CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

This chapter concludes the research analysis conducted in the previous chapter and makes recommendations for future research.

5.1 Conclusion

At present, the use of renewable energy is viewed as one promising strategy for the reduction of GHG emissions. Nevertheless, the sustainability of a large-scale substitution of fossil fuels with biofuels deriving from energy crops requires an in-depth examination of both CF and WF. Therefore, the aims of this research are to introduce the CF and WF of bioethanol production from sugarcane and cassava throughout their entire life cycle; and to explore scenarios of bioethanol production in Thailand.

5.1.1 Carbon footprint (CF)

CFs of unburned and burned sugarcane are respectively 0.0194 and 0.0571 kgCO_2-eq per ton of sugarcane. In the case of unburned sugarcane, the N-fertilizer application stage produces the highest CF of 0.0101 kgCO_2-eq (or 52.15% of 0.0194 kgCO_2-eq), followed by the nitrogen fertilizer production with 0.0056 kgCO_2-eq of CF (or 28.96%) and by diesel combustion with 0.0022 kgCO_2-eq of CF (or 11.25%). The application of P, K fertilizers and herbicide, on the other hand, produces only 1-2% of CF.

In the case of burned sugarcane, the highest quantity of CF, which is 0.0377 kgCO_2-eq (or 66.03%), is produced during the sugarcane leaf burning stage prior to harvest. The N-fertilizer application produces 0.0101 kgCO_2-eq of CF (or around 17.68%), followed by the nitrogen fertilizer production with 0.0056 kgCO2-eq of CF (or 3.82%) and by diesel combustion with 0.0022 kgCO2-eq of CF (or 3.82%). The application of P, K fertilizers and herbicide, on the other hand, produces a very small amount of CF.

For cassava, CF is 0.0651 kgCO2-eq per ton of cassava. The highest quantity of CF, which is 0.0327 kgCO2-eq (or 50.23%), is produced during the N-fertilizer application stage. The nitrogen fertilizer production produces 0.0182 kgCO2-eq of CF (or 27.89%), the herbicide application gives out 0.0060 kgCO2-eq (or 9.23%), and the diesel combustion produces 0.0054 kgCO2-eq of CF (or 8.28%). In comparison to sugarcane, CF produced by cassava is higher as the yield per cultivation area of cassava is lower irrespective of that fact that the amounts of herbicide and fuel used are almost identical to those used in sugarcane cultivation.

Therefore, the first and foremost solution to reducing CF in the process of growing sugarcane and cassava is to decrease the use of nitrogen fertilizer. Farmers should be advised to switch to organic fertilizers and not to burn sugarcane prior to harvest. According to the data collected, the production of one liter of bioethanol requires 60% of burned sugarcane and 40% of unburned sugarcane. Thus, by not burning sugarcane, CF can be reduced.

CF of one liter of sugarcane-based bioethanol is approximately 1.62 kgCO_2-eq/L, the figure which is accounted for by transportation (42%), burned sugarcane (24%), support systems (i.e., steam production, water production and waste water treatment) (21%), electricity (6%), unburned sugarcane (5%), chemical use (0.4%), and diesel (production and combustion) (0.002%). CF of cassava-based bioethanol is 1.02 kgCO_2-eq/L, dividing into transportation 38%, cassava cultivation 36%, electricity 20%, diesel (production and combustion) 3%, support systems 3%, and chemical use 1%.

5.1.2 Water footprint (WF)

The research study determines WF under rain-fed and irrigation conditions of the study site located in northern Thailand. The calculation of WF under irrigation condition uses the yield predicted from the linear crop-water production function of the FAO (1986). The result suggests that average WF of sugarcane under rain-fed condition equals 205 m^3/ton, of which 154 m^3/ton is WF_{green} and 51 m^3/ton is WF_{grey} while WF_{blue} is zero. WF of sugarcane under irrigation condition is equal to 191 m^3/ton, of which 123 m^3/ton is $WF_{gree,}$ 26 m^3/ton is WF_{blue}, and 42 m^3/ton is $WF_{grey.}$ For cassava, WF under rain-fed condition equals 449 m^3/ton, of which 284 m^3/ton is WF_{green} and 165 m^3/ton is WF_{grey}. Meanwhile, WF of cassava under irrigation condition is equal to 400 m^3/ton, of which 162 m^3/ton is WF_{green}, 125 m^3/ton is WF_{blue} and 113 m^3/ton is WF_{grey}.

In this research work, WFs of sugarcane-based bioethanol consist of the bioethanol production from sugarcane under rain-fed and irrigation conditions. WF of bioethanol under sugarcane under rain-fed condition is equal to 3,372.859 m^3/ton (WF_{green} 2,527.421, WF_{blue} 8.429 and WF_{grey} 837.009) or 2,661.185 L_{water}/$L_{ethanol}$ (WF_{green} 1,994.135, WF_{blue} 6.65 and WF_{grey} 660.4), while that under irrigation condition is 3,143.068 m^3/ton (WF_{green} 2,018.637, WF_{blue} 435.137, WF_{grey} 689.294) or 2,479.881 Lwater/Lethanol (WF_{green} 1,592.705, WF_{blue} 343.314, WF_{grey} 543.853).

For cassava, WF of bioethanol under rain-fed condition is 11,072.974 m^3/ton (WF_{green} 6,997.245, WF_{blue} 10.434 and WF_{grey} 4,065.295) or 8,736.576 L_{water} /$L_{ethanol}$ (WF_{green} 5,520.826, WF_{blue} 8.232 and WF_{grey} 3,207.518), while WF under irrigation condition is 9865.694 m^3/ton (WF_{green} 3,991.378, WF_{blue} 3,090.209 and WF_{grey} 2,784.107) or 7,784.032 L_{water}/$L_{ethanol}$ (WF_{green} 3,149.197, WF_{blue} 2,438.175 and WF_{grey} 2,196.660).

The study proposes that the demand for water underground, or irrigational water usage, defined as the 'blue component' be higher in agricultural sector than in industrial sector. It is found that a ton of sugarcane requires 26 m^3 of irrigational water for the maximum productivity, while a ton of sugarcane requires only 0.658 m^3 of water for the production of bioethanol. Similarly, a ton of cassava requires 125 m^3 of water for the agricultural purpose and 1.334 m^3 for the production purpose. Apparently, the water management should focus on the agricultural purpose given the higher demand. Usually, water in industries is more effectively utilized as it is often reused and recycled, which is a means to reduce WF.

A significant measure to reduce WF is to increase the yield per cultivation area. Based on the field data, cassava and sugarcane grown in the northern areas of Thailand were mostly dependent on rainwater. It is thus seasonal farming in which the productivity is subject to the amount of rainfall, and the irrigation system management is therefore very necessary.

5.1.3 Comparison of the impacts of gasoline 95, E10, E20 and E85

This research studied and compared the impacts on land use, carbon and water footprints of gasoline 95, E10, E20 and E85. The functional unit was 1 MJ and the findings are detailed as below:

The impact on land use is that more land space would be needed in proportion to increase in the production of ethanol. That is, the production of gasoline 95 requires no agricultural land use, while E10, E20 and E85 require 0.000003 ha/MJ, 0.000007 ha/MJ and 0.00004 ha/MJ, respectively. Thus, if Thailand were to implement a policy to encourage more use of ethanol with subsequent ascending of volume, it is advisable to start with gasoline 95 as it does not require land use. Nevertheless, transition from E10 to E20 increases land use by 107% and from E20 to E85 by 450%. Moreover, water consumption to grow sugarcane and cassava tends to increase in proportion to the amount of ethanol produced. Switching from gasoline 95 (no agricultural water required) to E10 increases the demand for water to 7.6 m^3/MJ, from E10 to E20 results in an increase of 8.1 m^3/MJ or 106%, and from E20 to E85 leads to an increase of 70.9 m^3/MJ or 450% of water use.

For carbon footprint, it was found that for one liter of E85 GHG emission was the lowest at 2.64 $kgCO_2eq/L$, followed by E20 at 2.78 $kgCO_2eq/L$ and E10 at 2.84 $kgCO_2eq/L$, whereas gasoline 95 produced the highest GHG emissions at 2.91 $kgCO_2eq/L$. In terms of per 1 MJ, GHG emission from gasoline 95 was 92.4 gCO2 eq/MJ, followed by E10, E20 and E85 at 93.3, 94.5 and 116.1 gCO2 eq, respectively. As such, the use of ethanol as an alternative fuel could help reduce reliance on fossil fuels; however, petroleum-based gasoline still gives better engine performance than does ethanol fuel.

5.1.4 Future of Bioethanol with AEDP

According to the Alternative Energy Development Plan (AEDP), which aims to promote more use of ethanol, the ethanol consumption target has been set at 9 million liters per day by 2021 against the backdrop of a total capacity of merely 1.5 million liters per day at present. As a result, in this study the possible impacts on land use, carbon and water footprints following the increase in ethanol production are investigated under two cases: the varying proportion and the fixed proportion.

Under the *varying proportion*, ethanol produced from sugarcane initially accounts for 70% and from cassava for 30% and proportion of the production of sugarcane-based ethanol is reduced by 5% per year while that of cassava-based ethanol is increased by 5% per year. Meanwhile, under the *fixed proportion*, the proportion of sugarcane-based ethanol to cassava-based ethanol remains constant at 70% to 30%. The findings are as follows:

By the end of the AEDP in 2021, the fixed proportion case would require the cultivation areas of 5.32 million ha/yr whereas in the varying proportion case the land use would initially increase and then decrease by the end of 2021. Land use required would be merely 3.43 million ha/yr if the production of ethanol were 25% sugarcane-based and 75% cassava-based, indicating that cassava-based ethanol requires less cultivation area than does sugarcane-based ethanol. For the same volume of ethanol produced, it would require a 38% increase in land use in the varying proportion case by the end of the plan but a 114% increase in the fixed proportion case. If cassava and sugarcane yields were to rise respectively from 19.47 to 31.25 million tons/ha and from 68.85 to 93.75 million tons/ha, it would reduce the cultivation areas from 5.32 million ha/yr to 3.60 million ha/yr for cassava and from 3.43 to 2.33 million ha/yr for sugarcane. Notwithstanding, with the implementation of the AEDP a higher annual demand for land use is inevitable in all cases due to the greater volume of ethanol use in 2021.

The water consumption increases with higher production volume of ethanol. As such, by the end of the AEDP in 2021 the water consumption would be 9.59 km^3/yr in the varying proportion scenario and 13.38 km^3/yr in the fixed proportion scenario. However, if the average yield improvement according to the AEDP plans were implemented, volume of water demanded would be reduced to 6.38 km^3/yr in the varying proportion scenario and 9.20 km^3/yr in the fixed proportion scenario. Furthermore, if the water allocation plan for agriculture of 2012 were taken into account, it would require an increase in the allocation of water for sugarcane as well as cassava to meet the target of 9 million L/day, for which 9% and 12% additional water would be required the varying proportion and the fixed proportion cases, respectively. In addition, if the AEDP plan to increase crop yield per cultivation area, based on the average yield of the year 2012, were fully implemented, by the end of 2021 water consumption would be slashed by approximately 32.5%.

The study on the greenhouse gas (GHG) emissions indicated an increase in GHG emissions in the fixed proportion with higher ethanol production. Even though ethanol production of 1.5 million L/day would produce emissions of 0.8 million tonCO_2eq for molasses by its economic value, GHG emissions from ethanol production at 9 million L/day would increase to 3.8 and 4.7 million tonCO_2eq for the varying and fixed proportions, respectively. At 1.5 million L/day of ethanol production GHG emissions was 1.4 million tonCO_2eq for molasses by mass. GHG emissions for ethanol production at 9 million L/day would increase to 5.1 and 8.4 million tonCO_2eq for the varying and fixed proportions, respectively. However, if there is an improvement in the yield per area, it would reduce the annual accumulation of GHG emissions.

Therefore, the transition from fossil fuel to ethanol would be an effective way to reduce GHG emissions. Nevertheless, the shift would have an adverse impact on land use as more cultivation areas would be required to meet higher demand of ethanol. Inevitably, demand for water to irrigate the agricultural areas would rise. As a result, any policy to promote ethanol use cannot look at just one or two positive impacts of GHG emissions reduction and/or more income for farmers; instead, such a policy requires looking at many other impacts, especially negative ones, which could ensue, including land use, water consumption and so forth.

5.2 Guidelines to promote ethanol use in Thailand

Thailand has long promoted the use of renewable energy including ethanol. Ethanol can benefit the country in several ways, such as reducing reliance on foreign oil import, increasing income of farmers, and lowering greenhouse gas (GHG) emissions from fossil fuel use. As GHG is a cause of global warming, it is imperative that ways to reduce GHG emissions be sought and one possible answer lies in ethanol use. Nevertheless, increase in ethanol use could lead to undesirable outcomes, such as demand for more land use and greater water consumption for cultivation of crops for ethanol production. As such, policy makers should deliberate all aspects of the environmental impacts when promoting the use of ethanol rather than looking at only the positive impact on GHG emission reduction. In addition, the policy makers will need to choose the most appropriate approach for renewable energy production. As a result, guidelines for aiding with policy formulation to promote more use of ethanol in Thailand are provided below:

5.2.1 Guidelines for land use to grow sugarcane and cassava

The 2010/2011 production cycle of Thailand produced 1.24 million L/day of molasses and 1.84 million L/day of cassava for ethanol production. It is obvious that the amounts of the raw materials in the country would be insufficient to meet the ethanol production demand of 9 million L/day. Therefore, Thailand is required to increase the cultivation areas for both crops, inevitably giving rise to competition with other food crops for limited cultivation areas. The government should then adopt the following suggestions to efficiently manage the land use:

5.2.1.1 Zoning areas

The government should draw up a zoning plan to clearly separate the zones for growing food crops from those for growing energy crops. The aim is to prevent future problems of competition for land to grow food crops and energy crops. In determination of suitable areas or zones for growing sugarcane or cassava, all pertinent factors, such as climate, plant suitability and soil properties, should be taken into account to achieve the highest yield possible.

5.2.1.2 Increase in cultivation areas

More studies should be undertaken to investigate the possibilities of converting abandoned and/or deserted areas into arable lands to grow both crops. This would make attainment of the ethanol production target of Thailand more likely.

5.2.2 Guidelines to reduce greenhouse gas emissions

Ethanol fuel use is promoted to reduce greenhouse gas (GHG) emissions from fossil fuel use. However, cultivation of sugarcane and cassava for ethanol production produces GHG emissions, such as from land plowing by machines, from burning of unwanted debris, and from the use of chemical fertilizers. Thus, the following guidelines are proposed to minimize GHG emissions.

5.2.2.1 Reduce the use of chemical fertilizers

Promoting the use of organic and humus instead of chemical fertilizers will reduce GHG emissions from the production of chemical fertilizers and use of chemical fertilizers, especially nitrogen fertilizers which produce N_2O emissions.

5.2.2.2 Reduce the burning of sugarcane prior to harvest

There should be legal measures to control the burning of sugarcane or cooperation should be sought from sugar factories whereby the buying factories could offer to farmers higher purchasing prices of sugar cane to dissuade them from burning sugarcane.

5.2.2.3 Reduce the GHG emission in the transportation sector

Transportation is required every step throughout the production cycle of ethanol, such as transportation of sugarcane or cassava from cultivation areas to factories and of raw materials to the ethanol production sites. Therefore, transport routes should be carefully studied to find ways to minimize GHG emissions. For instance, grouping of sugarcane and ethanol production factories in the same zone is one good way to minimize transport and thus GHG emissions.

5.2.3 Guidelines for water use

Increasing ethanol production impacts the demand for water in both agricultural and industrial sectors. The effect is however more pronounced in the agricultural than industrial sector. A study of the water footprint (WF) is a new concept as a tool for water management in the country, and it is anticipated that in the near future WF will be used for a trade barrier. Water use will definitely become a critical issue because of the global warming. Therefore, the suggestions for water management are given below:

5.2.3.1 Study of water footprints of major food crops and energy crops

A study of water footprints of major foods and energy crops is important because it will reveal the overall pictures of water demand for the cultivation in Thailand. Besides, WF will be used as a guide to water allocation plans. Data indicated that sugarcane and cassava grown in the North mostly relied on rainwater. Thus, if there were a drought, the crops would not receive enough rainwater to grow and thereby lower the productivity. Therefore, the irrigation system is essential. The water allocation plans have set aside 146,560 ha for sugarcane cultivation areas in the rainy season and 155,200 ha in the dry season, out of the total crop growing areas of 1.29 million ha. The water allocation plans are however unavailable for cassava cultivation areas.

5.2.3.2 Prepare the country for the water footprint

Thailand needs to establish a body responsible for WF as presently there is no such state agency. However, it is not the same as the agency responsible for carbon footprint as CF is responsible for by Thailand Greenhouse Gas Management Organization (TGO). This research has shown that the concept of water footprint is new to Thailand. Despite this fact, the new agency to be established should develop standards and guides suited to the country to evaluate the water footprints. In addition, these standards would help move future research studies as a whole in the same direction. At present, research works on WF are very fragmented and some overlap with others, causing unnecessary waste of research budgets.

The establishment of the WF agency in Thailand is a matter of urgency as this study has encountered many problems, one of which is the accuracy and reliability of the data for the assessment of water footprint, such as:

A) Crop coefficient (K_c) values

The available data do not include all crops and cultivation areas. Hence, there should be a database of factual data to calculate K_c values for Thailand.

B) Soil properties

Soil properties are used to approximate water footprint. However, the data on soil properties fail to include total available soil moisture, maximum rain infiltration rate, initial soil moisture depletion, and initial available soil moisture. It therefore should be a comprehensive study that covers all types of soils and areas. This research work is based on the data from the Food and Agriculture Organization of the United Nations (FAO).

C) Properties of the plants

This research work is based on the data from the Food and Agriculture Organization of the United Nations (FAO), examples of which are critical depletion, yield response, and so forth.

D) Lack of data on water use in industrial sector

It was found that most factories did not categorize the water use in the production process but only retained the data on total water used in all activities. It could be that water is inexpensive and thereby relegated to the back seat vis-à-vis energy or materials used in the manufacturing process. Therefore, Thailand should accelerate the development of a national database of water usage as it would be of great benefit to future research works on water footprint.

It has been proven that the most effective way to minimize the impacts of land use, carbon footprint and water footprint is to increase the annual yield per cultivation area for sugarcane and cassava production. However, higher yield production depends upon many factors including climate, crop type, soil property, efficient agricultural system, and adequate water. Therefore, farmers should be encouraged to grow both crops with better management using fertilizers that are suitable for the soil conditions and to use manure compost instead of chemical fertilizers. Furthermore,

more study on irrigation system should be carried out to increase crop productivity. At the same time, introduction of better production technology in the industrial sector that promotes efficient use of water must be encouraged.

5.3 Recommendations

It is recommended that future research works center around the following areas for the following reasons:

5.3.1 As this study focuses on sugarcane and cassava growing areas in the northern region of Thailand and thereby WF results of the region, analysis of water footprints of sugarcane and cassava from any other region is thus encouraged so that a more complete database of Thailand's water footprints of sugarcane and cassava could be developed.

5.3.2 The LCI data in the production of this research study were gathered from a few factories and thereby are not representative of the whole country. It is thus recommended that data be collected in accordance with the life cycle inventory database to obtain the result that is applicable to the bioethanol production industry in general.

5.3.3 The ethanol production systems of this research study are assumed to be Simultaneous Scarification and Fermentation (SSF) and two-column multi-pressure systems. However, it is advisable that future research works include many other fermentation and distillation methods available in Thailand.

5.3.4 There should be in-depth research that examines the collective impacts of land use, carbon and water footprints as this current research work looks at the impacts of the three factors individually.

5.3.4.1 Study of greenhouse gas (GHG) emissions from land use change. Increase of land use for sugarcane and cassava cultivation reduces the available land for other crops. This phenomenon could result in an increase in GHG emissions or may have a negative effect on the overall water footprint of the country.

5.3.4.2 Collective study of water footprint and carbon footprint. The introduction of irrigation system to an agricultural area could increase the average yield and thus possibly reduce the carbon footprint. However, if fuel is used in the irrigation, it could induce an increase in GHG emissions. It should be researched further.

5.3.4.3 Study of water footprints. A study on water footprints of all major crops of the country should be undertaken as the findings aid in the development of effective water management plans of Thailand.

5.3.5 Additional study on water requirements of different crops and their respective increase in average yield per cultivation area with increase in water should be undertaken. Since some crops double their productivity with increase in water, it is therefore worthwhile to invest in a water system; however, other crops do not respond positively to increase in water, so investment in the water system is unnecessary for these crops. As a result, a research study of such nature would be very useful to formulate the investment policy.

5.3.6 Further study on techniques to improve average yield per cultivation area should be carried out, examples of which are crops enhancement, watering system improvement, and planting management. This is to reduce cultivation areas, GHG emissions and water footprint.

5.3.7 The policy to promote ethanol use should take into consideration the issues of land use and water footprint of agricultural products within a country.

5.3.8 The result of water footprint can serve as a base for further research related to water management, cultivation planning and irrigation water planning in order to increase productivity per cultivation area, which is one effective way to reduce water footprint.