CHAPTER 1

INTRODUCTION

1.1 Introduction

Bioethanol has the potential to reduce a country's dependence on imported oil, to ensure diversity of energy sources, to increase the availability of renewable energy sources, and to address global environmental issues (Smith, 2008). In recognition of the potential benefits of the production and use of bioethanol, the Thai government has drawn up the Alternative Energy Development Plan (AEDP) aiming to increase the use of bioethanol in Thailand with the target for ethanol produced from sugarcane and cassava of 9 million liters by 2022 (Damen, 2010).

However, there are several barriers that need to be overcome before Thailand can establish a large-scale bioethanol industry to achieve the AEDP's bioethanol target. This includes environmental barriers, such as the availability of land for the cultivation of bioethanol feedstock, greenhouse gas (GHG) emissions, and water scarcity. This study focuses on these environmental barriers and aims to determine the potential for bioethanol production from sugarcane and cassava in Thailand looking into the future until the year 2026.

Presently, carbon footprints from activities and products have gained greater interest from the public and private sectors as the governments, businesses and individuals become increasingly aware of the adverse impacts of the climate change and are more concerned about their own actions. In addition, freshwater scarcity is becoming an important subject on environment agendas, and with it the water footprint is gaining recognition. This footprint, which is to study the hidden links between human consumption and water use and between global trade and water resource management, has had a promising start, with a strict definition and methodology (Ercin,A.E and Hoekstra A.Y., 2012). Freshwater is essential for human

human and ecosystems. Currently, a fifth of the world's population or around 1.2 billion people live in areas of physical water scarcity and a further 500 million people are approaching this situation (Jeswani, H. K., & Azapagic, A., 2011).The pressure on the freshwater resource is expected to increase significantly with the climate change as well as with some measures for reducing the emissions of greenhouse gases, e.g. cultivation of biofuel crops (Falkenmark, M., 2008).

Nevertheless, the rapid rise in the sugarcane and cassava cultivation and bioethanol production has caused more GHG emission, land use change, and greater water consumption. Current water management practices are probably not effective enough to cope with the impacts of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems. In several locations, water management fails to cope with current climate variability so much so that large flood and drought ensue (Bates, B.C et al., 2008). Therefore, Thailand should incorporate the information on current climate variability in the formulation of policy on water resource management and thereby would be better prepared for the eventual impacts of climate change in the long term.

Based on the aforementioned, the first objective of this research work is to assess the CF and WF of bioethanol production from sugarcane and cassava throughout the entire life cycle. The second aim is to examine seven different scenarios for the potential of bioethanol production from sugarcane and cassava in Thailand between 2013 and 2026. All the scenarios incorporate three key elements that impact the availability of land for the production of sugarcane and cassava, greenhouse emission, and water resource for the production of bioethanol. The results from this study could be used to form the guidelines for Thai policy-makers to pursue the option which has the least impact on the land use, GHG emission and water resource so as to achieve the sustainability of bioethanol production.

1.2 Literature Review

1.2.1 Bioethanol production

Bioethanol is the most common biofuel, accounting for more than 90% of total biofuel usage. Conventional production is a well-known process based on enzymatic conversion of starchy biomass into sugars, and/or fermentation of 6-carbon sugars with final distillation of ethanol to fuel grade. Ethanol can be produced from many feedstocks, including cereal crops, corn (maize), sugar cane, sugar beets, potatoes, sorghum and cassava. Coproducts (e.g animal feed) help reduce production cost. If sugarcane is used, conversion into sugar is easier. Crushed stalk (bagasse) can be used to provide heat and power for the process and for other energy applications. The world’s largest producers of bio-ethanol are Brazil (sugar-cane ethanol) and the United States (corn ethanol) as shown in Figure 1.1. Ethanol is used in low 5%-10% blends with gasoline (E5, E10) but also as E-85 in flex-fuel vehicles. In Brazil, gasoline must contain a minimum of 22% bioethanol.

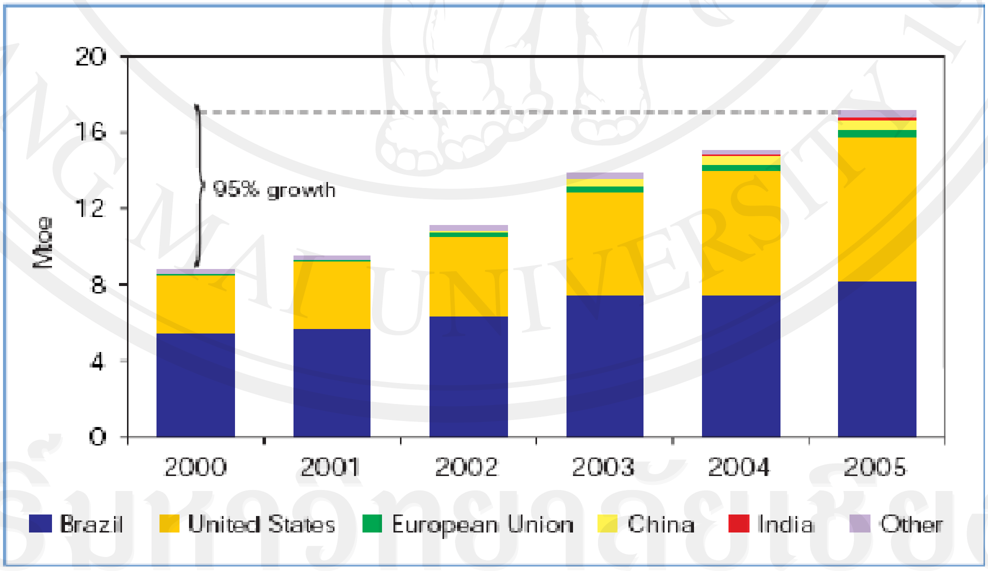


Figure 1.1 World production of bioethanol’s
(Source: IEA, 2007).

Biofuel (bioethanol and biodiesel) have been part of the energy discussions for decades. However, over the past few years, discussion and action has increased with rises in crude oil prices. But in addition to prices, there are a number of reasons why governments are showing interest in biofuels even when subsidies are needed to make them commercially viable. These include energy security, concerns about trade balances; desire to decrease GHG emissions and potential benefits to rural livelihoods (C. de Fraiture et al., 2008).

(1) Energy security—The volatility of world oil prices, uneven global distribution of oil supplies (75% in the Middle East), uncompetitive structures governing the oil supply (i.e. the OPEC cartel) and a heavy dependence on imported fuels leave oil importing countries vulnerable to supply disruption. Recent interruptions in oil supply from Russia to Belarus because of political disagreements acutely illustrate this vulnerability. Biofuels are often seen as part of a strategy to diversify energy sources to reduce supply risks.

(2) Trade balance—Poor oil importing countries spend a large part of their foreign currency reserve to buy oil. Producing biofuels to substitute oil imports helps reduce the oil bill.

(3) GHG emission reduction—Many studies indicate that the use of biofuels reduces GHG emission compared with fossil fuels though the extent of reduction is disputed and depends on crop and production technology (Sims et al., 2006; Farrell et al., 2006). Some studies indicate that biofuel production generates more GHG than it saves in burning.

(4) Rural development and income generation—Biofuels generate a new demand for agricultural products, creating jobs in rural areas and increases in farmer income through higher commodity prices.

1.2.2 Overview of bioethanol production in Thailand

Ethanol is a kind of alcohol derived from plant fermentation to convert starch from plant to sugar then converting sugar to alcohol, after purifying it to 95 percent alcohol by distillation it is called ethanol. Ethanol for blending with oil to fill in engine has its purity from 99.5% by volume which is capably used as fuel. In

Thailand, ethanol is used to blend with gasoline for fuel use or so-called as gasohol (DEDE, 2012).

Gasohol production in Thailand was originated by Royal initiative of our King Bhumibol in1985. Gasohol production for alternative energy use was initiated in a study of royal project byproducing ethanol from sugarcane. After that the public and private started alerting to co-develop and test with the engines. Even it was not widespread used until the world oil price increased sharply in 2003; the government has turned to seriously push up producing and consuming of gasohol. The target is set for ethanol promotion at 2.4 ml/day to substitute MTBE in gasoline 95 and to replace oil content in gasoline 91 by 2011 (DEDE, 2012).

1.2.2.1 Raw Materials for Bioethanol Production

Since Thailand is an agricultural country, thus various kinds of energy plants can be taken as feedstock or raw materials to produce ethanol, e.g. sugarcane, cassava, corn, sweet sorghum, etc. However, when considering the economic cost effectiveness, the main raw materials in present ethanol industry are molasses and cassava.

The first, Molasses is a by-product from sugar refining process. By crushing a ton of sugarcane would derive 45 kg of molasses or 4.5 percent of sugarcane feeding into the process. The second, Cassava is grown mainly in Nakhon Ratchsima, Kamphengphet, SaKaew, Chaiyapoom, Chachoengsao. The Agricultural Economic Office had estimated the cassava yield in 2009 at 29.60 million tons which will be processed to cassava chips, pellets and starch for local consumption and export. The rest as excessive products are used to produce the ethanol for 1.25 million tons and capable producing of ethanol at 0.58 million tons.

1.2.2.2 Bioethanol Production

In 2012, the number of operating ethanol plants will likely increase to 21 plants with total production capacity of 3.715 million liters/day, up from 19 plants with production capacity of 3.065 million liters/day in the previous year. The new ethanol plants will be cassava-based plants. There are six new cassava-based ethanol plants due for completion within 2012 with total production capacity of 2.220 million liters/day. Two of these are expected to operate as export plants. One manufacture has an export contract of 100.0 million liters/year with a partner in China for delivery in October 2012 onwards. In 2012, total ethanol production is expected to increase to 695 million liters (1.9 million liters/day), up 33.7 percent from 520 million liters (1.4 million liters/day) in the previous year (P. Sakchai and P. Ponnarong., 2012).

1.2.3 GHG emissions of bioethanol

Bioethanol have made a significant contribution to the reduction of greenhouse gas (GHG) emissions, substituting fossil fuels, gasoline and fuel oil, respectively (Davis, SC., 2009). However, bioethanol are used in the operations of planting, harvesting, transportation and processing of the feedstocks, resulting in GHG emissions. Energy and GHG balances are required to evaluate the net effects during the complete well-to-wheel cycle of ethanol, i.e. ethanol production from sugar cane and its use as fuel in the transport sector. To facilitate the comparison with other studies, the GHG data are presented as CO_2 equivalent emissions (CO_{2}-eq.). Growing with the development of process technologies involved in ethanol production evaluations of ethanol’s potential to substitute in the country have been conducted by group of researchers.

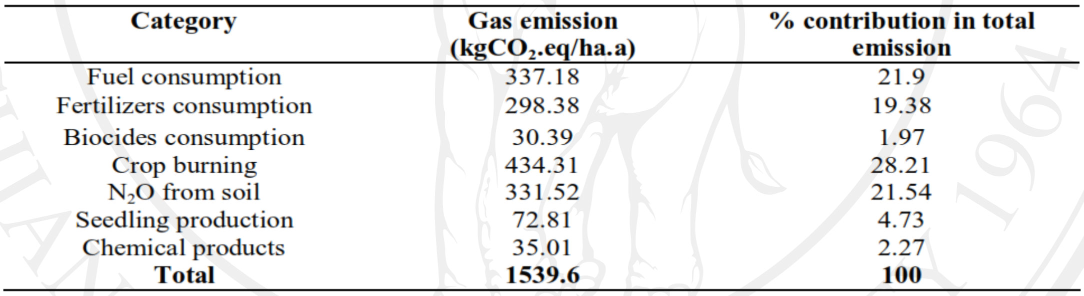
One of those studies available that assess GHG emissions in the production and use of fuel ethanol was conducted by Macedo, I. C., et al. (2004) in Brazil which two cases have been considered in the evaluation of energy flows: Scenario 1 based on the average values of energy and material consumption and Scenario 2 based on the best values being practiced in the sugar cane sector (minimum consumption with the use of the best technology in use in the sector). In both Scenarios the balance is referred to one metric ton of cane (TC). Under these conditions, the results obtained for GHG emissions have been divided into two groups: emissions derived from the use of nonrenewable energy (diesel and fuel oil) and emissions from other sources (cane trash burning, fertilizer decomposition). For the first group the calculated values were 19.2 kg CO_2eq./TC and 17.7 kg CO_2eq./TC for Scenarios 1 and 2, respectively, while the values determined for the second group were 12.2 kg CO_2 eq./TC for both Scenarios. The emissions avoided due to the substitution of ethanol for gasoline and surplus bagasse for fuel oil, deducting the above values, gives a net result of 2.6 and

2.7 t CO_2eq./m^3 anhydrous ethanol and 1.7 and 1.9 t CO2 eq./m^3 of hydrous ethanol, for Scenarios 1 and 2, respectively.

The International Energy Agency (IEA, 2007) was said about production of ethanol from sugar cane (Brazil) was energy-efficient since the crop produces high yields per hectare and the sugar is relatively easy to extract. If bagasse was used to provide the heat and power for the process, and ethanol and biodiesel was used for crop production and transport, the fossil energy input needed for each ethanol energy unit would can be very low compared with 60%-80% for ethanol from grains. As a consequence, ethanol well-to wheels CO_2 emissions can be as low as 0.2-0.3 kgCO_2/litre ethanol compared with 2.8 kg CO_2/litre for conventional gasoline (90% reduction). Ethanol from sugar beet requires more energy input and provides 50%60% emission reduction compared with gasoline.

Garcia, J.C.C. and Sperling, E.V. (2011) were the estimation of greenhouse gas emissions during the industrial process of ethanol production from sugarcane crops. The research was carried out in the period 2008-10 in the State of Minas Gerais, Brazil. Estimation of the environmental magnitude of the components of bioethanol production was performed by consulting technical literature and by a field survey which involved the visit to selected distilleries, together with the application of questionnaires related to the whole ethanol production process. Total emission of CO_2eq (representing the whole amount of greenhouse gases: CO_2, CH_4 and N_2O) could be estimated in 1540 kg/ha.year. The result of this study found that gaseous emissions from burning activity in sugarcane plantations have been estimated by the corresponding factors for agricultural wastes recommended by Intergovernmental Panel on Climate Change (IPCC): 2.7 g CH_4/kg and 0.07 g N_2O/kg of dry mass, which is equivalent to 82.82 gCO_2 eq/kg considering a combustion factor of 0.80. CO_2 emissions are here not taken into account since the emitted carbon will be reassimilated in the next crop. Nitrogen addition to the soil through the use of fertilizers intensifies nitrification and denitrification processes and liberates N_2O as a by-product to the atmosphere. N_2O emissions are around 20 g per kg of N used in the soil. In the present case all energy consumed in the researched factories is generated by burning bagasse (crushed sugarcane), therefore no gas emission from fossil fuels are registered. Direct CO emissions, which are associated with bagasse burning and molasses (sugarcane syrup) fermentation, are not considered in these calculations since, as pointed before, carbon will be reassimilated by the vegetation. Consequently only emissions coupled with the use of chemical products take part in the general account for the industrial phase of ethanol production. The total emission of CO_2eq (representing the whole amount of greenhouse gases) could be hence estimated in 1540 kg/ha/year as shown in Table 1.1. The key sources of greenhouse gas emissions in bioethanol production are sugarcane burning, fuel consumption, N_2O liberation from soil and finally fertilizers consumption, which account for more than 90 % of total emissions. Consequently there is an environmental limitation in the process of sugarcane utilization, which is represented by the possibility of the generation of greenhouse gases during the lifecycle of biofuels production.

Table 1.1 Emission of greenhouse in ethanol production from sugarcane



Category	Gas emission ($kgCO_2$.eq/ha.a)	% contribution in total emission
Fuel consumption	337.18	21.9
Fertilizers consumption	298.38	19.38
Biocides consumption	30.39	1.97
Crop burning	434.31	28.21
N_2O from soil	331.52	21.54
Seedling production	72.81	4.73
Chemical products	35.01	2.27
Total	**1539.6**	**100**

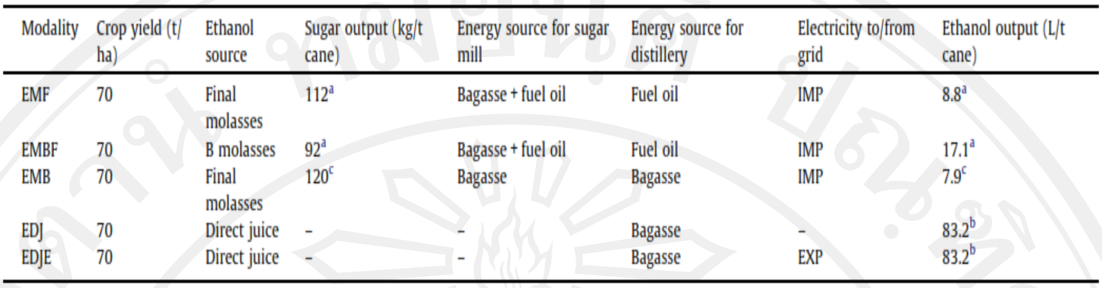
Source: Garcia, J.C.C. and Sperling, E.V. (2011)

de Figueiredo et al. (2010) determined a scope for sugarcane mills emissions within boundary and quantified the GHG emissions sources related to the sugarcane production in Brazil. It was applied the Intergovernmental Panel on Climate Change (IPCC) methodology, chapter 11, N_2O emissions from managed soils, and CO_2 emissions from lime and urea application, chapter 2 Generic methodologies applicable to multiple land-use categories and The First Brazilian Inventory to Mobile Combustion. The researchers examined the total sugar production in order to determine the carbon footprint in terms of carbon dioxide equivalent (CO_2eq) released to the atmosphere per area, ton of cultivated sugarcane and sugar produced. The results of our research study indicate that 241 kg of carbon dioxide equivalent were released to the atmosphere per ton of sugar produced (2406 kg of carbon dioxide equivalent per hectare of the cropped area and 26.5 kg of carbon dioxide equivalent per ton of sugarcane processed). The major part of the total emission (44%) was attributed to residues burning, about 20% to the use of synthetic fertilizers, and about 18% to fossil fuel combustion. The results of this study also suggest that a significant reduction in greenhouse gas emissions from sugarcane growing could be achieved by switching to a green harvest system, i.e., to harvesting without burning.

In Mexico, a research work on life-cycle greenhouse gas emissions and energy balances of sugarcane ethanol production was undertaken by C.A. et.al. (2011). The purposes of that work were to estimate GHG emissions and energy balances for future expansion of sugarcane ethanol fuel production in Mexico with one current and four possible future modalities. The researchers used the life cycle methodology recommended by the European Renewable Energy Directive (RED), which consists of five phases: direct Land Use Change (LUC), crop production, biomass transport to industry, industrial processing, and ethanol transport to admixture plants. Five modalities of ethanol production in Mexico were analyzed and shown in Table 1.2.

Three modalities for ethanol production in Mexico showed lower GHG emissions than the reference fossil fuel. The best modality was EDJE with 36.8 kgCO2e/GJethanol., followed by EDJ with 38.4 kgCO2e/GJethanol. None of the Mexican modalities achieved lower emissions than the Brazilian case (27.5 kgCO2e/GJethnaol), which was due to the following reasons: (1) less fertilizer was applied to sugarcane in Brazil than in Mexico, (2) smaller proportion of sugarcane areas were burned to facilitate manual harvest, (3) the shorter distance of sugarcane transport, and (4) fossil fuel energy was not used in the industrial phase. Emissions due to land use change associated with the expansion of crop areas were the main contributors to the total GHG emissions in Mexico, especially when this expansion took place on lands of high carbon stock, such as in tropical rain forests.

Table 1.2 Possible modalities for ethanol production in Mexico.



Modality	Crop yield (t/ha)	Ethanol source	Sugar output (kg/t cane)	Energy source for sugar mill	Energy source for distillery	Electricity to/from grid	Ethanol output (L/t cane)
EMF	70	Final molasses	112[a]	Bagasse + fuel oil	Fuel oil	IMP	8.8[a]
EMBF	70	B molasses	92[a]	Bagasse + fuel oil	Fuel oil	IMP	17.1[a]
EMB	70	Final molasses	120[c]	Bagasse	Bagasse	IMP	7.9[c]
EDJ	70	Direct juice	–	–	Bagasse	–	83.2[b]
EDJE	70	Direct juice	–	–	Bagasse	EXP	83.2[b]

Source: Carlos A. García et.al. (2011).

In Thailand, Damen, B. (2010) presented the life cycle GHG balances of various sugar ethanol production configurations as shown in Figure 1.2. It can be observed that in most cases ethanol production in Thailand either from molasses or from sugar juice offered considerable GHG reductions with regard to the threshold values for fossil gasoline and the EU sustainability directive. The researcher also suggested that ethanol production in Thailand offered net fossil energy savings when compared to fossil gasoline. The use of fossil energy in the refining process was a key variable determining the sustainability of each ethanol scenario in terms of climate and energy balances. In scenarios where fossil energy was used, the refining process was the main contributor of GHG emissions. Nevertheless, in the case where only renewable energy was utilized in this step, the largest GHG contributor was shifted to agriculture as shown in Figure 1.3. This suggests that policies to improve the GHG balance of sugar ethanol could be targeted at both better utilization of renewable biomass for power generation and encouraging more efficient agriculture.

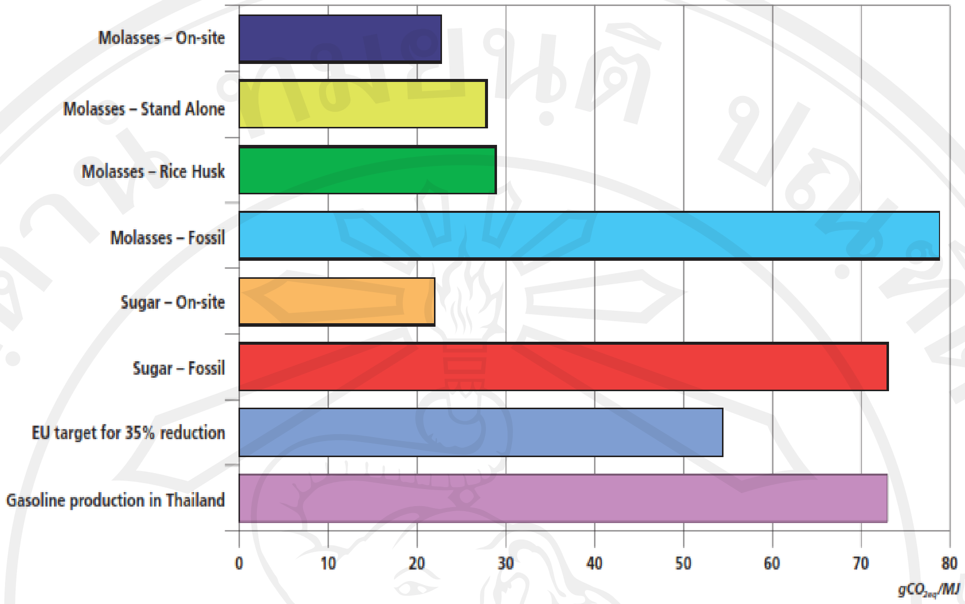


Figure 1.2 GHG emissions of different sugar-based ethanol configurations

(Source: Beau Damen, 2010)

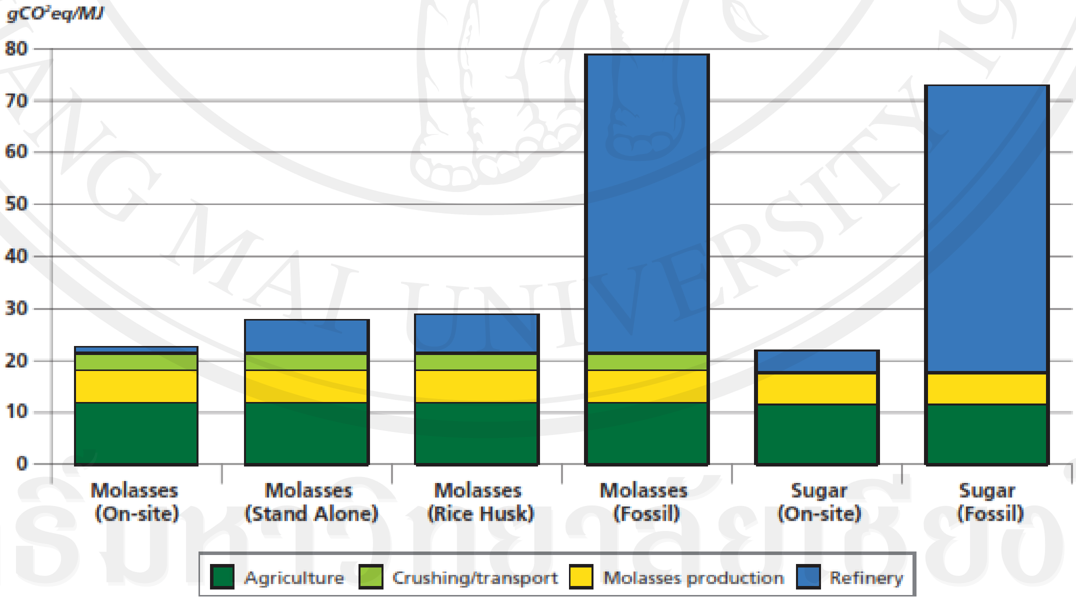


Figure 1.3 Breakdown of GHG emissions by activity for sugar-based ethanol scenarios.

(Source: Beau Damen, 2010)

Thapat Silalertruksa et al. (2009) used life cycle assessment (LCA) to evaluate the environmental consequences of possible (future) changes in agricultural production systems and to determine their effects on land use change (LUC) and greenhouse gas (GHG) implications with increases in cassava demand in Thailand. Six different cropping systems to increase cassava production, as shown in Figure 1.4, such as converting unoccupied land to cropland, yield improvement, displacement of area currently under sugarcane cultivation and the other potential changes in cropping systems in Viet Nam and Australia, were modeled and assessed. The comparative results showed that LUC was an important factor in overall GHG emissions of the first generation biofuels, especially change in soil carbon stock which contributed about 58–60% of the net GHG emissions. Increased cassava production by expanding cultivation area had a significantly larger effect on GHG emissions than on increased productivity. The analysis showed that increasing productivity of both sugarcane and cassava was one good solution to making full use of arable land in Thailand to serve both the food and fuel industries.

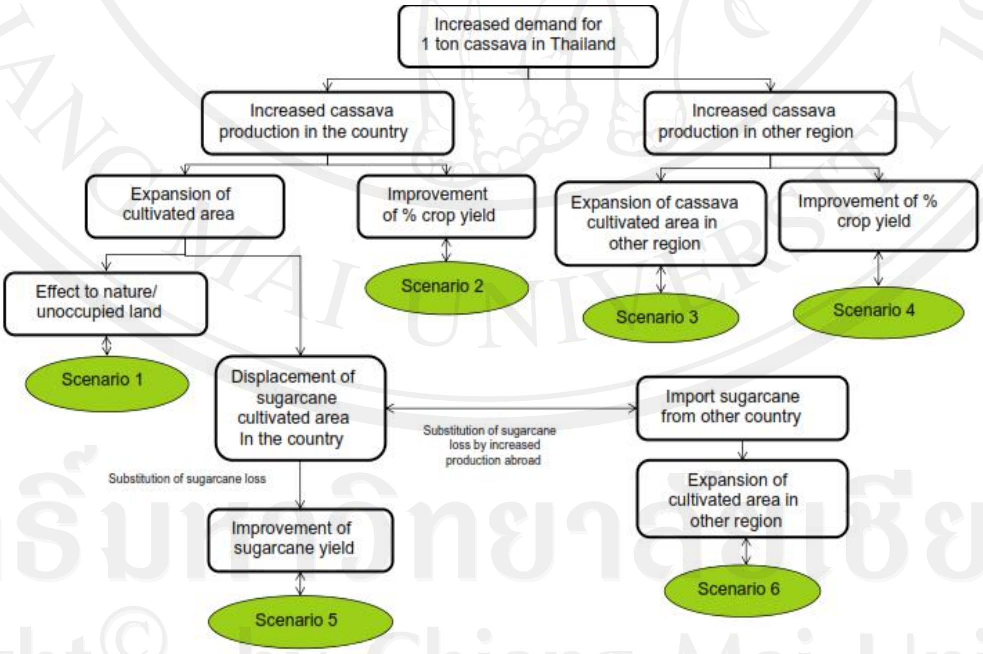


Figure 1.4 Modeling of changes in agricultural systems to satisfy increased demand of a ton of cassava in Thailand

(Source: Thapat Silalertruksa et al., 2009)

1.2.4 Water footprint of bioethanol

The available freshwater around the globe today is becoming increasingly scarcer due to an increase in population and subsequent increased water demand, worsening climate change, and deterioration of water quality. The impact of processing primary crops for production of energy on water resources can be assessed by the water footprint (WF), the topic of which have been recently widely researched.

In the Netherlands, Gerbens-Leenes, P. W. et.al. (2009a) assessed the WF of different primary energy carriers derived from biomass expressed as the amount of water consumed to produce a unit of energy (m^3/GJ). The paper observed large differences among the WFs for specific types of primary bio-energy carriers. It was found that WF depended on crop type, agricultural production system and climate. The WF of average bio-energy carriers grown in the Netherlands was 24 m^3/GJ, in the US 58 m^3/GJ, in Brazil 61 m^3/GJ, and in Zimbabwe 143 m^3/GJ. The WF of bio-energy was much larger than that of fossil energy. For the fossil energy carriers, the WF increased in the following order: uranium (0.1 m^3/GJ), natural gas (0.1 m^3/GJ), coal (0.2 m^3/GJ), and finally crude oil (1.1 m^3/GJ). Renewable energy carriers showed large differences in their WF. The WF for wind energy is negligible, for solar thermal energy 0.3 m^3/GJ, but for hydropower 22 m^3/GJ. Based on the average per capita energy use in western societies (100 GJ/capita/year), a mix from coal, crude oil, natural gas and uranium required about 35 m^3/capita/year. If the same amount of energy was generated through the growth of biomass in a high productive agricultural system, as applied in the Netherlands, the WF was 2420 m^3. The WF of biomass was 70 to 400 times larger than that of the other primary energy carriers (excluding hydropower). The trend toward larger energy use in combination with an increasing contribution of energy from biomass would increase the need for fresh water and thus led to competition with other claims, such as water for food.

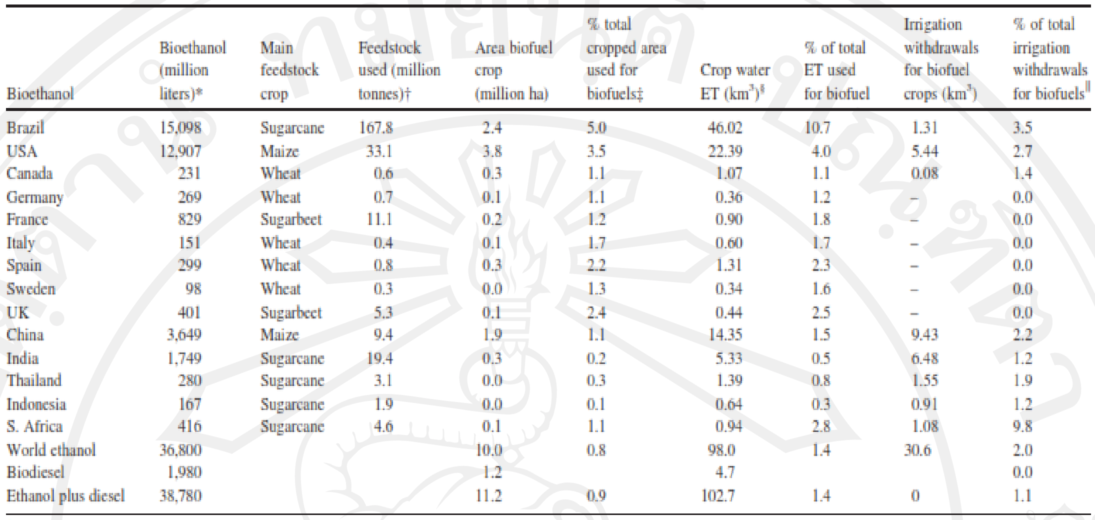
In addition, there existed an overview of WFs of bioenergy from 13 crops that accounted the most for the global agricultural production, i.e., barley, cassava, maize, potato, rapeseed, rice, rye, sorghum, soybean, sugar beet, sugar cane, wheat and jatropha. Since climate and production conditions differed among regions, calculations were thus performed by country. The WF of bioelectricity was found to be smaller than that of biofuels because it was more efficient to use total biomass (e.g., for electricity or heat) than a fraction of the crop (its sugar, starch, or oil content) for biofuel. The WF of bioethanol appeared to be smaller than that of biodiesel. For electricity, sugar beet, maize, and sugar cane were the most favorable crops (50 m^3/GJ). Rapeseed and jatropha, typical energy crops, were disadvantageous (400 m^3/GJ). For ethanol, sugar beet and potato (60 and 100 m^3/GJ) were the most advantageous, followed by sugar cane (110 m^3/GJ); sorghum (400 m^3/GJ) was the most unfavorable. For biodiesel, soybean and rapeseed appeared to be the most favorable WF (400 m^3/GJ) while jatropha had a very high WF figure (600 m m^3/GJ). When expressed per L, the WF ranged from 1,400 to 20,000 L of water per L of biofuel. If a shift toward a greater contribution of bioenergy to energy supply took place, the results of this study could be used to select the crops and countries to produce bioenergy in the most water-efficient way Gerbens-Leenes, P.W. et.al. (2009b).

Maria Eugenia Haro et.al. (2010) quantified the blue water footprint of sugarcane (WF_{sc}) production in a Mexican agricultural area for the year 2010. A water balance model was used, which took into account local climate conditions for agricultural land in Tamazula, Mexico, to calculate, with a daily time step, crop water requirements over time, actual crop water use, and finally the blue water footprint. The water availability and the demand on water services were also estimated for the region in order to evaluate the actual impact of WF_{sc} on the water resources. The estimated total WF_{sc} was 182 m^3/ton, the estimated annual water availability was 367 Mm^3, and the estimated total anthropogenic water demand was 257.5 Mm^3. These estimations showed that the blue water scarcity index (86%) indicated a water stress condition in the region.

Gerbens-Leenes, W. and Hoekstra, A. Y. (2012) in the Netherlands assessed the green, blue and grey water footprints (WF) of sweeteners and bio-ethanol from sugar cane, sugar beet and maize in the main producing countries. The WFs of sweeteners and bio-ethanol were mainly determined by crop type that was used as a source and by agricultural practice and agro-climatic conditions; process water footprints were relatively small. The weighted global average WFs of sugar cane, sugar beet and maize are 209, 133 and 1222 m^3/ton, respectively. Large regional differences in WFs indicated that WFs of crops for sweeteners and bio-ethanol could be improved. It was more favorable to use maize as a feedstock for sweeteners or bio-ethanol than sugar beet or sugar cane. The WF of sugar cane contributed to water stress in the Indus and Ganges basins. In Ukraine, the large grey WF of sugar beet contributed to water pollution. In some western European countries, blue WFs of sugar beet and maize needed a large amount of available blue water for agriculture. The allocation of the limited global water resources to bio-energy on a large scale would be at the cost of water allocation to food and nature.

C. de Fraiture et al, (2008) estimated the amounts of land and water resources devoted to biofuel crop production at 11–12 million ha, around 1% of the total area used for cultivation of crops as shown in Table 1.3. In Brazil, the biggest bioethanol producer, 2.5 million ha (5% of the cropped land) was used for biofuel production, with a production rate of ethanol of 6,200 l ha^{-1}, mostly from sugarcane. The USA, the second biggest ethanol producer, allotted early 4 million ha to biofuel crops (4% of the total cropped area), with yields of roughly 3,300 l ha^{-1}, mostly from maize. Using the data and conversion ratios listed in Table 1.3, it was estimated that the global average ethanol production from 1 ha of land was around 3,500 l. This was consistent with estimates by the International Energy Agency (IEA). In Europe, where biodiesel was the mainly made from rapeseed, 1 million ha was used, yielding on average 1,700 l ha^{-1} of biodiesel. China was becoming a major player in biofuel production, ranking among the world’s top three ethanol producers. In 2002 it produced 3.6 billion liters of bioethanol, of which 76% was derived from maize (China News, AFP, 2006). At prevailing yields and conversion factors, this corresponded to nearly 2 million ha of land, or only 1% of the total cultivated area in China. Production in India was roughly half that of China but was projected to grow rapidly. The bioethanol production was 1.7 billion liters, derived predominantly from sugarcane. India, the world’s second largest sugar producer, was also actively promoting biodiesel from Jatropha, a tropical tree-based oil crop. Jatropha could produce up to 1500 l ha^{-1} biodiesel in the most favorable soil and water conditions, though usually it produced much less. Because the trees can grow on marginal land with limited water and its seeds are non-edible, it does not compete directly with food (in terms of land and water resources). Together with sugarcane, Jatropha and other crops for biofuel production occupied only 0.3% of India’s total cultivated area.

Table 1.3 Land and water use for biofuels



Bioethanol	Bioethanol (million liters)*	Main feedstock crop	Feedstock used (million tonnes)†	Area biofuel crop (million ha)	% total cropped area used for biofuels‡	Crop water ET (km^3)§	% of total ET used for biofuel	Irrigation withdrawals for biofuel crops (km^3)	% of total irrigation withdrawals for biofuels‖
Brazil	15,098	Sugarcane	167.8	2.4	5.0	46.02	10.7	1.31	3.5
USA	12,907	Maize	33.1	3.8	3.5	22.39	4.0	5.44	2.7
Canada	231	Wheat	0.6	0.3	1.1	1.07	1.1	0.08	1.4
Germany	269	Wheat	0.7	0.1	1.1	0.36	1.2	–	0.0
France	829	Sugarbeet	11.1	0.2	1.2	0.90	1.8	–	0.0
Italy	151	Wheat	0.4	0.1	1.7	0.60	1.7	–	0.0
Spain	299	Wheat	0.8	0.3	2.2	1.31	2.3	–	0.0
Sweden	98	Wheat	0.3	0.0	1.3	0.34	1.6	–	0.0
UK	401	Sugarbeet	5.3	0.1	2.4	0.44	2.5	–	0.0
China	3,649	Maize	9.4	1.9	1.1	14.35	1.5	9.43	2.2
India	1,749	Sugarcane	19.4	0.3	0.2	5.33	0.5	6.48	1.2
Thailand	280	Sugarcane	3.1	0.0	0.3	1.39	0.8	1.55	1.9
Indonesia	167	Sugarcane	1.9	0.0	0.1	0.64	0.3	0.91	1.2
S. Africa	416	Sugarcane	4.6	0.1	1.1	0.94	2.8	1.08	9.8
World ethanol	36,800			10.0	0.8	98.0	1.4	30.6	2.0
Biodiesel	1,980			1.2		4.7			0.0
Ethanol plus diesel	38,780			11.2	0.9	102.7	1.4	0	1.1

Source: C. de Fraiture et al. (2008)

Globally around 7130 km^3 of water was evapotranspirated by crops per year, without accounting for biofuel crops. Biofuel crops accounted for an additional 100 km^3 (or around 1%). In terms of irrigation water, the share was slightly higher because of the relatively large share of irrigated sugarcane in the biofuel mix (Table 1.3). Total irrigation withdrawals amounted to 2,630 km^3 per year globally, of which 44 km^3 (or 2%) was used for biofuel crops (Table 1.3). It takes on average roughly 2,500 l of crop evapotranspiration and 820 l of irrigation water to produce one liter of biofuel. Nevertheless, regional variation is large. In Europe where rain-fed rapeseed was used, the amount of irrigation for biofuel crops was negligible. In the USA, where mainly rain-fed maize was used, only 3% of all irrigation withdrawals were devoted to biofuel crop production, corresponding to 400 l of irrigation water withdrawals per liter of ethanol. In Brazil, where the main biofuel crop, i.e., sugarcane, was mostly grown under rain-fed conditions, very little irrigation water was used for ethanol production. On the other hand, China withdrew on average 2,400 l of irrigation water to produce the amount of maize needed for one liter of ethanol. Around 2% of total irrigation withdrawals in China were therefore needed for biofuel crop production. With high sugarcane yields and conversion efficiency, Brazil yielded more than 6,200 l ha bioethanol. In India where conversion efficiencies were lower, one hectare yielded 4,000 l. As Indian sugarcane was fully irrigated, water withdrawals for every liter of ethanol were nearly 3,500 l.

Review of the literature has revealed that at present CF and WF are major causes for concern for a large scale development of bioethanol. For CF, most research studies assess GHG emissions by LCA methodology which are lack on the research of calculation CFs were estimated according to the National Guideline of Carbon Footprint of Product which use emission factor of Thailand. For WF, The lacks on research of WF of bioethanol in Thailand by use primary data. Most research works on WF of bioethanol in Thailand were published by foreign researchers whose main source of data was of secondary type. In addition, the existing policies on ethanol production indicate a shift toward an increased percentage of bioenergy and thus increased CF and WF. The challenge is thus to strive for policies on energy and water resources that minimize both CF and WF. Therefore, this research work examines the carbon and water footprints of bioethanol production and conducts the scenario analysis to arrive at the best scenario for future policy-setting.

1.3 Objectives of the Study

The objectives of this study are to:

1.3.1 To analyze the carbon and water footprints of bioethanol production from sugarcane and cassava.

1.3.2 To simulate the multi-criteria impacts on government’s ethanol policy

1.4 Scope of the Study

1.4.1 This research aims to initiate life cycle inventory database development of bioethanol production from sugarcane and cassava which the scope covered from cradle to gate stages in the life cycle of bioethanol.

1.4.2 The cultivation data and detail information of sugarcane and cassava was collected in the north region of Thailand.

1.4.3 The calculation methodology of carbon footprint followed the National Guideline of Carbon Footprint of Product and the water footprint evaluation was applied from the Water Footprint Assessment Manual.