues that could be sustainably extracted in Thailand would require further analysis to be determined by edapho-climatic studies. However, for this study, we assume a more conservative extraction rate of 20% for bioenergy applications, requiring balance for maintaining soil health and function and other utilizations in some sectors, such as animal fodder, *etc.*

In this study, we estimated the potential availability of sustainably-derived agricultural residues based on the information [29] to contribute to transportation fuels in Thailand from the following major crops—maize (*Zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), sugarcane (*Saccharum officinarum*), wheat (*Triticum aestivum*), cocoa (*Theobroma cacao*), coconut (*Cocos nucifera*) and coffee (*Coffea arabica*) (Table 4). Herein, we have quantified the technical potential for biofuel production via biochemical ethanol (enzymatic hydrolysis and fermentation) conversion, as well as diesel production (thermochemical syngas to Fischer-Tropsch diesel) (Table 4)

Our analysis shows that approximately 10.4×10^6 (10.4 million) bone-dry tonnes per year of agricultural residues to be potentially available for biofuel production (based on a 20% residue extraction rate).

Using the conversion factors [30], our estimation indicates that the potential for ethanol production per year from agricultural residues is in the range of 1.14–3.12 billion liters. This would be sufficient to offset 25.1%–68.5% of Thailand's (year 2011) national consumption of gasoline as transportation fuel (Tables 4 and 5). Alternatively, 0.8–2.1 billion liters per year diesel (biomass to F-T diesel) could be technically produced from agricultural residues to displace 5.7%–15.1% of its transportation diesel utilization in the year 2011 (Tables 4 and 5). Our estimated values are comparable to and consistent with a potential of 6–10 million liters/day of ethanol and 4–5 million liters/day of biodiesel calculated by the Department of Alternative Energy Development and Efficiency (DEDE) [18]. However, the likely growth and development of the cellulosic ethanol sector based on agricultural residue feedstock could result in increased competition over resources from other utilization, such as for animal fodder and cooking fuel. Previous work [31] recommends that targeted policies would be required to help achieve sustained access to available cheap feedstock, thereby ensuring long-term sustainably of the biofuel industry.

The government of Thailand is also promoting research and pilot projects for the development of second generation biofuels, generated from non-food feedstock, such as ligno cellulosic biomass from agricultural residues and waste. According to the Energy Policy and Planning Office and the Department of Alternate Energy Development and Efficiency, the total amount of crop and wood residues in Thailand in the year 2002–2003 was about 47.8 Mt, which would have been enough to replace 130% of the then gasoline consumption and 17% of Thailand's crude oil imports through biofuel production [32]. A facility using a molasses-based ethanol plant has opened a second production line using second-generation biofuels in the form of cane bagasse as a pilot project with the production of 10,000 liters/day bioethanol, which will be increased to its full capacity of 120,000 liters/day once fully developed [14].

However, full commercialization of second generation biofuels will be years away without significant additional government support. Unprofitable large-scale production due to relatively high production costs, the need for technological breakthroughs to make the processes more cost-and energy-efficient and additional development of a whole new infrastructure for harvesting, transporting, storing and refining biomass are some of the challenges for second generation biofuel production in Thailand [33]. The development and monitoring of large-scale demonstration projects and more investment in research, development, demonstration and deployment is needed to move forward to second generation biofuel production and to ensure it can be undertaken sustainably [33].

Table 4. Estimated technical potential of second generation biofuel production from agricultural residues in Thailand (Source: Authors).

Agricultural Residues[a]	Production (tonnes/ year)	Residue Type	Residue to Product Ratio (RPR)[b]	Moisture Content (%)[c]	Residue (wet tonnes/ year)	Residue (dry tonnes/ year)	Residue, 20% Sustainable Extraction (dry tonnes/ year)	[d]Biochemical Ethanol (million liters/year)		[e]Biomass to Fischer-Tropsch Diesel (million liters/year)	
								Low	High	Low	High
Maize	4.45×10^6	Stalk	1.5	15	6.68×10^6	5.68×10^6	1.14×10^6	125	341	85.2	227
Rice	3.16×10^7	Straw	1.5	15	4.74×10^7	4.03×10^7	8.06×10^6	886	2,420	604	1610
Sorghum	5.40×10^4	Stalk	2.62	15	1.42×10^5	1.20×10^5	2.41×10^4	2.65	7.22	1.8	4.81
Sugarcane	6.88×10^7	Bagasse	0.3	75	2.06×10^7	5.16×10^6	1.03×10^6	114	310	77.4	206
Wheat	1.10×10^3	Straw	1.2	15	1.32×10^3	1.12×10^3	2.24×10^2	0.0247	0.0673	0.0168	0.0449
Cocoa	7.63×10^2	Pods,Husk	1	15	7.63×10^2	6.49×10^2	1.30×10^2	0.0143	0.0389	0.0097	0.0259
Coconut	1.30×10^6	Shell	0.6	10	7.79×10^5	7.01×10^5	1.40×10^5	15.4	42.1	10.5	28
Coffee	4.90×10^4	Husk	2.1	15	1.03×10^5	8.74×10^4	1.75×10^4	1.92	5.24	1.13	3.5
Total							**1.04×10^7**	**1,140**	**3,120**	**781**	**2,080**

Note: [a]agricultural crop production based on year 2010 statistics information [34]; [b]RPR based on information in [35]; [c]moisture content based on information in [35]; [d]low biochemical enzymatic hydrolysis ethanol based on a conversion factor of 110 l/dry t; high biochemical enzymatic hydrolysis ethanol based on conversion a factor of 300 l/dry t [30]; [e]low thermochemical syngas-to-diesel using the Fischer-Tropsch process and based on a conversion factor of 75 l/dry t; high thermochemical syngas-to-diesel using the Fischer-Tropsch process and based on a conversion factor of 200 l/dry t [30].

Table 5. Estimated biofuel potential in relation to Thailand's transportation fuel consumption. F-T, Fischer-Tropsch (Source: authors).

	Potential feedstock sustainably extracted (dry million tonnes/year)[a]	Estimated bioethanol production (billion liters/year)	Percentage of national (year 2011) gasoline consumption it could potentially displace	Estimated biomass to F-T diesel production (billion liters/year)	Percentage of national (year 2011) diesel consumption it could potentially displace
Agricultural residues (year 2010 data)[a]	10.4	1.14–3.12	25.1%–68.5%[b]	0.8–2.1	5.7%–15.1%[c]

Note: [a]in order to maintain soil health and minimize any potential competition for the resource from other sectors, only 20% of available agricultural residues is used in this estimation; [b]ethanol production amount was compared with gasoline on an energetic basis. The year 2011 national gasoline consumption in the transportation sector of 2.27×10^6 t (Table 1) was used for comparison; [c]the year 2011 national diesel consumption in the transportation sector of 11.2×10^6 t (Table 1) was used for comparison.

3. Biofuel Policy in Thailand

The main policy for promotion and development of renewable energy sources was given by the Alternative Energy Development Plan (AEDP) (2008–2012). The plan set an ambitious 15-year target to increase the share of the alternative energy mix to be 20% of the country's total energy demand by 2022 and the share of biofuel in it to be around 4.1%. Based on the AEDP, the 15-year Ethanol Development Plan set production targets of bioethanol at 3.0, 6.2 and 9.0 million liters/day for the short-term (by 2011), medium-term (by 2016) and long-term (by 2022), respectively. Similarly, the 15-year Biodiesel Development Plan (2008–2022) set production targets of biodiesel at 3.0, 3.6 and 4.5 million liters/day for the short-term (by 2011), medium-term (by 2016) and long-term (by 2022), respectively [8]. In December 2011, the government modified its old 15-year AEDP (2008–2022) with the current 10-year AEDP (2012–2021), which is set to increase the share of renewable and alternative energy from 20% to 25% by 2021. The driving force behind the AEDP was to reduce oil imports, strengthen energy security, enhance the development of alternative energy industries and conduct research and develop renewable energy technologies [8].

The new 10-year AEDP (2012–2021) is set to increase ethanol consumption to 9.0 million liters/day by 2021, unchanged from the old 15-year plan (2008–2022). To make the new plan operational, the government devised strategies and incentives at both the supply and demand sides, as follows [8]:

(1) On the production side, the plan focuses on increasing the national average production of cassava and sugarcane and promotes other alternative feedstock commercially.

(2) On the demand side, the government plans to:

- Terminate using Octane 91 regular gasoline by October 2012;
- Subsidize E20 gasohol from the State Oil Fund at 3.0 Baht/liter (36 US cents/gallon) cheaper than Octane 95 gasohol and encourage the extension of E20 service stations;

- Support the manufacturing of eco-cars and E85 cars in general, by reducing the excise tax to car makers by 50,000 Baht per each E85 car (about US$ 1,600/vehicle) and 30,000 Baht (about US$ 950/vehicle) for each eco-car;
- Support the manufacture of eco-cars (E20 vehicles) and flex-fuel vehicles (FFV), which are compatible with E85 gasohol, by reducing the excise tax for automobile manufacturers by 50,000 Baht/vehicle (about US$ 1,600/vehicle) for FFV and 30,000 Baht/vehicle (about US$ 950/vehicle) for eco-cars;
- Support research and development; encourage gasohol usage through public campaigns.

The new 10-year Biodiesel Development Plan revised its target for biodiesel consumption from the previous 4.5 million liters/day to 5.97 million liters/day by 2012. The government's strategies and incentives at both the supply and demand sides are [8]:

- Expansion of the oil palm area and increasing the production capacity of crude palm oil above 3.05 million tonnes/year;
- Compulsory biodiesel blending requirements (currently, B5) and managing the proportion of biodiesel blend relevant to the domestic palm oil production and plan to increase the blending share up to 7% in diesel.

Table 6. Price structure of petroleum products in Bangkok (as of November 5, 2012) [36].

Unit: Baht/liter	Premium Gasoline (Octane 95)	Regular Gasoline (Octane 91)	Gasohol			B3 Biodiesel
			E10 (Octane 95)	E20 (Octane 95)	E85 (Octane 95)	
Ex-refinery Factory Price	23.1596	22.7253	23.0134	22.7818	20.4314	25.1665
Excise Tax	7.0	7.0	6.3	5.6	1.050	0.0050
Municipal Tax	0.7	0.7	0.63	0.56	0.1050	0.0005
State Oil Fund	8.0	6.7	2.3	- 2.3	- 11.80	0.70
Conservation Fund	0.25	0.25	0.25	0.25	0.25	0.25
VAT and Market Margin	8.3904	5.2747	4.2366	4.3881	11.0436	3.6679
Retail Price	47.50	42.65	36.73	31.28	21.08	29.79

Note: Exchange rate 30.87 Baht/ US Dollars. VAT, value added tax.

Table 6 shows the current price structure of petroleum products in Thailand, showing the preferential tax to promote biofuels in Thailand. Both excise and municipal tax for biodiesel and gasohol is lower compared to that of conventional gasoline, with further reduction for increased blending types. Moreover, the contribution to the state oil fund from conventional gasoline subsidizes biofuels, particularly E20 and E85 blends. These set of incentives make the retail price (Baht per liter) of both ethanol and biodiesel less than that of conventional gasoline.

4. Sustainability of First Generation Biofuel Production in Thailand

Biofuels are an important alternate source of energy, but their impact on society and the environment, besides its oil import reduction capability, must be assessed carefully if they are to be considered as a sustainable resource. In line with the World Commission on Environment and

Development definition of sustainable development, which is to meet the needs of present without compromising that of future generations [37], the sustainability dimension of biofuels should consider potential tradeoffs between food production and fuels, as well as the need to apply a broad systems perspective [38]. Measuring the sustainability of biofuel is equally difficult and depends on factors, such as the definition of system boundary, the reference scenario and any assumptions taken regarding the impact of the results [39].

The sustainability of biofuels, *i.e.*, the environmental, social and economic impacts, are usually assessed using suitable criteria and indicators. At the international level, initiatives, such as The Roundtable on Sustainable Biofuels (RSB), The Roundtable on Sustainable Palm Oil (RSPO), Global Bioenergy Partnership (BGEP) and EU Renewable Energy Directive, *etc.*, have developed standards and criteria that focus on environmental impacts, such as greenhouse gas (GHG) emissions, land use change, social impacts, such as food security, and economic impacts, such as economic viability for sustainable biofuel production [40], to assess the sustainability of biofuels.

At the national level, only a few countries have implemented sustainability components into the production requirement and lifecycle standards. The USA, Brazil and some European countries (Germany, the UK and the Netherlands) have also developed and implemented standards, policies and initiatives that deal with the sustainability aspect of biofuel production and consumption. For example, the Renewable Fuel Standard (RFS) of the United States, amongst others, deals with GHG sustainability and has specific provisions on the GHG reduction target and GHG savings, which biofuel production should meet [27,41]. Similarly, the Social Fuel Seal program of Brazil deals with social sustainability by providing incentives for the producers to purchase (10% to 30%) of their feedstock from small holder farmers [42].

When standards and regulations directly assessing biofuel sustainability are non-existent, policies and plans through incentives set constraints to ensure that some elements of biofuel sustainability are addressed. For example, the AEDP plan of Thailand mentions that to promote biodiesel production from the supply side, palm trees will be grown in appropriate areas not competing with any food crops and priority will be given to promote new fuel (e.g., from jatropha, microalgae) for future diesel substitution [8]. The following section thus discusses the sustainability issues on Thailand's biofuel development efforts in terms of environmental sustainability, socio-economic sustainability and food security.

4.1. Environmental Sustainability

On a positive note, biofuels are an alternative to fossil fuels. Generally, sustainably-derived biofuels are considered carbon neutral, as the carbon released from burning it is removed from the atmosphere by growing the plant. The advantage of biofuels over fossil fuels is the possibility of making them carbon negative, and only carbon-negative fuel can reduce the build-up of carbon in the atmosphere and its greenhouse effect [43]. According to Quadrelli and Petersons [44], the greenhouse gas reduction of ethanol with respect to conventional gasoline, on a well to wheel basis, is about 13% when ethanol is derived from grain and up to 90% for sugarcane-based ethanol. Similarly, when compared to conventional petroleum diesel on a well to wheel basis, oil seed-derived biodiesel leads to greenhouse gas emission reductions of 40% to 60%. Therefore, use of biofuels as an alternative energy

source in the transport sector is a positive step towards reduction of GHG emission to address the global warming issue.

However, the emissions generated from indirect land use change due to biofuel production can counteract the greenhouse emissions savings achieved from biofuel use. A study by Reijnders and Huijbregts [45] on the lifecycle emission of greenhouse gases associated with rapeseed-based biodiesel showed that biodiesel performs worse than conventional diesel (as the biogenic emissions exceeded the 1.2 kg CO_2 equivalent of kg^{-1} biodiesel) when one considers not only fossil fuel inputs, but also N_2O emissions and changes in carbon stocks of agro-ecosystems linked to cultivation of biofuel crops.

Biofuel production is also controversial for its potential to negatively affect land use, natural habitat and biodiversity and to displace valuable food production. Studies indicate that depending on the method of conversion, it could take between 75 to 93 years for the carbon emissions saved through the use of biofuel to compensate for the carbon lost through forest clearing. If the original habitat was peatland, the carbon balance would take more than 600 years and planting oil palms on grassland would lead to removal of carbon within 10 years [46].

A study by Silalertruksa and Gheewala [47] on the GHG performance of bioethanol in Thailand observed that there are wide ranges of GHG emissions depending on the production environment, such as types of fuel used in ethanol plants, crop productivity and approaches to manage the crop residues and, especially, if direct land use change (LUC) is included in the system boundary. According to them, if the changes of tropical forest land (FL) and/or grassland (GL) to cropland (CL) are included in the analyses, GHG emissions can possibly increase from 1 to 10 times as compared to cases where LUC is excluded. The conversion of tropical forest to cropland results in the highest GHG emissions, due to the CO_2 emissions from the loss of carbon stock in above-and below-ground biomass and non-CO_2 emissions from burning biomass as part of the first clearance of land.

Even more important and controversial is the issue of indirect land use change (ILUC), which occurs when the diversion of crops to produce biofuels causes farmers to respond by clearing non-agricultural lands to replace the displaced crops [48]. The indirect land use impact of ethanol production in Thailand analyzed through the displacement of the cultivated area of other crops (sugarcane) in the country and reduced sugar production showed that ILUC could result in a larger impact on the emission of GHGs, mainly due to the change of above-ground and below-ground biomass and the soil carbon stock [49].

The production of biofuels can also significantly impact water resources as a result of land use change, which can affect water runoff, ground water recharges, water availability and the local climate by altering the levels of evapotranspiration from the land [50]. In a study to evaluate a potential impact of biofuel production on the hydrology of a small watershed, Khlong Phlo in Thailand, through a water footprint revealed that although oil palm expansion has a negligible alteration in evapotranspiration (0.5 to 1.6%) and water yield (−0.5% to −1.1%), nitrate loading (1.3% to 51.7%) to the surface water can increase and the expansion of cassava and sugarcane can decrease evapotranspiration (0.8 to 11.8%) and increase water yield (1.6 to 18.0%), thereby increasing sediment (10.9 to 91.5%), nitrate (1.9 to 44.5%) and total phosphorus (15.0 to 165.0%) [51]. Thus, the land use change for biodiesel production had the potential to affect both the water quality and water balance components.

4.2. Socio-Economic Sustainability

Another key element of biofuel is the impact of biofuel production in the social-economic conditions, including the employment generation potential and the effect on GDP and trade balance. The impact of biofuel development in socio-economic development of Thailand based on the 15-years AEDP target for 2022 showed that employment generation would be around 238,700–382,400 person-years and 150 million dollars in additional GDP, imported goods worth 1,583 million dollars with 2,547 million dollars of imports would be saved compared to petroleum fuels (Table 7) [52].

Table 7. Socio-economic impact of biofuel production in Thailand [52].

Biofuels	Employed Persons (Person-years) of Biofuels Production (per TJ of biofuels)			GDP Effects of Biofuels (k$ TJ^{-1} of biofuels)			Import Effects of Biofuels (k$ TJ^{-1} of biofuels)			
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Difference (import of biofuel - import of gasoline/diesel)
Cassava Ethanol	3.3	2.2	5.5	12	11	23	8	21	29	−31
Molasses Ethanol	0.5	4.8	5.3	11	8	19	5	13	18	−41
Sugarcane Ethanol	4.0	1.7	5.7	13	16	28	18	32	49	−10
Palm Biodiesel	2.0	1.5	3.5	13	5	17	5	9	15	−46

Although the Thai government has been promoting the use of biofuels to reduce the consumption of fossil fuel, there are, however, concerns over promoting biofuels because of the high costs involved in its production and the need for the government to provide subsidies to make the fuel affordable. Thailand also has a lower unit of production costs, which could be further lowered with increases in yields and technology improvements. For example, the production cost of sugar-based ethanol in Thailand is approximately 0.27 US$/liter (2005 price), whereas the cost of wheat/sugar beet ethanol in EU ranges between 0.44–0.51 US$/liter (2005 price) [53]. This is mainly due to the relatively lower cost of feedstock production (as feedstock costs account from 58% to 65%) and cheap skilled and abundant labor [53].

Biofuel production can also undermine land tenure and labor rights, where these are not respected. For example, forest areas might be exploited for plantations without consideration for its rightful owners. However, independent smallholder oil palm growers constitute the vast majority of growers in Thailand, and large estates of oil palm plantations are rather rare, in comparison to neighboring Malaysia and Indonesia. Therefore, Thai oil mills strongly depend on purchasing fresh fruit bunch (FFB) from independent oil palm growers, mostly smallholder farmers, leaving the farmers in a good bargaining position with fewer chances of land rights and security issues [54].

4.3. Food Security

The expansion of the biofuel market has created many trade-offs, new linkages and also competition between the different economic sectors, such as agriculture and energy [55]. Biofuels may help to avoid the risk to energy security, but at the same time, introduce risks to food security. Over 93% of palm plantations are situated in southern Thailand, and these rice plantations are likely to be reduced as a result of oil palm plantations [56].

According to the study by Salvatore and Damen [57], the effect of implementing the AEDP biofuel targets of Thailand will result in an increase in the price of these crops and food crops in general. Analysis of the impact of biofuel development on households (especially the poor), due to a general rise in the price of agriculture goods (especially food crops) showed that, following a rise in food prices, the incidence of poverty increases in all regions of Thailand under the vast majority of scenarios tested, the rice-only growing farmers being hit the hardest, as poorer households would need to spend a large proportion of their (slightly greater) income on more expensive food.

However, at a macro level, increased food prices could affect the Thai economy in many ways. On the one hand, domestic prices of food could be pushed upwards as domestically produced food products progressively substitute for imports. On the other hand, the higher price could provide incentives for supporting industries to increase the output of products and services, such as fertilizer, energy, transportation, retail services, *etc.* This increase in output among agricultural and supporting sectors could flow on to the broader economy and increase national income [57].

To evaluate the security of the feedstocks supply for long-term bio-ethanol production in Thailand, Silalertruksa and Gheewala [58] conducted an assessment based on the policy targets set by the government, *i.e.*, 3.0, 6.2 and 9.0 million liters/day by year 2011, 2016 and 2022, respectively, for bio-ethanol production. Feedstock supply potentials were analyzed based on three scenarios of yield improvement, such as low yield improvement, moderate yield improvement and high yield improvement. The results showed that based on surplus availabilities and the net feedstock balances, the total capacity of bio-ethanol production in Thailand in 2022 could vary from 3.6 to 17.6 million liters of ethanol/day. Only the high yields improvement scenario would result in a reliable and sufficient supply of molasses, cassava and sugarcane to satisfy the long-term demands for bio-ethanol and other related industries.

Therefore, to enhance the long-term security of feedstock supply for sustainable biofuel production in Thailand, improved yields of existing feedstocks and promoting production of biofuel derived from agricultural residues are critical. Since Thailand is among the world's largest producers and exporters of many food products (rice, sugar, corn, *etc.*), the issue of food security not only impacts domestic supply, but also the global food supply chain [59]. Therefore, it becomes imperative for the government to identify the risks of changes of food price and carefully weigh the real costs and benefits of biofuel production. Many of the problems associated with the risks posed to food security by biofuel crops can be addressed by the production of biofuels through agricultural residues and non-food crops. Significant research, development, investment and pilot demonstration projects are required to further commercialize the deployment of such second generation biofuels.

4.4. Sustainability Assessment

In order to determine the net cost and benefit of the biofuels, a lifecycle assessment (LCA) can be used to assess the sustainability of fuel products [22]. It can assess the impacts in the complete lifecycle of the fuel product, from raw material production and extraction, processing, transportation, manufacturing, storage, distribution, use and disposal and, hence, is a valuable tool in assessing the sustainability of the fuel products [39]. In the context of biofuel, the system boundary is determined as "well to tank", "tank to wheel" or "well to wheel", and the results of the assessment are usually compared with fossil fuel or alternative biofuel product [39]. A LCA study of palm biodiesel production in Thailand indicates that although biodiesel can lead to a GHG reduction of about 46%–73% as compared to conventional diesel, the production and utilization of biodiesel also leads to emissions of other products and contaminants, which affect the environment in terms of photochemical oxidation, toxicity, acidification, eutrophication, global warming, *etc.* [60].

In spite of the above mentioned environmental impacts, another important aspect to be considered while evaluating the lifecycle cost of biofuel production is the externalities that are internalized through biofuel compared to conventional fuel. Silalertruksa *et al.* [61] evaluated the influence of externalities on the cost performance of various palm oil biodiesel blends (B5, B10 and B100) when internalized into their respective production cost for the case of Thailand through the lifecycle costing approach. The key environmental burdens considered included land use, fossil energy resources depletion and air pollutants emissions, *i.e.*, CO_2, CH_4, N_2O, CO, NO_x, SO_2, VOC and PM10, and the results showed that environmental costs contributed to 34% of the total costs of conventional diesels. In comparison to diesel and for the same performance, the total environmental cost of biodiesel-based palm methyl ester (PME) was about 3%–76% lower, depending on the blending levels. Therefore, an important benefit of biofuel production is the lower environmental externalities it causes in comparison to regular gasoline.

5. Conclusion

Biofuels can potentially provide several benefits to Thailand, particularly in energy diversification, energy independence, rural development, income generation opportunities for farmers and poverty alleviation. Due to concerns mainly related to energy security, the Thai government has promoted the production and utilization of biofuels through various policies, plans and initiatives. Ambitious short-term, medium-term, long-term targets have been put in place, blending mandates have been enforced and several financial and non-financial incentives have been devised to producers and consumers. As a result, ethanol and biodiesel production have increased over the years, albeit not to the targeted level, and Thailand is undoubtedly one of the regional leaders in the biofuel market.

However, biofuel development in Thailand is unlikely to remain non-contentious. Although initially promoted to address energy security, first generation biofuel has now been increasingly linked to other social and environmental issues, like food security and land use change impacts. On the one hand, many studies have demonstrated tangible benefits of biofuel to Thailand in terms of GHG reduction, increased job creation, reduction of imports, increased GDP contribution, *etc.* On the other hand,

impacts due to land use change and vulnerability to food security, particularly to the poor, are worrying.

Following the increased trajectory of biofuel production and the government's interest and support for biofuel, the production and consumption of biofuels in Thailand is likely to increase in the future. There is reason for concern for whether the fast development of first generation biofuel industry causes an increase in already scarce resources. In the absence of biofuel-specific sustainability standards and initiatives, the government needs to carefully examine the tradeoffs concerning food security and environmental repercussion of biofuel development. The second generation of biofuels using agricultural residues and wastes presents an opportunity to deal with the existing issue of food insecurity and environmental damage. This study has shown that an annual availability of 10.4 million bone dry tonnes of agricultural residues could potentially yield 1.14–3.12 billion liters per annum of cellulosic ethanol or, alternatively, 0.8–2.1 billion liters per year of diesel (biomass to Fischer-Tropsch diesel) in Thailand. This could potentially displace 25%–69% or 6%–15% of Thailand's transportation fuel consumption of gasoline and diesel, respectively. This will require dealing with existing barriers of second generation biofuel and considerably more investment in research, development, demonstration and deployment.

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Conflict of Interest

The authors declare no conflict of interest.

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