CHAPTER 3

METHODOLOGY

This chapter describes the procedure of this research work as illustrated in Figure 3.1. The entire procedure consists of four main parts: 1) the part on the study area where field data were collected, 2) the discussion and calculation of carbon footprint, 3) the discussion and computation of water footprint, and 4) scenario analysis to determine the potential for bioethanol production from sugarcane and cassava in Thailand.

3.1 The review of harvested areas, products and yields of sugarcane and cassava

This research examines the statistical data of 2008-2012 of sugarcane and cassava collected by the Office of Agricultural Economics of Ministry of Agriculture and Cooperatives (2011). The data include harvested areas, products and yield per hectare of the provinces in northern Thailand where both crops are cultivated. The data will be used in the selection of study areas and analysis.

3.2 The study of the increase in the sugarcane and cassava harvested areas by Geographic Information System

In this process, the overlay analysis using the Geographic Information System (GIS) has been conducted on the land use and soil series data from the Land Development Department to find the density of the sugarcane and cassava harvested areas in northern Thailand. The soil series data will be used in the water footprint analysis in the next step.

3.3 Area selection and field data collection

The study results from 3.1 and 3.2 will be used in selecting provinces with large harvested areas to be the representative provinces for field data collection of sugarcane and cassava. In this research, the data have been collected by close-ended questionnaires, with which each agriculturist will be individually interviewed.

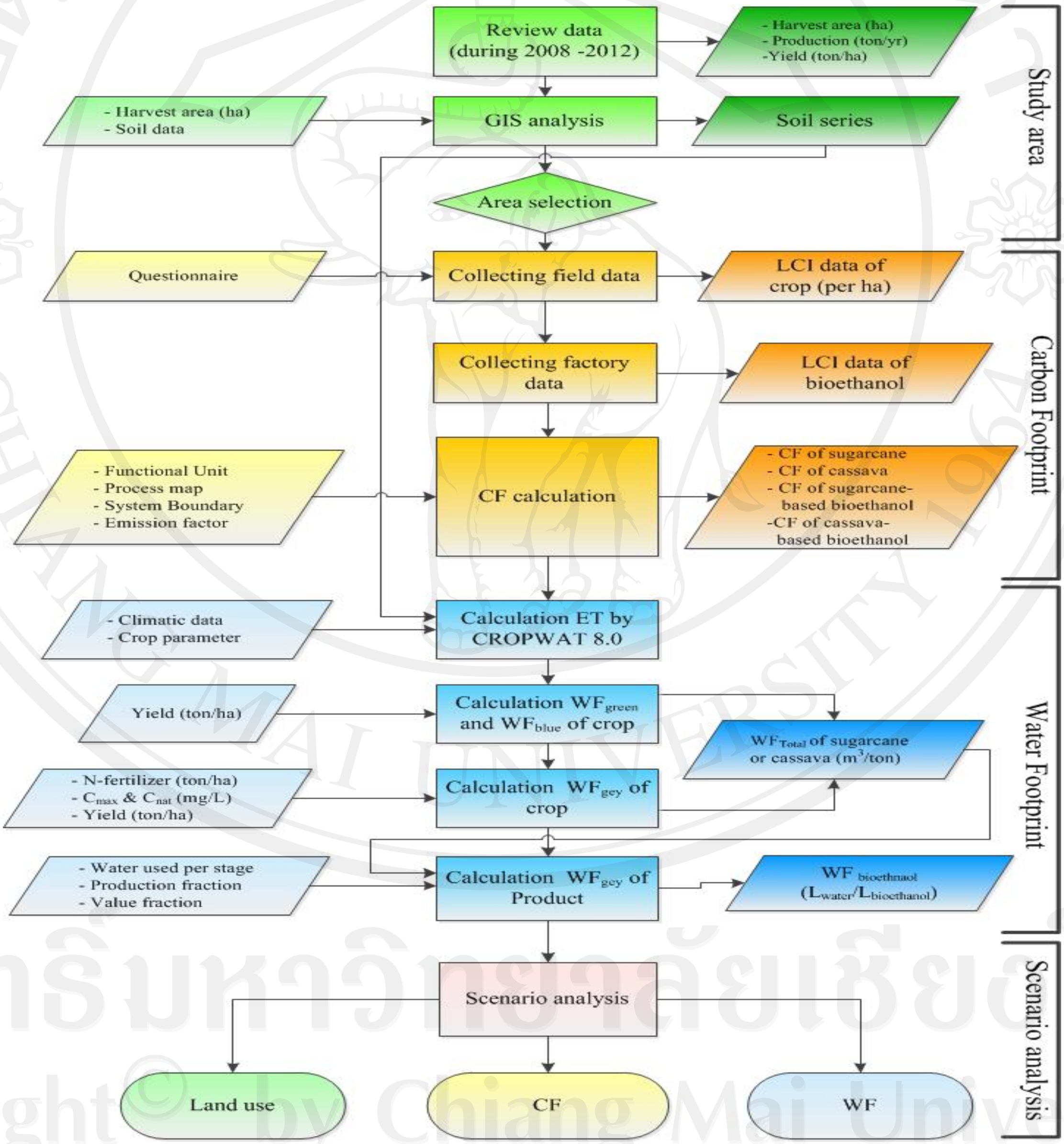


Figure 3.1 Graphical depiction of the methodology of this research work

3.4 Carbon footprint assessment of sugarcane-based and cassava-based bioethanol

The processes of carbon footprint (CF) assessment of sugarcane- and cassava-based bioethanol of this study are described below.

3.4.1 Goal definition

This study aims to assess CF of bioethanol from sugarcane and cassava to determine resources use, energy use, and GHG emission in each process. This will lead to development of bioethanol production guidelines and proper reduction of GHG emissions.

3.4.2 Scope definition

This step is to specify a functional unit and draw a process map so as to have an overall picture of bioethanol product and to determine the system boundary.

i) Functional Unit

The life cycle GHG emissions for the product shall be specified per functional unit. The function unit is defined as $kgCO_2e/L$, which is applicable to CFs of bioethanol from sugarcane and cassava. All inputs and outputs in producing bioethanol from sugarcane and cassava are examined to estimate GHG emissions throughout the entire production cycle.

ii) Draw a map of the bioethanol life cycle

Figures 3.2 and 3.3 respectively depict the process maps for bioethanol from sugarcane and cassava.

iii) System boundary

As seen in Figures 3.2 and 3.3, the system boundary of CF in this study is the “cradle-to-gate” or “business-to-business (B2B)”, which takes into account all life cycle stages from raw material extraction up to the point at which the final product leaves the organization undertaking the assessment. Figure 3.4 shows the system boundary of this study, which consists of four stages: (1) cultivation, (2) raw material production, (3) ethanol production, and (4) transportation in all stages.

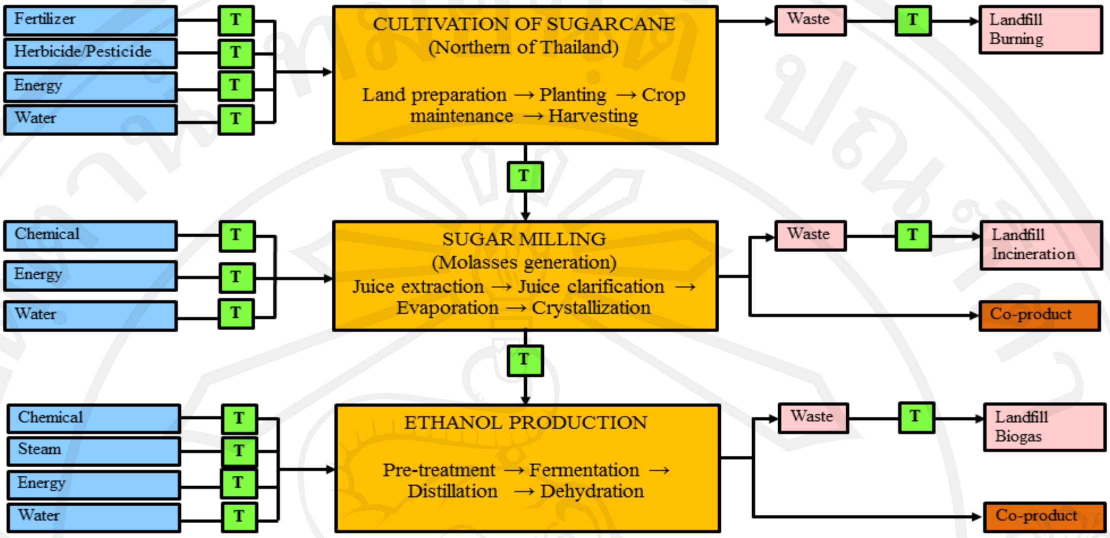


Figure 3.2 A process map for sugarcane-based ethanol

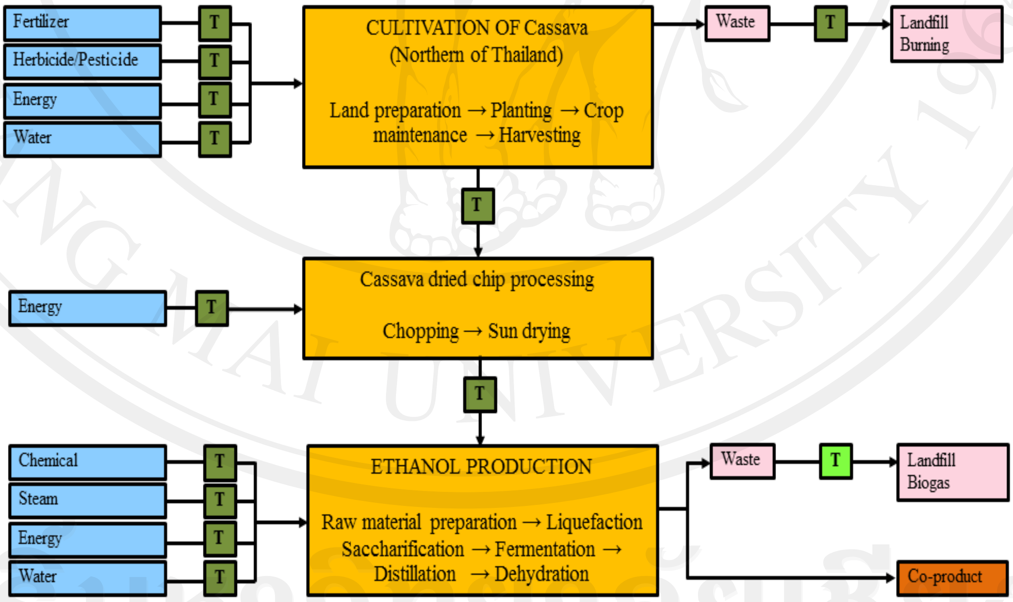


Figure 3.3 A process map for cassava-based ethanol

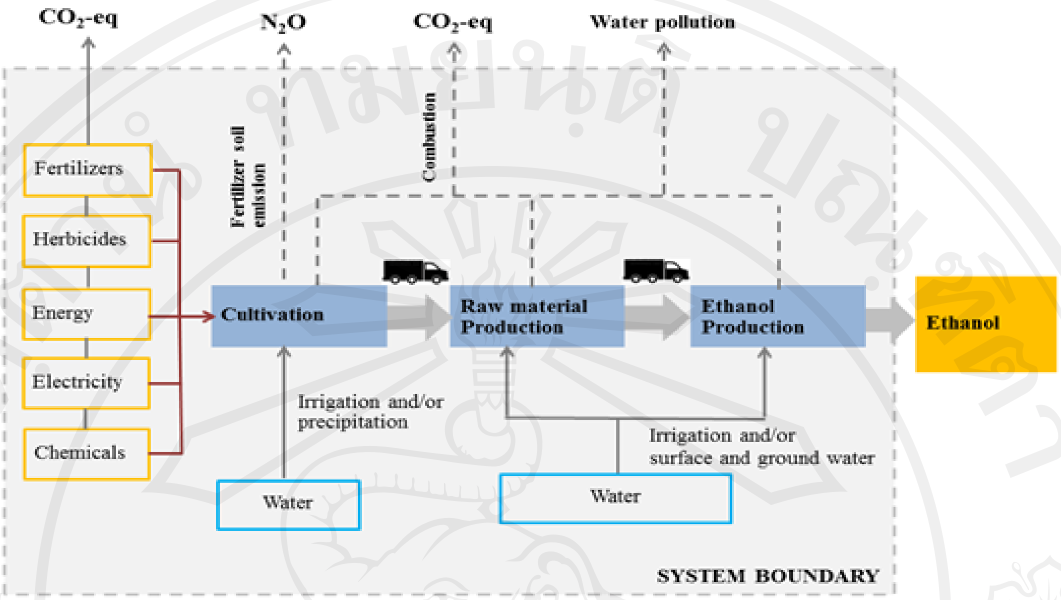


Figure 3.4 The entire system boundary of this research study

An Evaluation of Carbon footprint of sugarcane-based and cassava-based ethanol will be used in this multi-level study. However, most of the primary data is from the operator. And in part with the use of secondary data is obtained from local research. Framework of the study, how that data was used is shown in Table 3.1 and Table 3.2.

Table 3.1 Scope of information used to assess the carbon footprint of sugarcane-based ethanol

Life Cycle Stage	Level of the Study
Sugarcane cultivation	▪ An average data of sugarcane growers of selected provinces by researcher
Sugarcane Transportation	▪ A primary data from 2 sugarcane factories
Sugarcane Factories	▪ A primary data from 2 sugarcane factories ▪ An average data from 2 sugarcane factories
Ethanol Production	▪ A primary data from one ethanol factory ▪ A secondary data from research in the country

Table 3.2 Scope of information used to assess the carbon footprint of cassava-based ethanol

Life Cycle Stage	Level of the Study
Cassava cultivation	▪ An average data of cassava growers of selected provinces by researcher
Cassava Transportation	▪ A primary data from one ethanol factory
Cassava chips Production	▪ A primary data from one ethanol factory
Ethanol Production	▪ A primary data from one ethanol factory

3.4.3 Data collection

Based on the goal and scope of the study, the data collection was carried out following the complete chain of the ethanol from sugarcane and cassava as shown in Tables 3.3 and 3.4, respectively. The data collection of this research has been divided into two stages: agricultural stage and industrial stage.

For the agricultural stage, the data collection in the selected provinces has been undertaken with a close-ended questionnaire. The crop growers are individually interviewed as previously stated. The questionnaire data are then substituted in Equation 3.1 to compute the weighted mean, the value of which will be used in the calculation of the next step.

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i} \tag{3.1}$$

where X_i = Data
W_i = Weight of data

The industrial stage entails both primary and secondary data. The primary data are those of the previous year (i.e., one year back) collected from factories and are important inputs/outputs. The data from the factories are calculated for their respective weighted means. Meanwhile, the secondary data are gleaned from Thai language publications and technical reports.

Table 3.3 Data collection procedure of sugarcane-based ethanol

Main data	Data required	Data sources	Collecting method
Sugarcane production	Fertilizer use Energy use Water use	Farmers	- Questionnaire - On-site interview
Sugar milling	Chemical use Energy use Water use Support systems	Factories	- Plant records - Interview
Sugarcane-based ethanol	Chemical use Energy use Water use Support systems	Factories, Thai public journals, Thai technical reports	- Plant records - Interview - Literature review
Transportation	Transport mode, Distance, Loading	Farmer / Factories	- Plant records - Interview

Table 3.4 Data collection procedure of cassava-based ethanol

Main data	Data required	Data sources	Collecting method
Cassava production	Planting date Fertilizer use Water consumption	Farmers	- Questionnaire - On-site interview
Dried chip processing	Energy use	Thai public journal	- Literature review
Cassava-based ethanol	Chemical use Energy use Water use Support systems	Factories	- Plant records - Interview
Transportation	Transport mode Distance Loading	Farmer, Factories	- Plant records - Interview - Assumption

3.4.4 Carbon footprint calculations

The collected data are used in finding mass balance per FU for calculating carbon footprints (CFs). CFs are estimated according to the Life Cycle Assessment (LCA) concept and the National Guideline of Carbon Footprint of Product. The CFs are estimated from the activity data (kg/liter/kWh/tkm, etc.) multiplied by the emission factor (kgC2Oe per kg/liter/kWh/tkm, etc.). These are summed to give a total carbon footprint against each life cycle stage, and for the total system.

For the agricultural stage, GHG emission is estimated from fertilizers, herbicides and fossil fuels in machinery for the entire cultivation and harvest. For fertilizers, the GHG emissions are obtained from the production of N, P, K fertilizers and N_2O direct emission from application of N-fertilizers. For herbicides, the estimated GHG emission is from the production, and the production and combustion of fossil fuels are used to estimate GHG emission. CH_4 and N_2O from sugarcane trash burning are accounted for using the IPCC emission factors. The emission factors employed in this study are those of country specific emission factors of Thailand Greenhouse Gas Management Organization and of the IPCC as listed in Table 3.5.

For the industrial stage, GHG emission was estimated from raw materials, chemicals and energy used in production process for the entire life cycle of bioethanol. For raw materials and chemicals, the estimated GHG emission is from the production. For energy, the production and combustion are used to estimate GHG emission. The emission factors employed in this study are those of country specific emission factors of Thailand Greenhouse Gas Management Organization, of the IPCC and of the international database. The emission factors from primary data of sugarcane factories are calculated from generating steam water, water, and electricity to support the production. The factories are using two sources of electricity in the production process; internal and external supplier. Therefore, the internal electricity users have to calculate their own emission factors while the external electricity users apply the country specific emission factors of Thailand Greenhouse Gas Management Organization. Therefore, the emission factors between the two sources are being calculated by their own team.

For the calculation process in this study, Microsoft Excel files from Thailand Greenhouse Gas Management Organization (TGO), or the so-called 'verification sheet', have been used. It is a common form used in Thailand. In CF assessment, the results have to be in the form of carbon dioxide equivalent per FU. The CF results should be in a three-digit number, with a space between the number and unit.

Table 3.5 Emission factors for calculation of bioethanol from sugarcane and cassava.

Activity	Emission Factor ($kgCO_2eq\ Unit^{-1}$)	Unit
Fertilizer		
Production of fertilizer N[a]	2.6000	$kgCO_2eq\ kg^{-1}\ N$
Production of fertilizer P[a]	0.2520	$kgCO_2eq\ kg^{-1}\ P$
Production of fertilizer K[a]	0.1600	$kgCO_2eq\ kg^{-1}\ K$
Herbicide		
Production of paraquat[a]	3.2300	$kgCO_2eq\ kg^{-1}$
Production of ametryne[a]	8.5100	$kgCO_2eq\ kg^{-1}$
Production of glyphosate[a]	16.000	$kgCO_2eq\ kg^{-1}$
Fossil fuel		
Production of diesel[a]	0.3282	$kgCO_2eq\ kg^{-1}$
Utilization		
Diesel combustion[a]	2.7080	$kgCO_2eq\ L^{-1}$
N_2O direct from fertilizer use[b]	0.0100	$kgN_2O\text{-}N\ kg^{-1}\ N$
Biomass burning[b]	300	$kg\ CH_4\ TJ^{-1}$
	4	$kg\ N_2O\ TJ^{-1}$

[a] Emission Factor for Carbon Footprint of Product (TGO, 2013).

[b] IPCC, 2006.

3.4.5 Interpretation

After calculating CF, the results will be interpreted to determine the amount of GHG emission for each process throughout the life cycle and which process gives the highest GHG emission. The activities causing high GHG emission are the important issues that should be addressed and thereby are the guideline for factories to reduce CF throughout the life cycle of bioethanol production.

3.5 Water footprint assessment of bioethanol from sugarcane and cassava

The processes of water footprint (WF) assessment of sugarcane- and cassava-based bioethanol consist of the following:

3.5.1 Setting goals and scope of the study

The objective of the study is to assess the WFs of bioethanol production from sugarcane and cassava in northern Thailand. The system boundary refers to Figure 3.4, which encompasses cultivation, raw material production, and bioethanol production. Since every step in the process consumes water, calculation of the total water use throughout the life cycle of bioethanol is thus performed. WFs consist of green, blue and grey components, each of which looks at the use of water from different sources. The green component refers to the use of rainwater excluding run-off water, the blue component to the use of surface water and groundwater, and the grey component is indicative of the amount of clean water for the dilution of waste water to meet the standard of surface water. The results of WFs are expressed in terms of cubic meter per ton of crop and cubic meter per litre of bioethanol.

3.5.2 Data collection

The data for the WF calculation were collected from several sources as shown in Table 3.6.

Table 3.6 Data and sources for the calculation of WFs

Main data	Data required	Data sources	Collecting method
Crop production	Planting date Fertilizer use Water consumption (Rain, Irrigation, Ground an surface water)	Farmers	Questionnaire/ on-site interview

Table 3.6 (Continued)

Main data	Data required	Data sources	Collecting method
Climate Data	Temperature (max, min) Humidity Wind Sunshine Rain	Thai Meteorological Department	Literature review
Crop Data	Crop coefficients (K_c) Length of growth stage	Royal Irrigation Department	Literature review
	Rooting depth Critical depletion Yield response factor Crop height	FAO	
	Planted area (ha) Production (ton/year) Yield (ton/ha)	Office of Agriculture Economics	
Soil Data	Total available soil moisture Maximum rain infiltration rate Maximum rooting depth Initial soil moisture depletion Initial available soil moisture	FAO	Literature review
	Land use Data of soil series	Land Development Department	GIS
Bioethanol Production	Direct and indirect water Production fraction Value fraction	Factories, Thai public journal, Thai technical reports	Plant records /Interview/ Literature review

3.5.3 Calculation of WFs of sugarcane and cassava

In this study, the calculation of WFs of sugarcane and cassava grown in northern Thailand comprises two parts: calculation of the green and blue evapotranspiration of sugarcane and of cassava in northern Thailand; and of WFs of sugarcane- and cassava-based bioethanol.

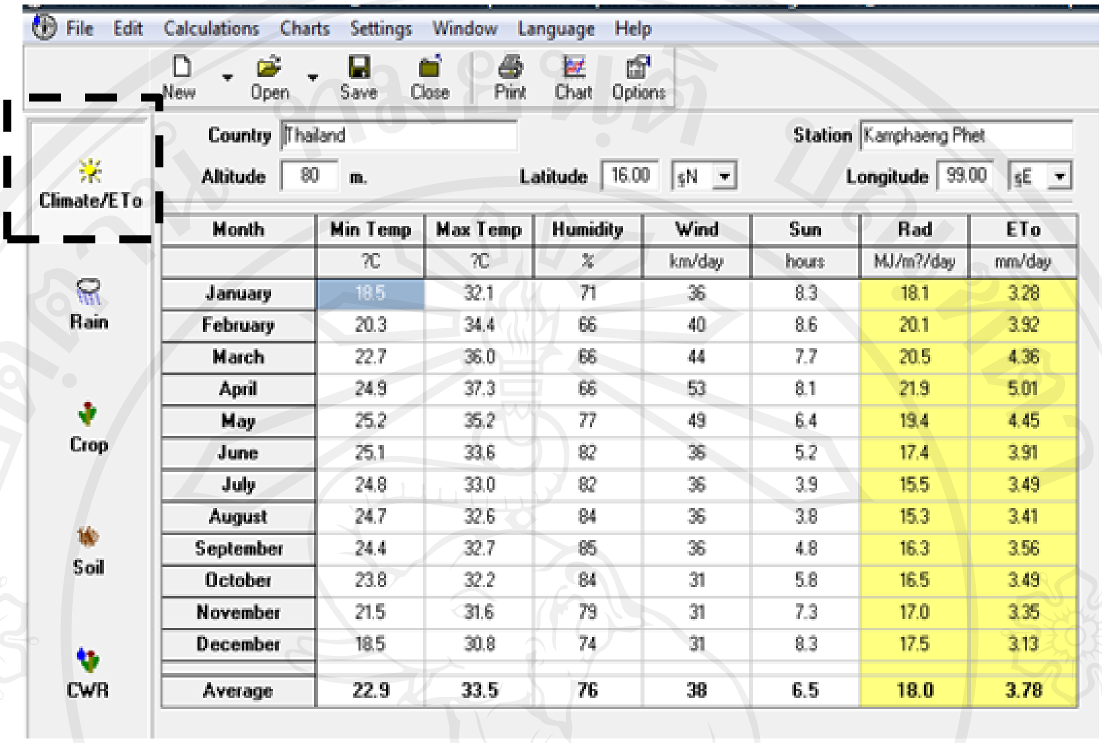
3.5.3.1 Calculation of green and blue evapotranspiration of sugarcane and cassava using the CROPWAT model 8.0

Calculation of ET_{green} and ET_{blue} using CROPWAT requires the inputs of climate data, crop data and soil data. This study uses the 'irrigation schedule option' in the CROPWAT model. The calculation process using the model begins with the input of climatic data as shown in Figure 3.5. Since WF, as an indicator, is subject to the location, the geographical data including country, province, altitude, latitude and longitude of the provinces being studied must be determined. Then, the climate data is to be input. The monthly climate data used have to be the average estimation of the past 30 years. The result obtained from the model, the monthly $ET_{o,}$ is then calculated using the Penman – Montieth equation (Equation 2.4). The white grids in Figure 3.5 present the data to be input to the model, while the yellow grids list the result calculated using the model.

The second step is to input the monthly average rainfall data based on the estimation of the past 30 years as shown in Figure 3.6. In this model, the calculation of effective rain fall (P_{eff}) is performed through the USDA Soil Conservation Service (SCS) Method, which was developed by The U.S. Department of Agriculture's Soil Conservation Service. Estimation of P_{eff} can be achieved either using Equation 3.2 when the value of Total rain (P_{tot}) is less than 250 millimeters or Equation 3.3 when the value of Total rain (P_{tot}) is greater than 250 millimeters. The unit of P_{eff} is expressed in millimeter.

$$P_{eff} = P_{tot}\left(\frac{125-0.2\times P_{tot}}{125}\right) \quad \text{when } P_{tot} < 250 \text{ mm} \tag{3.2}$$

$$P_{eff} = 125 + 0.1\times P_{tot} \quad \text{when } P_{tot} > 250 \text{ mm} \tag{3.3}$$



Country Thailand

Station Kamphaeng Phet

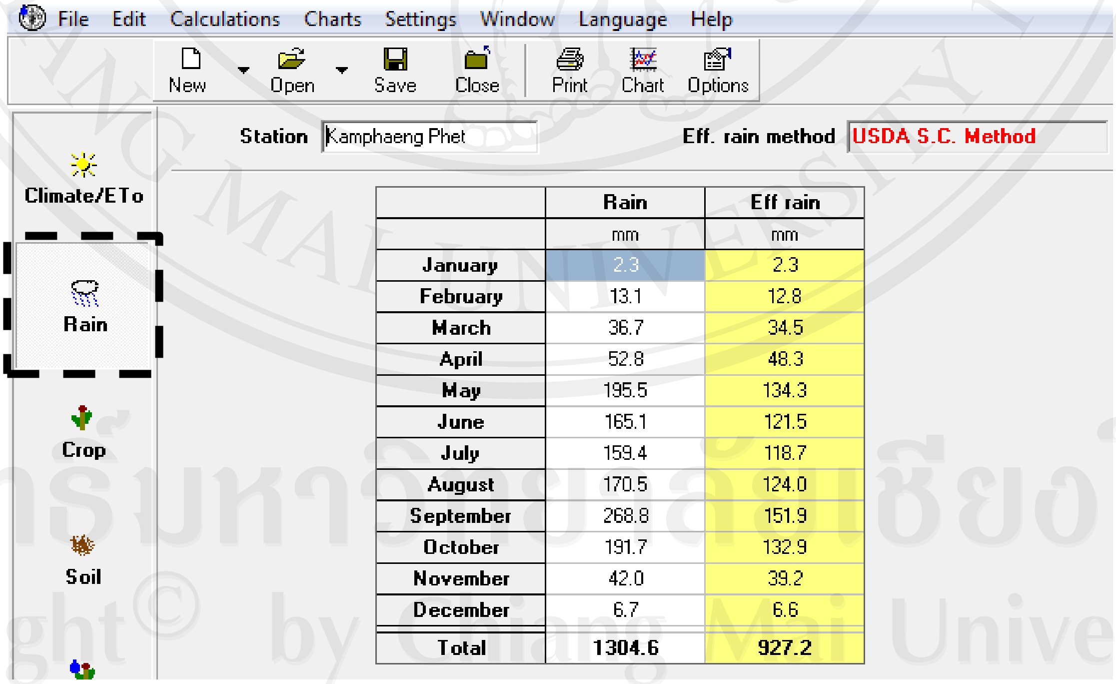
Altitude 80 m.

Latitude 16.00 ºN

Longitude 99.00 ºE

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	?C	?C	%	km/day	hours	MJ/m?/day	mm/day
January	18.5	32.1	71	36	8.3	18.1	3.28
February	20.3	34.4	66	40	8.6	20.1	3.92
March	22.7	36.0	66	44	7.7	20.5	4.36
April	24.9	37.3	66	53	8.1	21.9	5.01
May	25.2	35.2	77	49	6.4	19.4	4.45
June	25.1	33.6	82	36	5.2	17.4	3.91
July	24.8	33.0	82	36	3.9	15.5	3.49
August	24.7	32.6	84	36	3.8	15.3	3.41
September	24.4	32.7	85	36	4.8	16.3	3.56
October	23.8	32.2	84	31	5.8	16.5	3.49
November	21.5	31.6	79	31	7.3	17.0	3.35
December	18.5	30.8	74	31	8.3	17.5	3.13
Average	22.9	33.5	76	38	6.5	18.0	3.78

Figure 3.5 Climate data input to the CROPWAT model



Station Kamphaeng Phet

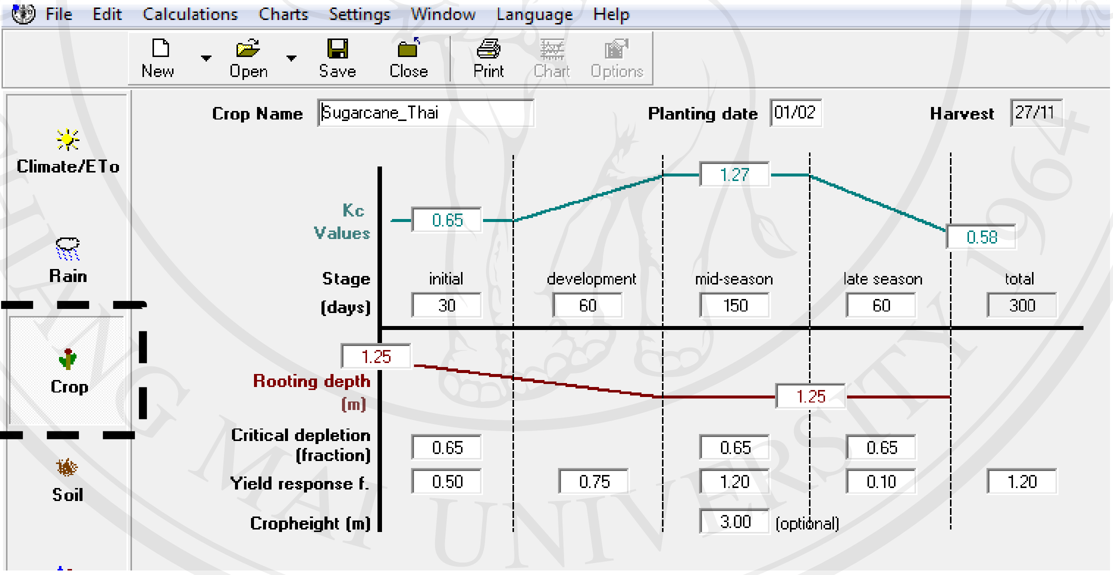
Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	2.3	2.3
February	13.1	12.8
March	36.7	34.5
April	52.8	48.3
May	195.5	134.3
June	165.1	121.5
July	159.4	118.7
August	170.5	124.0
September	268.8	151.9
October	191.7	132.9
November	42.0	39.2
December	6.7	6.6
Total	1304.6	927.2

Figure 3.6 Rain data input to the CROPWAT model

The third step looks at the input of crop data, and this reseach focuses specifically on sugarcane and cassava. K_c is regarded as one significant factor in the calculation of WF in the study, according to the Royal Irrigation Department. The crop data will be utilized in the process of WF calculation for all provinces in the northern of Thailand, without differentiating both types of crops. The features of sugarcane and cassava used in this study are shown in Figures 3.7 and 3.8, respectively.

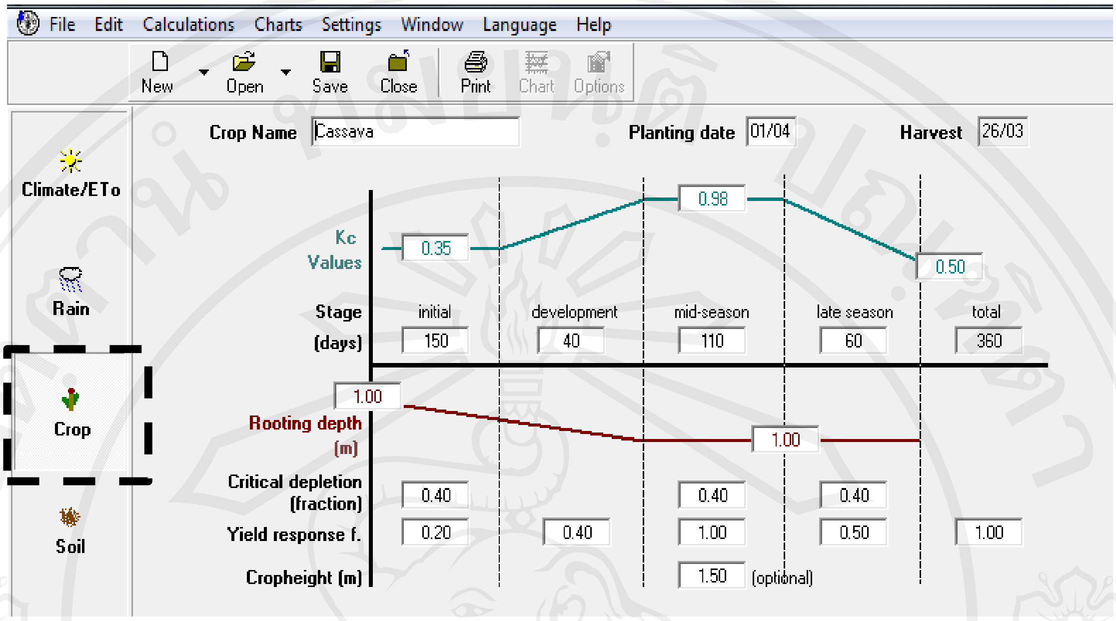
The fourth step is to input the soil data. As discussed in Section 3.2, the information on soil series from each cassava growing area is to be derived from GIS. The features of each type of soil used in this model for calculation are presented in Figure 3.9. In this study, data from the model database have been employed.



Crop Name: Sugarcane_Thai
Planting date: 01/02
Harvest: 27/11

	initial	development	mid-season	late season	total
Kc Values	0.65		1.27	0.58	
Stage (days)	30	60	150	60	300
Rooting depth (m)	1.25		1.25		
Critical depletion (fraction)	0.65		0.65	0.65	
Yield response f.	0.50	0.75	1.20	0.10	1.20
Cropheight (m)			3.00 (optional)		

Figure 3.7 Sugarcane data input to the CROPWAT model



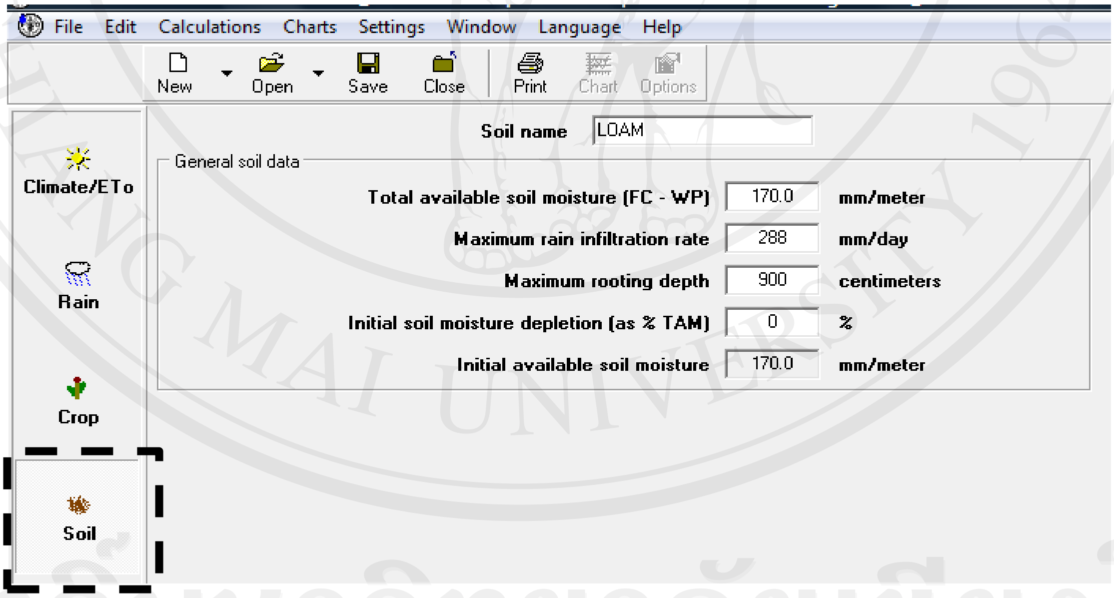
Crop Name: Cassava

Planting date: 01/04

Harvest: 26/03

	initial	development	mid-season	late season	total
Kc Values	0.35		0.98		0.50
Stage (days)	150	40	110	60	360
Rooting depth (m)	1.00			1.00	
Critical depletion (fraction)	0.40		0.40	0.40	
Yield response f.	0.20	0.40	1.00	0.50	1.00
Cropheight (m)			1.50 (optional)		

Figure 3.8 Cassava data input to the CROPWAT model



Soil name: LOAM

General soil data

Total available soil moisture (FC - WP)	170.0	mm/meter
Maximum rain infiltration rate	288	mm/day
Maximum rooting depth	900	centimeters
Initial soil moisture depletion (as % TAM)	0	%
Initial available soil moisture	170.0	mm/meter

Figure 3.9 Soil data input to the CROPWAT model

The last step is running the model. Prior to the run, conditions to be considered in calculation, which are time and irrigation types of water used, i.e. rainfed or irrigation condition, must be indicated. In this study, the indication of conditions is based on the data collected during the field survey. The data acquired after running model are presented in Figure 3.10 in which ET_a is equivalent to 'Actual water use by crop', ET_{blue} represents the lowest value between 'Total net irrigation' and 'Actual irrigation requirement', and ET_{green} equals to ET_a minus ET_{blue}. Every term is expressed in millimeter per day unit. The study aims to calculate ET_{green} and ET_{blue} for sugarcane and cassava in northern provinces where both crops are grown.

As a significant factor for the growth of crops, loss of water at any certain point during the growth process can lead to the decline in yield. Therefore, this study will measure the yield of crops under irrigation condition through the linear crop-water production function introduced by FAO (1986) and as shown in Equation 3.4. The equation is an attempt to compare WFs under real circumstances from field survey and that under irrigation condition.

$$\left[1-\frac{Y_a}{Y_m}\right] = K_y \times \left[1-\frac{ET_{c\,adj}}{ET_c}\right] \tag{3.4}$$

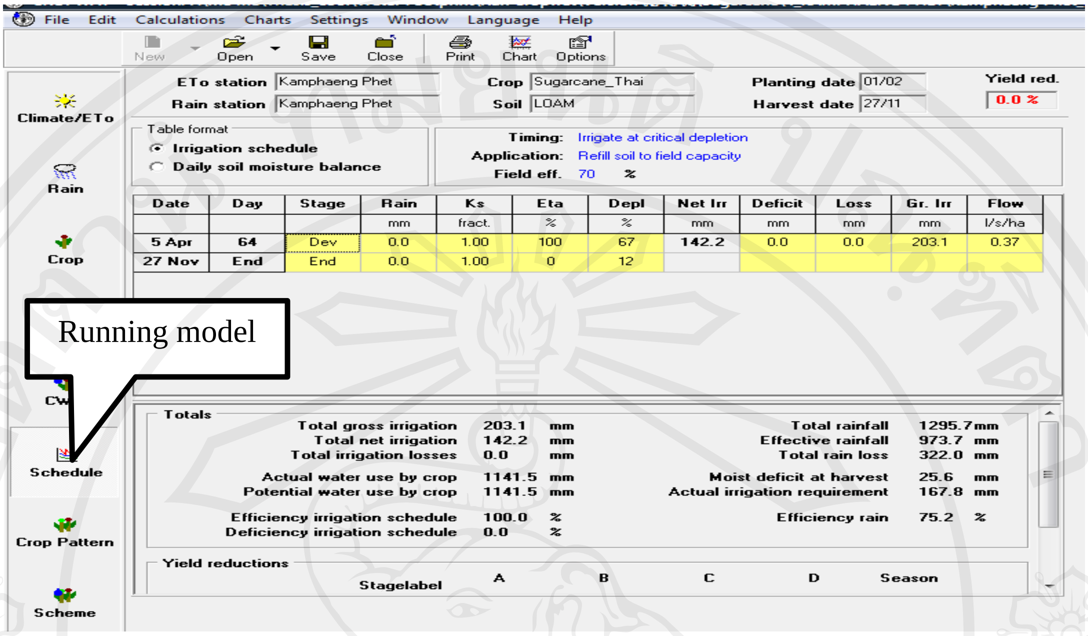
When K_y = Yield response factor

Y_a = Actual crop yield (ton ha^{-1})

Y_m = Maximum crop yield when there is no water stress and $ET_{c\ adj} = ET_c$ (ton ha^{-1})

ET_c = Crop evapotranspiration for standard conditions (mm)

$ET_{c\ adj}$ = Adjusted (actual) crop evapotranspiration (mm)



ETo station: Kamphaeng Phet
Rain station: Kamphaeng Phet
Crop: Sugarcane_Thai
Soil: LOAM
Planting date: 01/02
Harvest date: 27/11
Yield red.: 0.0 %

Table format
● Irrigation schedule
○ Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff.: 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
5 Apr	64	Dev	0.0	1.00	100	67	142.2	0.0	0.0	203.1	0.37
27 Nov	End	End	0.0	1.00	0	12					

Totals

Total gross irrigation	203.1	mm	Total rainfall	1295.7	mm
Total net irrigation	142.2	mm	Effective rainfall	973.7	mm
Total irrigation losses	0.0	mm	Total rain loss	322.0	mm
Actual water use by crop	1141.5	mm	Moist deficit at harvest	25.6	mm
Potential water use by crop	1141.5	mm	Actual irrigation requirement	167.8	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	75.2	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

	A	B	C	D	Season
Stagelabel					

Figure 3.10 The results derived from the model execution

3.5.3.2 Calculation of the green, blue and grey WFs of sugarcane and cassava

The green and blue WFs are calculated following Equations 2.2 and 2.3 by substituting the equations with ET_{green} and ET_{blue} obtained from the calculation using the CROPWAT model. This study calculates the green, blue and grey WFs of sugarcane and cassava under the two conditions growth: rainfeded and irrigation condition. The yield of rainfed condition obtained from section 3.1 and the yield of irrigation condition using forcaste yield from Equation 3.4.

On the other hand, the grey WF was calculated according to Equation 2.5. In general, grey WFs take into consideration only the use of nitrogen fertilizers because nutrients leaching from agricultural fields are main causes of non-point source pollution of surface and subsurface water bodies (Hoekstra et al., 2011). The effects of the use of other nutrients, herbicides and pesticides are however not analyzed. Northern-specific nitrogen fertilizer application rates of sugarcane and cassava are based on the average LCI data from the field surveys of the sampled provinces, the rates of which are representative of the rates of the remaining provinces in the study. Around 10% of the applied nitrogen fertilizer is assumed lost through leaching (Chapagain, A. K. et al, 2006). The natural concentration (C_{nat}) is the concentration in the water body that would occur if there were no human influence. It is however not zero because all rivers naturally transport some nutrients (Liu, C., Kroeze. et al., 2012). Because of lack of data, the natural nitrogen concentrations were assumed to be zero (Mekonnen, M. M., and Hoekstra, A. Y., 2011). The standard maximum value of nitrate in surface water referenced from the Pollution Control Department of Thailand (PCD) is 5 mg per liter measured as nitrate-nitrogen (NO_3-N). The WFs of sugarcane and cassava are expressed as cubic meter per ton of sugarcane or cassava.

3.5.4 Calculation of WFs of sugarcane- and cassava-based bioethanol

In this study, the calculation of WFs of sugarcane- and cassava-based bioethanol follows the stepwise accumulative approach. The process begins by conducting the mass and water balances per ton of crop. The same series of data was used to for CF calculation.

The calculation of the water footprint is based on only one processed product *p*, and product *p* is sugarcane- or cassava-based bioethanol obtained from a root product *i*. The root product *i* is the raw material to produce bioethanol, which is sugarcane or cassava for this study,. However, from one root product often several products can be obtained, and thereby each product can be expressed as a fraction of the root product. The product fraction ($f_p[p]$) can be calculated following Equation 2.8. The value fraction of a product p ($f_v[p]$) is obtained from the work of W. Scoholten (2009).

In the industrial process of the input product, water is used in different production stages. Each product, originated at the end of a production stage, only consumes the water in the previous stages and not the water used in the subsequent stages. For this reason, only the process water use ($WF_{proc}[p]$, m^3/ton) involved with the production of product p is added to the WF of that product. Thus, in this study the direct water is fresh water use in production stages, including support systems, e.g. steam and cooling water; and the indirect water is only WFs of sugarcane or cassava.

3.6 The scenario analysis for bioethanol production in Thailand

In order to determine the future potential for bioethanol production in Thailand, a tool that can incorporate numerous and diverse views regarding the future is necessary. For this reason, the scenario planning approach has been selected as the tool to ‘predict’ the future.

3.6.1 Definitions and system boundaries

Five key points to be taken into account regarding the bioethanol production from sugarcane and cassava in Thailand are:

- Bioethanol demand is influenced by population size and economic growth of the country.
- Bioethanol demand impacts biomaterial demand and subsequently bioethanol production demand.
- The demand for sugarcane and cassava as biomaterials impacts land use, GHG emission and water consumption.
- The effects of the demand for bioethanol production on GHG emission and water consumption.
- The crop production, available land area and water resource are subject to climatic factors.

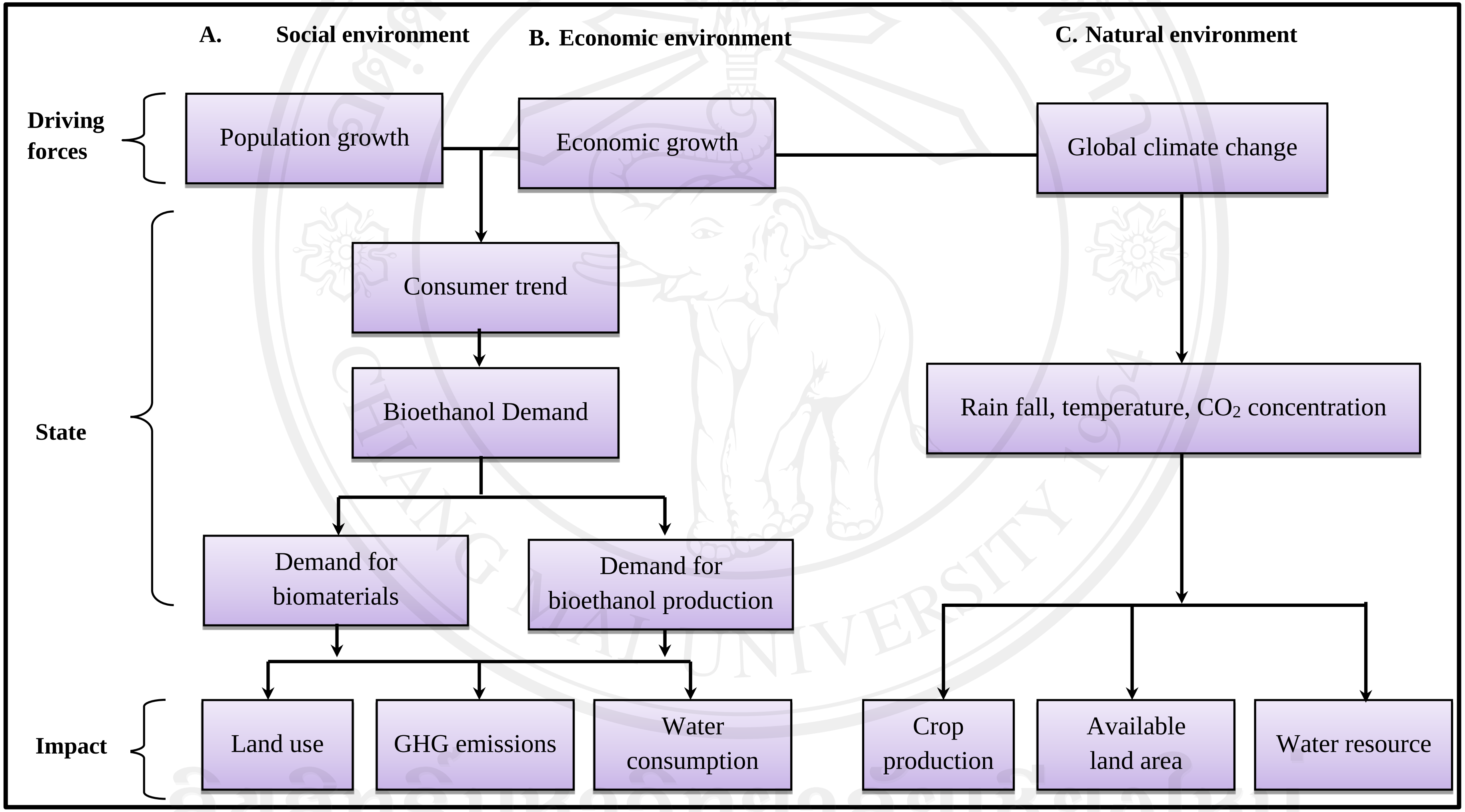


Figure 3.11 Key determinants of the potential for bioethanol production from sugarcane and cassava in Thailand

As illustrated in Figure 3.10, these elements interact with each other within Thailand’s social, economic and natural environments to ultimately influence the viability of bioethanol production. Population growth and economic growth are two of the primary driving forces. A driving force is an “…environmental force, driving a possible outcome of a critical uncertainty.” (Van der Heijden, 2005). Together, these driving forces influence the demand of bioethanol in Thailand, which subsequently influences the demand for sugarcane and cassava as food, animal feed and biomaterials. Global climate change is the third driving force which influences crop productivity, the arable land suitable for the production of sugarcane and cassava, and available water resources. Three main focuses are the availability of land for the production of biomaterials, greenhouse emission throughout the entire life cycle of bioethanol production, and required irrigation for the biomaterials production.

In this study considers 2 scenarios: scenario I was to compare land use, carbon footprint, and water footprint between gasoline, E10, E20 and E85, and scenario II was to compare land use, carbon footprint, and water footprint in the event of increasing capacity to 9 million liters of ethanol production per day by 2021.

Firstly, land used for growing sugarcane and cassava for ethanol production is considered in each scenario. Secondly, GHG emissions throughout the production cycle is the value of carbon footprint. Finally, irrigation water demand in the agricultural sectors only is the water footprint values which use more water than industrial sectors. Assumptions for each scenario are as follow:

- Production proportion of ethanol to be blended E10, E20 and E85 is from sugarcane-based ethanol 70% and cassava-based ethanol 30%
- Molasses 1,000 kg produced 238 liters
- Cassava chips 1,000 kg produced 333 liters
- Fresh cassava 2,100 kg produced cassava chips made 1,000 kg
- Sugarcane 1,000 kg made molasses 45 kg
- Area 1 hectare produced sugarcane 68,850 kg
- Area 1 hectare produced cassava 19,470 kg
- Amount of water per area for sugarcane and cassava have not change
- Amount of greenhouse gas emission of each fuels types have not change

3.6.2 Scenario I: Compare gasoline 95, E10, E20 and E85

Figure 3.12 is the scope of the study. This research indicated the impacts on land use, carbon footprint, and water footprint of gasoline 95, E10, E20 and E85 by using 1 MJ of each blended, then compare their impacts to each other to comply with policies to promote the use of gasohol replace the gasoline in Thailand

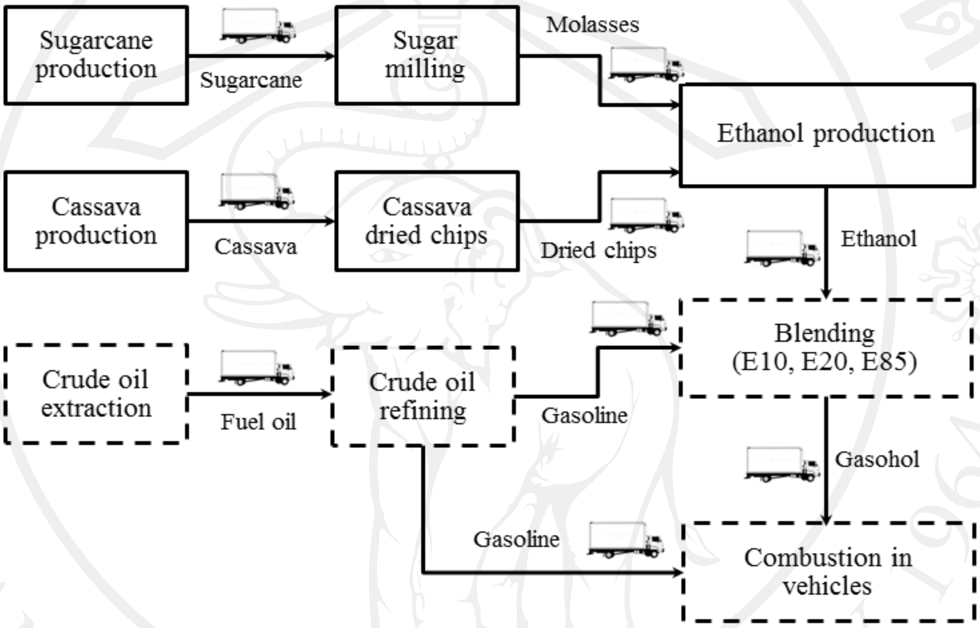


Figure 3.12 System boundary of scenario I

Measuring and collecting data from primary and secondary sources is the study of a Life cycle inventory (LCI) of ethanol production cycle. It consists of agriculture, processing plant material, production of ethanol, and Oil refinery Oil depots, energy used and transport that occurs in each step. Secondary data sources are database of both domestic's, foreign LCI, and other related research's LCI. All data is attributed to the primary data. Furthermore, the scope of the study includes the consumption of raw materials, chemicals, energy and waste co-product.

3.6.3 Scenario II: Increase capacity to 9 million liters of ethanol per day by 2021

The scope of the study is shown in Figure 3.13. The research is indicated impacts on land use, carbon and water footprint in the 2021 target is at 9 million liters per day where a total capacity is at 1.5 million liters per day at the present (2012). The two cases studies are a fixed and a change proportion of ethanol productions. Case one consists of 70% of ethanol from molasses and 30% from cassava. Case two is a change in the proportions, reduce molasses produced by 5% per year, and increase 5% of cassava production per year. Details of the processes are as indicated in Table 3.7

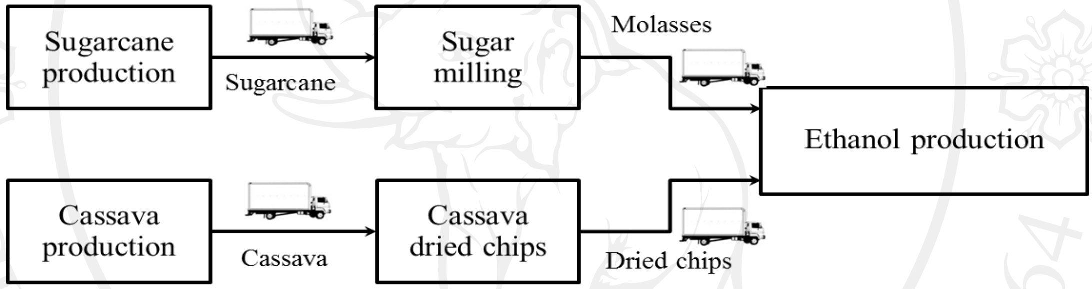


Figure 3.13 System boundary of scenario II

Table 3.7 Capacity for ethanol and proportion production in each year.

Year	Ethanol production (L/day)	% ethanol fixed		% ethanol changes	
		Sugarcane	Cassava	Sugarcane	Cassava
2012	1,500,000	70	30	70	30
2013	3,000,000	65	35	70	30
2014	4,000,000	60	40	70	30
2015	5,000,000	55	45	70	30
2016	6,000,000	50	50	70	30
2017	7,000,000	45	55	70	30
2018	7,500,000	40	60	70	30
2019	8,000,000	35	65	70	30
2020	8,500,000	30	70	70	30
2021	9,000,000	25	75	70	30

The results of the study are intended to provide information for policy makers to be aware of trends of the potential land use, GHG emission, and water use for sugarcane and cassava cultivation. The research has proposed how to calculate land use, GHG emission, and water use by each equation are as follows.

3.6.3.1 Land use

In determining the total area or Land use (LU_T) by obtaining from sugarcane combined with cassava growing areas. The two areas are the sugarcane and cassava growing areas. Sugarcane is used to produce Molasses for ethanol, and sugar is used in other industries such as liquor factory, fodder, and MSG for export. The cassava is also to produce ethanol production, and to use in other industries such as cassava pellets, starch for domestic use and export, etc. The demand for molasses and cassava every year for other industries were 1.90 and 29.6 million tons per year, and other assumptions based on 3.6.1. Therefore, the land uses to grow both crops by using the following equation as below:

$$\begin{aligned} LU_T &= (LU_{SC} + LU_{SCO}) + (LU_{CS} + LU_{CSO}) \\ &= \left\{\left(\frac{E_T\,P_m}{E_m M_{sc} Y_{sc}}\right) + \left(\frac{D_m}{M_{sc} Y_{sc}}\right)\right\} + \left\{\left(\frac{E_T\,P_c}{E_c\,C_{cs}\,Y_{cs}}\right) + \left(\frac{D_{cs}}{Y_{cs}}\right)\right\} \\ &= \left\{\frac{1}{M_{sc} Y_{sc}}\left(\frac{E_T\,P_m}{E_m} + D_m\right)\right\} + \left\{\frac{1}{Y_{cs}}\left(\frac{E_T\,P_c}{E_c C_{cs}} + D_{cs}\right)\right\} \qquad (3.5) \end{aligned}$$

Where

LU_T = Total land use for sugarcane and cassava cultivation (ha/yr)

LU_{SC} = Land use of sugarcane cultivation for ethanol production (ha/yr)

LU_{SCO} = Land use of sugarcane cultivation for other industrials (ha/yr)

LU_{CS} = Land use of cassava cultivation for ethanol production (ha/yr)

LU_{CSO} = Land use of cassava cultivation for other industrials (ha/yr)

E_T = Demand of bioethanol production (L/yr)

P_m = Percent of bioethanol production from molasses (%)

E_m = Bioethanol production per molasses (L/ton of molasses)\

M_{sc} = Molasses production per sugarcane (ton of molasses/ton of sugarcane)

Y_{sc} = Yield of sugarcane (ton/ha)

D_m = Demand of molasses for other industrials (ton/yr)
P_c = Percent of bioethanol production from cassava (%)
Ec = Bioethanol production per cassava chips (L/ton of cassava chips)
C_{cs} = Cassava chips per fresh cassava (ton of cassava chips/ ton of fresh cassava)
Y_{cs} = Yield of cassava (ton/ha)
D_{cs} = Demand of cassava for other industrials (ton/yr)

3.6.3.2 Carbon footprint

Carbon footprint value of sugarcane-based and cassava-based bioethanol assigned is equal to 1.62 and 1.02 $kgCO_2eq$ accordingly. Nevertheless, the greenhouse gas emissions throughout the life cycle of ethanol production can be calculated by an equation below.

$$\begin{aligned} CF_T &= CF_{sc} + CF_{cs} \\ &= \{(E_T\, P_m CF_{scb}) + (E_T\, P_c CF_{csb})\} \\ &= E_T\{(P_m CF_{scb}) + (P_c CF_{csb})\} \end{aligned} \tag{3.6}$$

Where

CF_T = Total of carbon footprint for bioethanol production ($kgCO_2eq$/yr)
CF_{sc} = Total of carbon footprint for sugarcane-based bioethanol production ($kgCO_2eq$/yr)
CF_{sc} = Total carbon footprint for cassava-based bioethanol production ($kgCO_2eq$/yr)
E_T = Demand of bioethanol production (L/yr)
P_m = Percent of bioethanol production from molasses (%)
P_c = Percent of bioethanol production from cassava (%)
CF_{scb} = Carbon footprint for sugarcane-based bioethanol production ($kgCO_2eq$/L)
CF_{scb} = Carbon footprint for cassava-based bioethanol production ($kgCO_2eq$/L)

3.6.3.3 Water footprint

The research is the study of the demand for irrigation water for sugarcane and cassava for the production of ethanol and other industrial sectors. By considering, the plants that have enough water to use during growth period. Therefore, the crop water requirement of sugarcane and cassava were assigned at 2,080 and 3,527 m^3/ha of water footprint is given by the following equation.

$$\begin{aligned} \mathrm{WF_T} &= \mathrm{WF_{sc}} + \mathrm{WF_{cs}} \\ &= \mathrm{CWU_{sc}}(\mathrm{LU_{SC}} + \mathrm{LU_{SCO}}) + \mathrm{CWU_{cs}}(\mathrm{LU_{CS}} + \mathrm{LU_{CSO}}) \\ &= \left\{\frac{CWU_{sc}}{M_{sc}Y_{sc}}\left(\frac{E_T\,P_m}{E_m} + D_m\right)\right\} + \left\{\frac{CWU_{cs}}{Y_{cs}}\left(\frac{E_T\,P_c}{E_cC_{cs}} + D_{cs}\right)\right\} \end{aligned} \tag{3.7}$$

Where

$\mathrm{WF_T}$ = Total of water footprint for bioethanol production (m^3/yr)

$\mathrm{WF_{sc}}$ = Total of water footprint for sugarcane-based bioethanol production (m^3/yr)

$\mathrm{WF_{sc}}$ = Total water footprint for cassava-based bioethanol production (m^3/yr)

$\mathrm{CWU_{sc}}$ = Crop water requirement of sugarcane (m^3/ha)

$\mathrm{CWU_{cs}}$ = Crop water requirement of cassava (m^3/ha)

The Alternative Energy Development Plan (AEDP) in 2012-2021 targets to increase the national average production per ha per year of cassava, and sugarcane, and to yield not less than 31.25 and 93.75 ton/ha/yr in 2021 as follows Table 3.8

Table 3.8 Target of increase the national average production

Feedstock	Planting area (million rai)	Average Production (ton/rai)	Annual Production (million ton/yr)
Cassava	1.12 (7)*	31.25 (5)**	35
Sugarcane	1.12 (7)*	93.75 (15)**	105

Note: * million rai, ** ton/rai

Therefore, the study considers an increase in the average yield per rai by the AEDP of both crops. Where sugarcane production yield is increased from 68.85 to 93.75 ton/ha, and cassava is increased from 19.47 to 31.25 ton/ha. All results are under the assumption that demand for water per area of both crops does not change, and understand the impact that will have on land use, carbon and water footprint. The results of the study can be used as guidelines policies to promote ethanol in Thailand properly.